世界互联网大会
World Internet Conference

科技之魅

CHARM OF SCIENCE AND TECHNOLOGY

世界互联网大会
领先科技奖收录成果集

Collection of Shortlisted Achievements of World Internet Conference Awards for Pioneering Science and Technology

2025 WORLD INTERNET CONFERENCE
乌镇峰会 Wuzhen Summit
世界互联网大会

共筑开放合作、安全普惠的数智未来
——携手构建网络空间命运共同体

Forging an Open, Cooperative, Secure and Inclusive Future of Digital Intelligence
— Jointly Build a Community with a Shared Future in Cyberspace

写在《科技之魅》的前面

Preface to the Charm of Science and Technology

当前，新一代信息技术、人工智能、量子科技、生物科技、新能源、新材料等领域加快突破，推动全球科技创新以前所未有的速度重塑人类社会。科技不仅是工具，更成为驱动社会进步的核心引擎，为全球经济增长注入新韧性，为产业转型升级与可持续发展提供关键基石和澎湃动能。

Nowadays, breakthroughs are accelerating in new generation of information technology, artificial intelligence, quantum technology, biotechnology, new and renewable sources of energy, and advanced materials, driving global technological innovation to reshape human society at an unprecedented speed. Technology is not merely a tool; it has become the driving force at the heart of societal progress, infusing global economic growth with new resilience and providing the critical foundation and dynamic momentum for industrial transformation, upgrading, and sustainable development.

互联网正从“万物智联”向“数智共生”跃迁，以创新之力引领数字世界向智慧化、泛在化演进，勾勒出更具包容性与生命力的数字文明图景。世界互联网大会领先科技奖勇立时代潮头，聚焦全球互联网领域最具突破性的成果，搭建创新协作平台，促进前沿技术交流与落地转化，为互联网持续赋能人类社会源源不断地注入动力，推动人类社会迈向更加智慧、更加美好的未来。

The internet is transitioning from “the internet of everything” to “digital intelligence symbiosis”, using the power of innovation to lead the digital world toward smarter and ubiquitous evolution, outlining a more inclusive and vibrant vision of digital civilization.The World Internet Conference Awards for Pioneering Science and Technology (WIC Awards) stand at the forefront of the era, focusing on the most groundbreaking achievements in the global internet field. They build an innovative collaboration platform to promote the exchange and application of cutting-edge technologies, continuously empowering the internet to inject ongoing momentum into human society, and driving humanity toward a smarter and better future.

作为世界互联网大会领先科技奖评审委员会主席，我深感荣幸地见证了科技奖的国际影响力再上新台阶。本年度吸引了来自全球 34 个国家和地区的申报方积极参与，共征集有效申报成果 424 项，涵盖类脑计算、群体智能、6G 通信、高性能芯片、量子计算、卫星互联网等前沿领域，呈现智能化与融合化趋势，彰显全球科技界对数字化未来的共同关切与积极探索。在基础研究组主任委员美国互联网先驱戴夫·法伯先生、关键技术组主任委员中国工程院院士吴建平先生、工程研发组主任委员韩国互联网之父全吉男先生等 40 位全球互联网领域权威专家的推荐下，53 项优秀成果脱颖而出，收录于本年度《科技之魅》。这些创新成果凝聚着全球科技人员的智慧与心血，随着它们的持续应用与推广，将为经济社会发展贡献积极力量，在促进全球数字技术协同创新、共建网络空间美好未来中展现重要价值。

As the chairman of the World Internet Conference Awards for Pioneering and Technology Review Committee, I am deeply honored to witness the international influence of the WIC awards reaching new heights. This year, the award attracted active participation from applicants across 34 countries and regions worldwide, receiving a total of 424 valid submissions.These encompass cutting-edge fields such as brain-inspired computing, swarm intelligence, 6G communication, high-performance chips, quantum computing, and satellite internet. The submissions highlight trends of intelligence and integration, demonstrating the global scientific community's shared concern and active exploration of the digital future.With the recommendations of 40 authoritative experts in the global internet field, including Mr. David Farber, an American Internet pioneer and the Director of the Basic Research Group, Mr. Wu Jianping, an Academician of the Chinese Academy of Engineering and the Director of the Key Technology Group, and Mr. Kilnam Chon, known as the "Father of the Internet" in the Republic of Korea and the Director of the Engineering Research and Development Group, 53 leading achievements have been selected and compiled into a collection called "the Charm of Science and Technology". These innovative achievements embody the wisdom and efforts of global scientists and researchers. As they continue to be applied and promoted, they will contribute positively to economic and social development, demonstrating significant value in promoting global digital technology collaborative innovation and jointly building a bright future for cyberspace.

时光流转，创新不止。《科技之魅》将继续忠实记录互联网技术的发展轨迹，继续以开放之姿汇聚全球智慧，以向善之心点亮科技之光，为构建网络空间命运共同体、推动人类文明进步提供更多机遇。

As time flows, innovation never ceases. "The Charm of Science and Technology" will continue to faithfully record the development trajectory of internet technology, persist in gathering global wisdom with an open mindset, and illuminate the light of technology with a benevolent heart. It will provide more opportunities for building a community of shared destiny in cyberspace and advancing the progress of human civilization.



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Professor Emeritus of the Korea Advanced Institute of Science and Technology

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Award-winning Achievements of World Internet Conference Awards for Pioneering Science and Technology

基础研究组 Basic Research Group

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01

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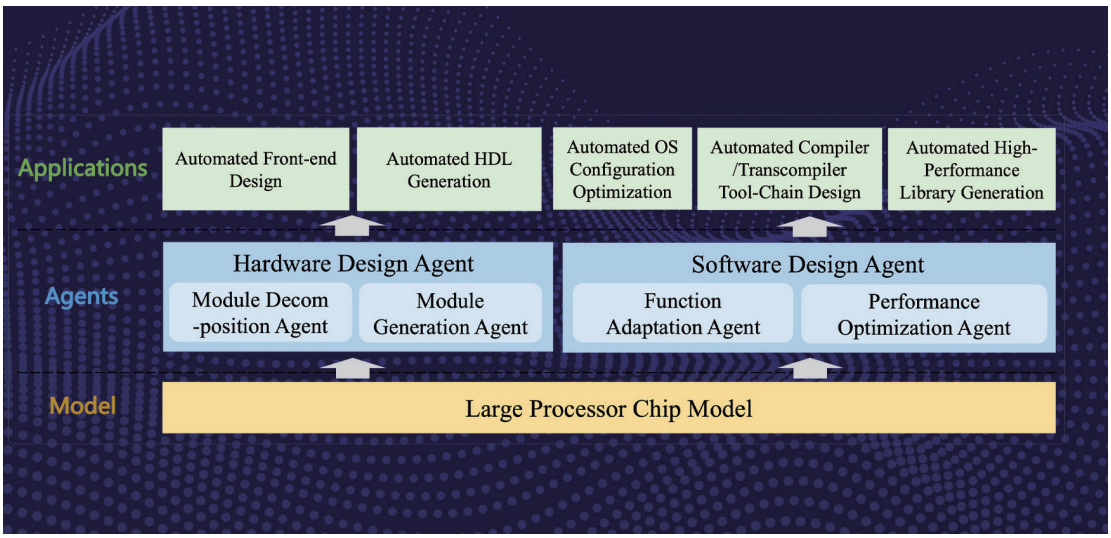
Award-winning Achievements of World Internet Conference
Awards for Pioneering Science and Technology

基础研究组
Basic Research Group



“启蒙”处理器芯片软硬件自动设计系统的总体框架
Overview of QiMeng processor chip hardware and software automated design system

启蒙：处理器芯片软硬件全自动设计

QiMeng: Fully Automated Hardware and Software Design for Processor Chip

中国科学院计算技术研究所
Institute of Computing Technology, Chinese Academy of Sciences

中国科学院软件研究所
Institute of Software, Chinese Academy of Sciences

引言

“启蒙”处理器芯片软硬件自动设计系统，旨在基于大模型和智能体技术实现芯片软硬件栈的全自动设计。目前已实现自动设计 RISC-V CPU，并能自动配置操作系统、转译程序、高性能算子库，达到或部分超过人类专家设计水平。

Introduction

The QiMeng processor chip hardware and software automated design system aims to achieve fully automated design of the chip hardware/software stack by leveraging large language models (LLMs) and agent technologies. QiMeng has achieved automated designing RISC-V CPUs, automated optimizing operating system kernel configuration, automated transcompiling tensor programs and automated developing high-performance libraries, achieving performance that matches or even surpasses that of human expert design.

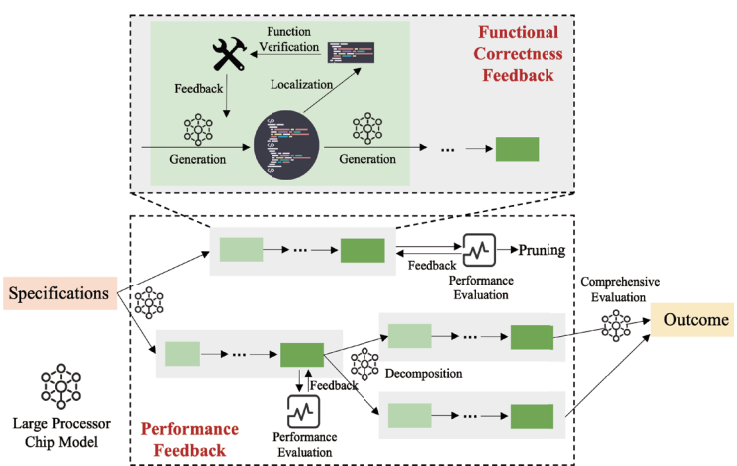
创建处理器芯片软硬件全自动设计新体系
Creating a new fully automated software and hardware design paradigm for processor chip

处理器芯片自动设计是计算机科学领域的核心问题之一。不同于传统自动设计方法以人工智能为工具完成芯片设计的某些环节，“启蒙”系统创建了处理器芯片全自动设计新体系，依托大模型和智能体技术，旨在根据功能需求实现芯片软硬件的全自动设计和适配优化。

Automated processor chip design represents one of the core challenges in computer science. Unlike conventional automated design approaches that use artificial intelligence (AI) as a tool for specific stages of the chip design process, QiMeng system establishes a new fully automated design paradigm for processor chips. Leveraging LLMs and agent technologies, QiMeng aims to achieve fully automated design and optimization for both hardware and software from given functional specifications.

鉴于处理器芯片设计领域的特殊性，实现全自动处理器芯片软硬件设计需要解决正确性和求解规模两方面的关键挑战。为此，“启蒙”系统构建具备正确性反馈和性能反馈两种反馈机制的处理器芯片设计智能体。一方面通过自动功能验证和基于功能正确性反馈的自动修复，确保生成结果的正确性；另一方面通过自动性能评估和基于性能反馈的自动搜索，对解空间进行分解和裁剪，实现解空间降维，从而对高性能设计结果进行高效搜索。

Considering the unique challenges of processor chip design, realizing fully automated hardware and software design requires addressing two critical issues: the correctness guarantee and the enormous solution space. To this end, QiMeng constructs processor chip design agents with two feedback-driven mechanisms: correctness feedback and performance feedback. By constructing automated functional verification and autonomously repairing erroneous results based on correctness feedback, QiMeng is able to ensure the validity of generated outputs. Concurrently, by leveraging automated performance evaluation and autonomously search based on performance feedback, QiMeng is capable of decomposing the solution space and pruning the low-performance subspaces, effectively reducing the dimensionality of the solution space and enabling efficient exploration of high-performance design solutions.



具备反馈机制的处理器芯片智能体
Processor Chip Design Agent with Feedback Mechanism

通过构建处理器芯片领域大模型，“启蒙”系统构建芯片生成智能体和基础软件智能体，并产出处理器芯片软硬件多个关键环节的自动设计方法和成果。

By constructing a domain-specific large processor chip model (LPCM) and further building hardware and software design agents, QiMeng produces automated design methodologies and results for multiple key stages of processor chip hardware/software development.

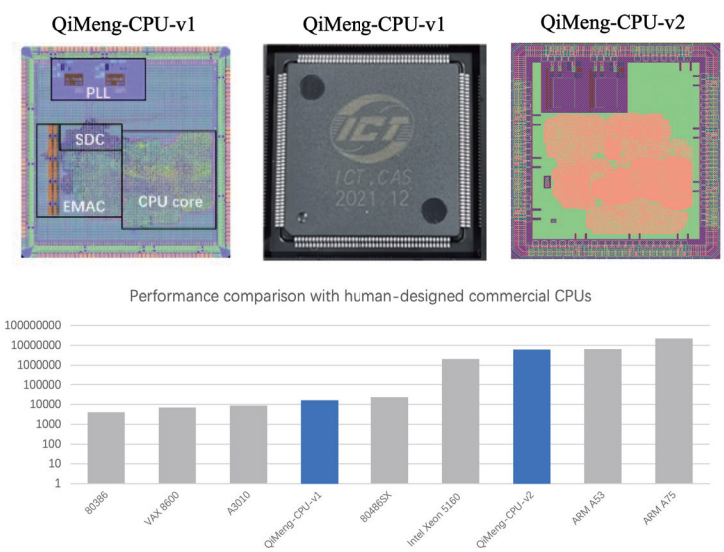
“启蒙”系统产出的自动设计方法达到人类专家水平
The automated design methodologies produced by QiMeng matching the performance of human expert design

目前，“启蒙”系统已产出处理器芯片软硬件多个环节的自动设计方法和成果，达到或部分超过人类专家设计水平。基于“启蒙”系统，实现国际首个全自动设计的 CPU 芯片“启蒙 1 号”和超标量处理器核“启蒙 2 号”，分别达到 Intel486 和 ARM Cortex A53 性能；实现国际首个基于大模型的操作系统内核配置自动优化方法，自动优化性能优于人类专家手工优化；实现国际首个自动跨平台张量程序转译工具，实现不同处理器芯片和不同编程模型间的自动程序转译；实现国际首个基于大模型的高性能矩阵乘算子自动生成框架和高性能张量算子自动生成框架，性能优于 OpenBLAS 和 cuBLAS。

At present, QiMeng has delivered automated hardware/software design methodologies and results for processor chips, matching or surpassing the performance of human expert design. QiMeng develops the world’s first fully automated designed CPU named QiMeng-CPU-v1 (also named Enlightenment-1), and the world’s first fully automated designed superscalar processor core named QiMeng-CPU-v2, achieving performance comparable to Intel 486 and ARM Cortex-A53, respectively. QiMeng realizes the world's first LLM-based automated OS kernel configuration optimization method, whose optimized performance surpasses manual tuning by human experts. QiMeng introduces the world's first automated cross-platform tensor program translation tool, enabling automated code translation across different processor architectures and programming models. QiMeng develops the world's first LLM-based automated high-performance matrix multiplication code generation framework and high-performance tensor operator auto-generation framework, the performance of generated operators outperforming that of OpenBLAS and cuBLAS.

“启蒙”系统重塑处理器芯片软硬件的设计范式，不仅有望在当前工艺下实现芯片性能的进一步提升，同时可以通过自动设计大幅提升设计效率、缩短设计周期、降低成本，此外可以针对场景需求实现快速定制化设计，满足日益多样化的需求。

QiMeng pioneers novel design methodologies for processor chips. QiMeng holds the potential to surpass manual design and achieve better performance under identical fabrication technology, significantly improving design efficiency while shortening development cycles and lowering costs based on automated design, and enabling rapid customization of chip stacks tailored to specific application domains to address the growing demand for specialized computing solutions.



国际首个 AI 全自动设计的 CPU“启蒙 1 号”和超标量处理器“启蒙 2 号”

QiMeng-CPU-v1(Enlightenment-1) and QiMeng-CPU-v2, the world's first CPU and superscalar processor automatically designed by AI

研究成果在国际学术界获得高度认可
The Research Achievements Have Been Highly Recognized in the International Academic Community

“启蒙”处理器芯片软硬件自动设计系统的多项研究成果发表于国际顶级会议和期刊，包括集成电路国际顶级会议 DAC 和国际顶级期刊 TCAD、系统软件国际顶级会议 OSDI、人工智能国际顶级会议 IJCAI 和 AAAI，机器学习国际顶级会议 ICML 和 NeurIPS、自然语言处理国际顶级会议 ACL 和 EMNLP 等。其中，“启蒙 1 号”被《自然》新闻评价为“中国芯片发展的好消息”，进一步证明了其在领域内的卓越贡献和影响力。HDL 代码自动生成大模型 CodeV 系列在开源社区下载量超过 32K，被英伟达、英特尔、IBM、亚马逊、华为、苏黎世联邦理工、佐治亚理工、加利福尼亚大学圣迭戈分校、伊利诺伊大学厄巴纳 - 香槟分校、南加州大学等国际知名机构跟踪引用，彰显了其在国际学术界的重要影响力。

Multiple related research outcomes of QiMeng have been published at top international conferences and journals in related areas, including Design Automation Conference (DAC) and IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems (TCAD) which are top conference and journal in integrated circuits, USENIX Symposium on Operating Systems Design and Implementation (OSDI) which is top conference in systems software, International Joint Conference on Artificial Intelligence (IJCAI) and Association for the Advancement of Artificial Intelligence (AAAI) which are top conferences in artificial intelligence, International Conference on Machine Learning (ICML) and Conference on Neural Information Processing Systems (NeurIPS) which are top conferences in machine learning, as well as the Annual Meeting of Association for Computational Linguistics (ACL) and Empirical Methods in Natural Language Processing (EMNLP) which are top conferences in natural language processing. Among these, QiMeng-CPU-v1 (also named Enlightenment-1) was described by Nature News as "good news for Chinese chip development," further demonstrating its exceptional contributions and influence in the field. The domain-specific LLM for automated HDL code generation, CodeV series, has been downloaded over 32K times in open-source communities and has been tracked and cited by leading institutions such as NVIDIA, Intel, IBM, Amazon, Huawei, ETH Zurich, Georgia Tech, UC San Diego, University of Illinois Urbana-Champaign, and the University of Southern California, underscoring its significant impact in the global academic community.



nature

nature › news › article

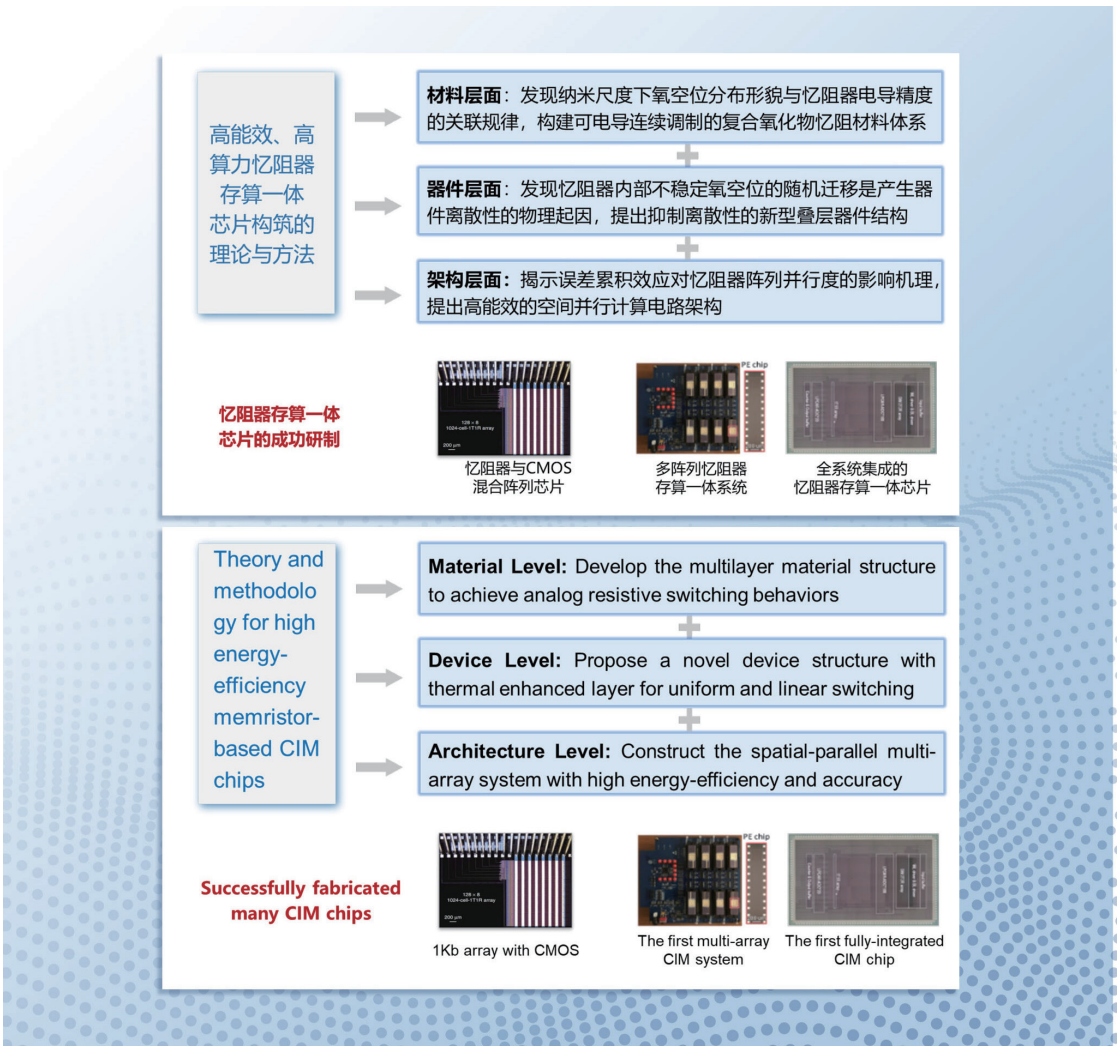
NEWS | 03 May 2024

Who's making chips for AI? Chinese manufacturers lag behind US tech giants

There has been some good news for Chinese chip development — using AI itself to design computer chips. Yunji Chen, a computer scientist at the Chinese Academy of Sciences Institute of Computing Technology in Beijing, and his colleagues said in the past year that they have developed the first chip to be designed by AI without human input[1], called Enlightenment-1. "I believe that in five or ten years, AI can design chips as good as human beings," says Chen. "If you want to design an AI chip, traditionally you need 3 years and 1,000 people. But if you use AI, you just need several hours. If this cycle becomes real, how AI evolves will be much faster."

“启蒙 1 号”被《自然》新闻评价为“中国芯片发展的好消息”

QiMeng-CPU-v1(Enlightenment-1) has been described by Nature News as "good news for Chinese chip development"



高能效忆阻器存算一体芯片与系统构筑方法
Method for High-Efficiency Memristor-Based Computing-In-Memory Chip and System

忆阻器存算一体芯片器件及架构基础理论

Fundamental Theory of Devices and Architectures for Memristor-based Computing-in-Memory Chip

引言

高能效、高算力芯片是驱动人工智能发展的核心技术，也是集成电路国际科技竞争制高点的战略方向。成果围绕新型高能效、高算力忆阻器存算一体芯片与系统构筑，在忆阻器的材料体系、器件结构及电路架构取得突破。

Introduction

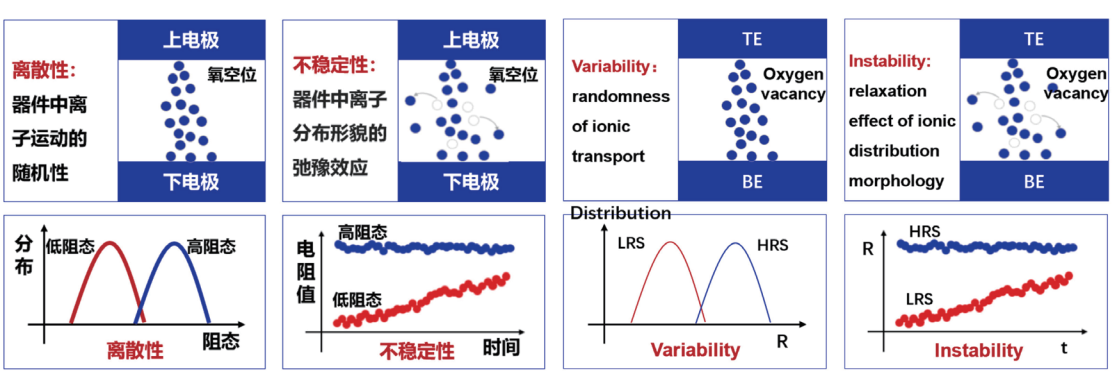
High-efficiency, high-performance chips are the core technologies driving the development of artificial intelligence and represent the strategic frontier in the global competition of integrated circuits. This project focuses on the construction of novel high-efficiency, high-performance memristor-based computing-in-memory chips and systems, achieving breakthroughs in memristor material system, device structure, and circuitry architecture.

忆阻器存算一体“材料 - 器件 - 架构”协同创新
Synergistic Innovation in ‘Materials–Devices–Architectures’ for Memristor-Based In-Memory Computing

忆阻器是一种兼具存储与计算功能的新器件，基于忆阻器的存算一体芯片避免了数据在存储与计算之间的反复搬运，为后摩尔时代算力芯片技术的发展开辟了全新路径，是当前集成电路的国际前沿和研究热点。探索高精度、可大规模集成的忆阻材料和器件、以及高阵列并行度的电路架构，是构筑高能效、高算力忆阻器存算一体芯片的关键。然而，忆阻器电导调制涉及复杂的电离子耦合输运机理，如何突破传统存算分离架构下器件和芯片局限，是长期困扰全球学术界的一个基本难题。

The memristor is a novel device that integrates both storage and computing functions. Memristor-based computing-in-memory(CIM) computing chips avoid the data transfer between memory and processing units, thereby opening a new pathway for the development of high-performance chip technologies in the post-Moore era and becoming the international frontier in integrated circuits. Exploring high-precision memristor materials, highly scalable device stacks, as well as spatial architectures with high array-level parallelism, are keys to building efficient CIM chips. However, memristor conductance modulation involves complex electro-ionic coupling transport mechanisms, and how to overcome the limitations of conventional memory-compute separated architectures in devices and chips has long been a fundamental and global challenge.

成果从忆阻器的材料体系、器件结构及电路架构入手，通过深入阐明电导调制机理、离散性物理起因及阵列并行度影响因素，创新性地提出了复合氧化物材料、叠层器件结构以及空间并行计算电路架构，实现了能效的显著提升。建立了构筑高能效、高算力忆阻器存算一体芯片的理论与方法，成功实现了多款忆阻器存算一体芯片，为后摩尔时代算力芯片技术的发展开辟了新路径。



器件离散性与不稳定性影响存算一体芯片性能
Device variability and instability degrade the performance of memristor-based CIM chips

This project addresses the challenge from the perspectives of memristor material systems, device structures, and circuit architectures. By deeply elucidating the mechanisms of conductance modulation, the physical origins of variability, and the factors influencing array-level parallelism, the group innovatively proposed composite oxide materials, stacked device structures, and spatially parallel computing circuit architectures, achieving significant improvements in energy efficiency. A theoretical framework and practical methodology for constructing high-efficiency, high-performance CIM chips have been established, leading to the successful development of multiple prototypes. These advances open a new pathway for the evolution of computing chips in the post-Moore era.

高能效存算一体芯片与系统构筑
Construction of Energy-Efficient Computing-In-Memory Chip and System

清华大学吴华强、钱鹤教授团队发现纳米尺度下氧空位分布形貌与忆阻器电导精度的关联规律，构建出复合氧化物 $Hf_xAl_yO_z$ 忆阻材料体系，解决了精确调制氧空位分布的科学难题，实现了从早期电导单比特调制到“编程到任意电导态”的跨越。

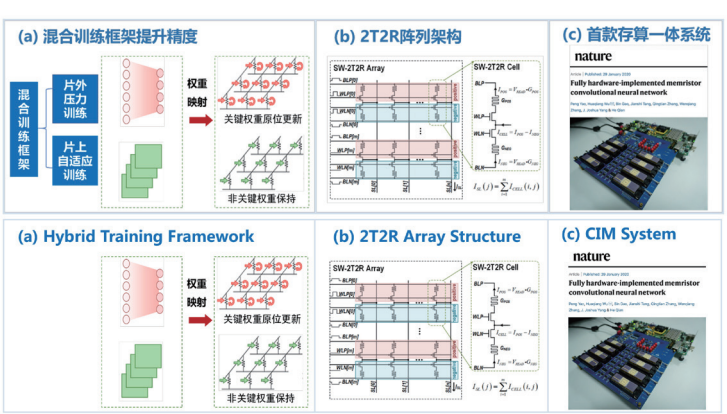
The team led by Professor Huaqiang Wu and He Qian from Tsinghua University discovered the correlation between the nanoscale oxygen vacancy distribution morphology and the memristor conductance modulation precision. The project elucidated the mechanism of linear changes in the conductance of memristor materials under the action of voltage pulses, and developed a novel memristor material system of composite oxide $Hf_xAl_yO_z$, solving the scientific challenge of precise modulation of oxygen vacancy distribution. It is hence achieved a giant leap from single bit to continuous linear conductance modulation.

此外，研究成果阐明器件内部电场和温度分布对氧空位迁移的作用机理，提出热增强层 / 忆阻材料的新型叠层器件结构，建立了有效调控器件内部电热场的理论方法，实现了从千级到千万级集成规模的重大突破。

In addition, the team identified the random migration of unstable oxygen vacancies inside the memristor as the physical cause of device variability. Moreover, a novel stacked device structure of thermal enhanced layer/resistive switching layer was proposed. This provided an effective method for regulating the internal electric field and thermal distribution of the device, achieving a significant boost of the integration scale from Kb to tens of Mb.

成果还揭示了误差累积效应对忆阻器阵列并行度的影响机理，提出基于混合训练框架的空间并行存算一体电路架构，解决了阵列并行度不足导致的能效降低问题，在国际上首创多阵列忆阻器存算一体系统，能效提升两个数量级，是“基于存算一体的深度神经网络推理中最先进的实验验证之一”。

Furthermore, this project revealed the error accumulation effects as the key factor determining the parallelism of CIM architecture. Based on this, a spatially parallel CIM architecture with hybrid training framework and differential mapping mechanism was established. The feasibility and high-energy-efficiency advantage of the fully parallel CIM architecture was verified. For the first time, a fully hardware implemented multi-array memristor CIM system was demonstrated, showing two orders of magnitude higher energy efficiency than GPU. E. Eleftheriou, a member of the US National Academy of Engineering, cited this project, stating: ‘The state-of-the-art experimental demonstrations of DNN inference based on in-memory computing…’



新型空间并行存算一体电路架构和国际首款多阵列忆阻器存算一体系统
Novel spatially parallel CIM architecture and the world's first fully hardware implemented multi-array CIM system

忆阻器存算一体构筑理论获得国际广泛认可
The theory of memristor-based CIM architecture has gained wide international recognition

研究成果建立了构筑高能效、高算力忆阻器存算一体芯片的理论方法体系，有力推动了存算一体芯片技术的发展，为后摩尔时代算力芯片技术的发展开辟了全新路径。成果被 MIT、IBM、台积电等来自 61 个国家和地区的高校和企业引用，先后 5 次被列入国际半导体技术发展路线图，肯定了项目成果在器件结构上的创新和忆阻器存算一体架构的引领性：“基于忆阻器全硬件实现了神经网络推理加速”；“热增强层调控阻变过程，实现了具有多比特精度的纳米尺度氧化物忆阻器”；“HfO_2/Al_2O_3 阻变材料有效降低氧离子扩散，提高了器件稳定性”。基于本成果，研究团队受邀在 *Nature Electronics*、*Nature Communications*、*Proceedings of the IEEE* 等期刊撰写综述 8 篇，其中 5 篇入选 ESI 高被引论文。项目成果获得 2022 年中国电子学会自然科学奖一等奖、2020 年度中国半导体十大研究进展、2020 年世界人工智能大会最高奖—SAIL 奖，是 2025 年教育部自然科学一等奖待授奖项目。

The project has established a theoretical and methodological framework for constructing high-efficiency, high-performance memristor-based CIM chips, opening a new pathway for computing chip technologies in the post-Moore era. The project has been cited by universities and companies from 61 countries and regions, including MIT, IBM, and TSMC, and has been included five times by IRTS/IRDS(International Roadmap for Devices and Systems), affirming the innovations in device structures and the pioneering achievement in CIM architecture: ‘Neural network inference acceleration fully implemented in hardware based on memristors’; ‘Thermally enhanced layers regulate the resistive switching process, achieving nanoscale oxide memristors with multi-bit precision’; ‘HfO_2/Al_2O_3 resistive switching materials effectively reduce oxygen ion diffusion and improve device stability.’ Based on these achievements, the research team was invited to write eight review articles in journals such as *Nature Electronics, Nature Communications, and Proceedings of the IEEE*, of which five were selected as ESI highly cited papers. The project has received the 2022 First Prize of the Natural Science Award from the Chinese Institute of Electronics, was recognized as one of the Top Ten Semiconductor Research Advances in China in 2020, and received the highest award—SAIL Award—at the 2020 World Artificial Intelligence Conference. It is also a recipient of the 2025 First Prize of the Natural Science Award from the Ministry of Education.







受邀撰写综述与成果获奖证明
Invited Review Publications and Certification of Awarded Research Outcomes

世界互联网大会
领先科技奖获奖成果

Award-winning Achievements of World Internet Conference
Awards for Pioneering Science and Technology



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世界互联网大会
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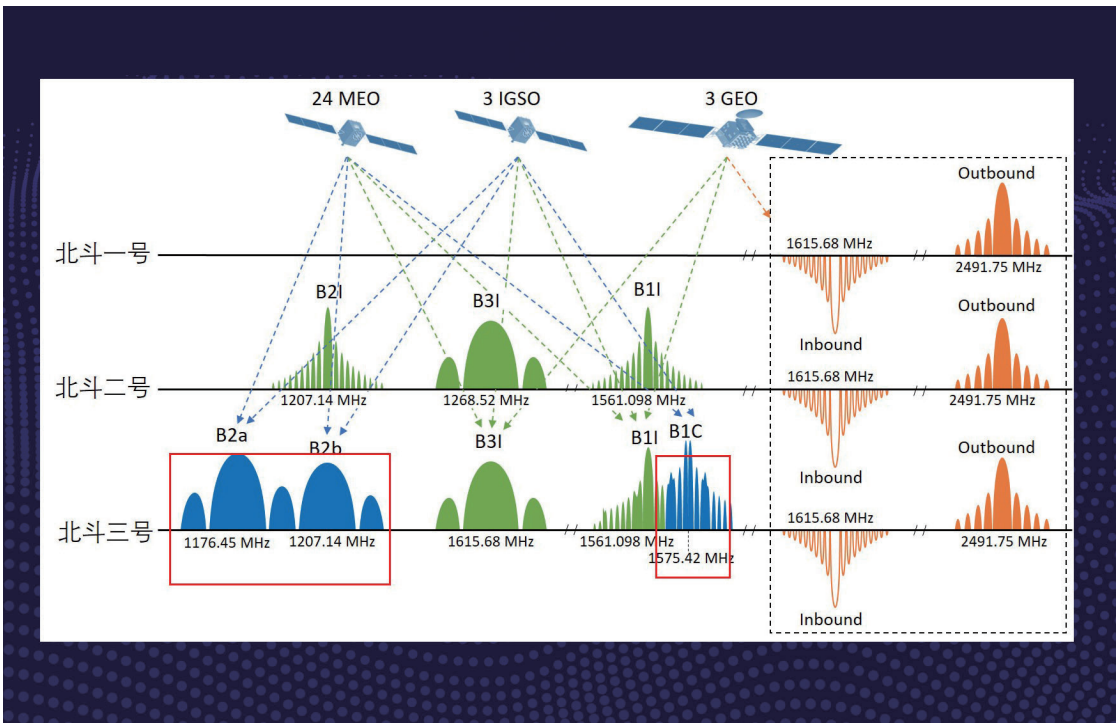
Awards for Pioneering Science and Technology

关键技术组
Key Technology Group



北斗导航系统导航信号演变示意图
Schematic Diagram of the Evolution of BDS Signal Structures

北斗三号卫星导航信号关键技术及应用

Key Technologies and Applications of BDS-3 Satellite Navigation Signals

清华大学
Tsinghua University

引言

卫星导航信号是卫星导航系统的核心技术，其性能直接决定了系统的服务能力。性能优异、与 GPS 等已有导航信号兼容互操作的新一代导航信号是北斗建成世界一流系统、推动导航产业发展、实现全球服务的关键。

Introduction

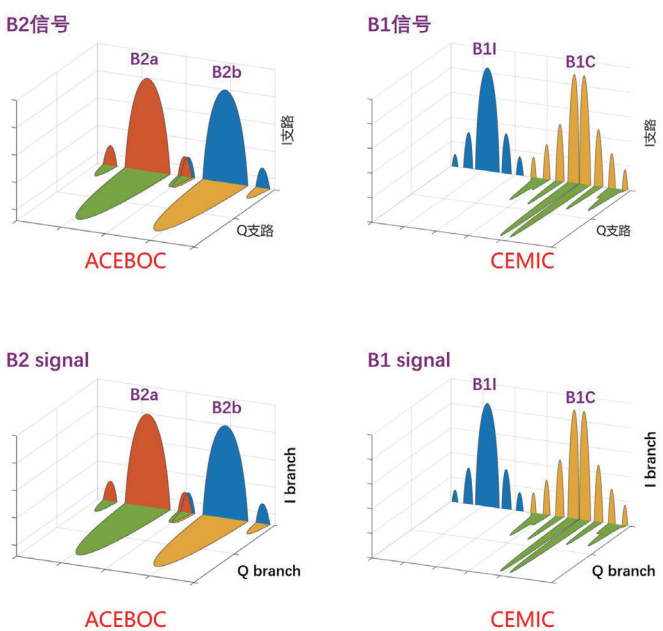
Navigation signals serve as a core technology of satellite navigation systems, with their performance directly determining the system's service capability. High-performance navigation signals compatible with and interoperable with existing systems such as GPS represent a critical factor for the BeiDou Navigation Satellite System (BDS) to achieve world-class status, drive industry development, and deliver global services.

中国特色、世界一流的导航信号体制
Chinese-Characteristic, World-Class Navigation Signal System

1. 发明正交复用二进制偏移载波（QMBOC）调制技术，攻克了国际电联频谱约束下宽 / 窄带多分量频 / 相 / 码三域正交合并技术难题，与 GPS L1C 兼容、测距误差降低 20%。基于 QMBOC 的 B1C 信号显著提升测距精度及抗多径能力。

2. 发明基于交调构造的恒包络复用（CEMIC）技术，攻克了多个跨频信号在任意功率配比和任意相位关系下的恒包络复用技术难题，复用效率可达 83.6%。成功应用于 B1 频段新旧两代信号的高效率播发，支撑了北斗二号到三号的平稳过渡。

3. 发明非对称恒包络二进制偏移载波（ACEBOC）调制 / 复用技术，攻克了双频多分量任意功率配比恒包络合成技术难题，与 Galileo E5a/b 兼容、测距误差降低 33%。基于 ACEBOC 的 B2a/b 信号成功实现以统一信号结构播发 5 种业务，支撑北斗建成全球首个多功能混合星座。



北斗三号 B1 频点、B2 频点导航信号结构示意图

Schematic Diagram of Navigation Signal Structure for BDS-3 B1 and B2 Frequency Points

1. The project invented Quadrature Multiplexed Binary Offset Carrier (QMBOC) modulation. It overcame the challenge of orthogonal combination across frequency, phase, and code domains under ITU spectrum constraints, achieving 20% lower ranging error compared to GPS L1C. The BDS B1C signal based on QMBOC enhances ranging accuracy and multipath mitigation significantly.

2. The project invented a Constant Envelope Multiplexing with Intermodulation Construction (CEMIC) method. It resolved the challenge of constant-envelope multiplexing for signals with arbitrary power ratios and phase relationships, achieving an 83.6% multiplexing efficiency. It enables high-efficiency broadcasting of two generation signals in the B1 band, ensuring a smooth transition from BDS-2 to BDS-3.

3. The project invented Asymmetric Constant Envelope Binary Offset Carrier (ACEBOC) modulation. It solved the challenge of constant-envelope synthesis for dual-frequency multi-components with arbitrary power ratios, achieving 33% lower ranging error compared to Galileo E5a/b. The B2a/b signal based on ACEBOC enables five services broadcasting with a unified architecture across satellites, supporting the world's first multi-functional hybrid constellation for BDS-3.

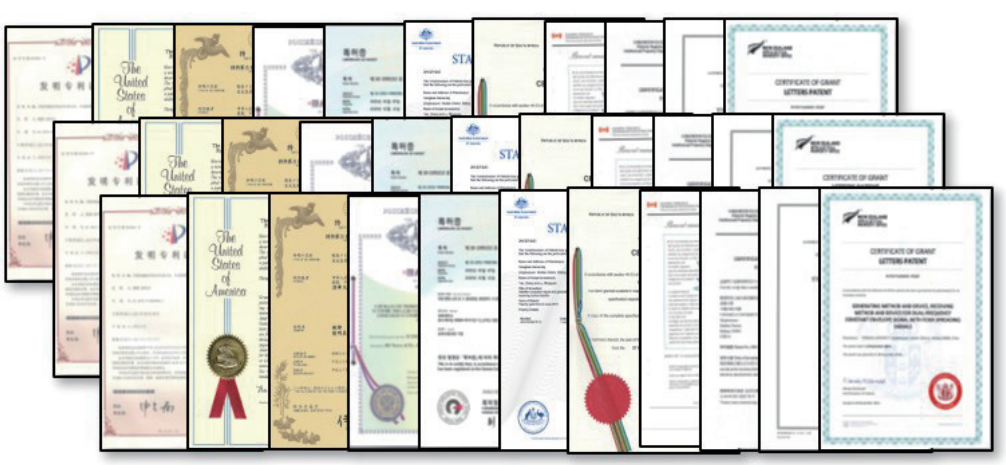
性能领先、覆盖全球的北斗导航信号
BeiDou Signal: Global Coverage, Leading Performance

本项目成果获 2025 年中国教育部技术发明一等奖（待授奖），2020 年中国卫星导航定位协会卫星导航科学技术特等奖，获中国发明专利 28 件、国际专利 48 件，促成中美签署北斗 /GPS 联合声明，成功应用于所有 35 颗北斗三号卫星并向全球提供服务，实测定位精度居世界第一，推动形成了中国 5 千亿规模卫星导航产业，并被纳入中国国家标准和 ICAO、IMO、3GPP 等国际标准，已服务于全球 200 多个国家和地区、数以十亿计用户。

项目发明专利包含信号发射与信号接收，已在全球 17 个国家和地区获得授权，为开发性能更优、功耗更低的接收机芯片奠定了坚实的技术基础，助力国际导航产业的发展。根据中国卫星导航定位协会的数据，最近 3 年中国直接依赖卫星导航信号的终端芯片、器件、算法等的核心产值达到 966 亿元，项目技术成果按 1% 的贡献率测算，近三年已创造经济效益约 9.6 亿元人民币。

The project has received the 2025 First Prize of Technological Invention from the Ministry of Education of China's (pending award) and the 2020 Special Prize for Satellite Navigation Science and Technology from the GNSS and LBS Association of China. It has secured 28 Chinese and 48 foreign patents, and facilitated the China-US BDS/GPS bilateral statement. It has been applied to all 35 BDS-3 satellites, providing global services, and field tests demonstrate world-leading positioning accuracy. It has driven the formation of a 5-trillion-yuan satellite navigation industry in China, and been incorporated into national standards and international standards such as ICAO, IMO, and 3GPP. The project now serves over 200 countries and regions with billions of users worldwide.

The project's patents include signal transmission and signal reception, and have been authorized in 17 countries and regions globally. It has laid a solid technical foundation for developing high-performance, low-power receiver chips, propelling the global navigation industry forward. According to data from the GNSS and LBS Association of China (GLAC), the core output value of terminal chips, components, and algorithms relying directly on satellite navigation signals in China reached 96.6 billion yuan in the past three years; with a 1% contribution rate, the project's technological achievements have generated approximately 960 million yuan in economic benefits over the same period.



取得中国发明专利 28 件、在 17 个国家和地区获发明专利 48 件
28 invention patents granted in China and 48 invention patents granted in 17 countries/regions

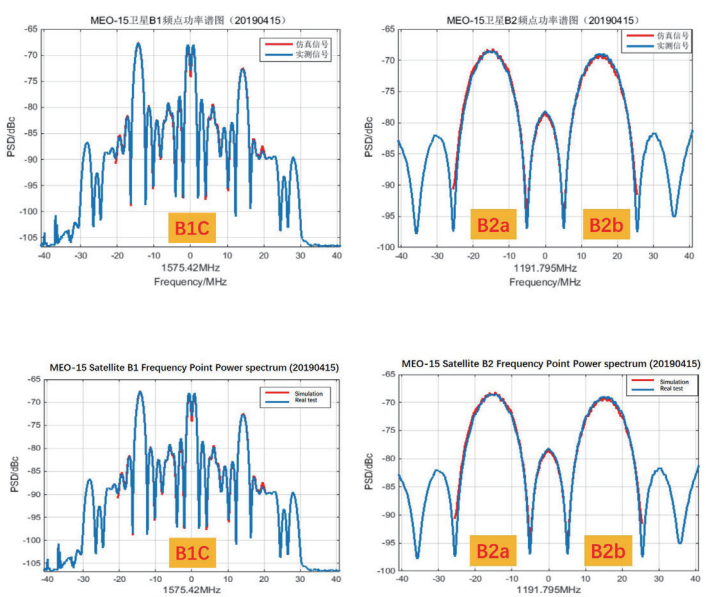
中国的北斗、世界的北斗
BeiDou of China, BeiDou for the World

项目提出的 B1、B2 频段信号结构方案，克服了频谱资源匮乏、发射功率受限、多信号多业务播发、平稳过渡要求、兼容与互操作限制等挑战，北斗三号所有 30 颗组网卫星和 5 颗备份卫星已全部应用项目成果并向全世界提供服务。根据中国北斗办测评中心发布的《GNSS 服务监测评估月报》，自 2020 年 7 月正式开通以来，北斗三号服务性能保持了世界一流水平，定位精度位居世界第一。

在国际合作与交流中，卫星导航信号的兼容互操作是开展国际合作的重要基础。在完成 ITU 框架下的频谱协调的基础上，2017 年基于 QMBOC 的 B1C 信号直接促成中美 B1C 和 L1C 信号互操作谈判圆满完成并发表两国联合声明，扫清了北斗三号系统建设道路上最后的障碍。此后，北斗三号已经顺利加入了 ICAO、IMO、3GPP、COSPAS-SARSAT 等国际标准，研究成果成功支撑了北斗三号服务全球、造福人类的使命。

The project proposed BDS-3 B1 and B2 signal schemes addressed challenges such as spectrum resource scarcity, transmission power limitations, multi-signal and multi-service broadcasting, smooth transition requirements, and compatibility and interoperability constraints. To date, all 35 networking satellites have adopted the project's achievements, providing services globally. According to the GNSS Service Monitoring and Assessment Monthly Report released by the Test and Assessment Research Center of China Satellite Navigation Office, since its official launch in July 2020, BDS-3 has maintained world-class service performance, with positioning accuracy ranking first globally.

In international collaboration and exchanges, the compatibility and interoperability of navigation signals are critical to fostering international partnerships. Following spectrum coordination under the ITU framework, the QMBOC-based B1C signal directly facilitated the successful completion of the China-U.S. B1C and L1C signal interoperability negotiations in 2017, culminating in a joint statement between the two countries and removing the last obstacle in BDS-3's development. Subsequently, BDS-3 has been integrated into international standards set by organizations such as ICAO, IMO, 3GPP, and COSPAS-SARSAT, and the research enabled BDS-3 to serve the global community and benefit humanity.



北斗三号卫星导航系统在轨信号地面监测结果
Ground monitoring results of on-orbit BDS-3 signals



全球首发大众智能手机直连卫星语音及双向短信商用服务
The global debut of smartphone direct connection to satellite for audio and bi-directional SMS commercial service

大众智能手机直连天通卫星系统的关键技术及规模应用

Key Technologies, and Scale Application of Smartphone Direct Connection to Tiantong Satellite System

中国电信集团有限公司
China Telecom Corporation Limited

华为终端有限公司
Huawei Device Co., Ltd.

中国电子科技集团公司第五十四研究所
Chinese Electronics Technology Group 54Th Institute

北京华力创通科技股份有限公司
Hwa Create Corporation

引言

大众智能手机直连卫星技术是全球卫星移动通信领域的重大突破性创新，是未来 6G 先导技术，是拉动天地一体产业链融合发展的关键奠基技术。

Introduction

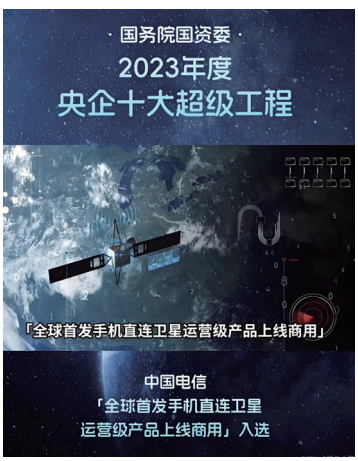
Smartphone Direct Connection to Satellite technology is a huge innovative breakthrough in global mobile satellite communication, which is the leading technology in the future 6G and serves as the crucial and fundamental technology for the integrated development of space-ground industry chain.

突破高轨卫星超长距离通信难关，建成首个天地融合移动通信网络

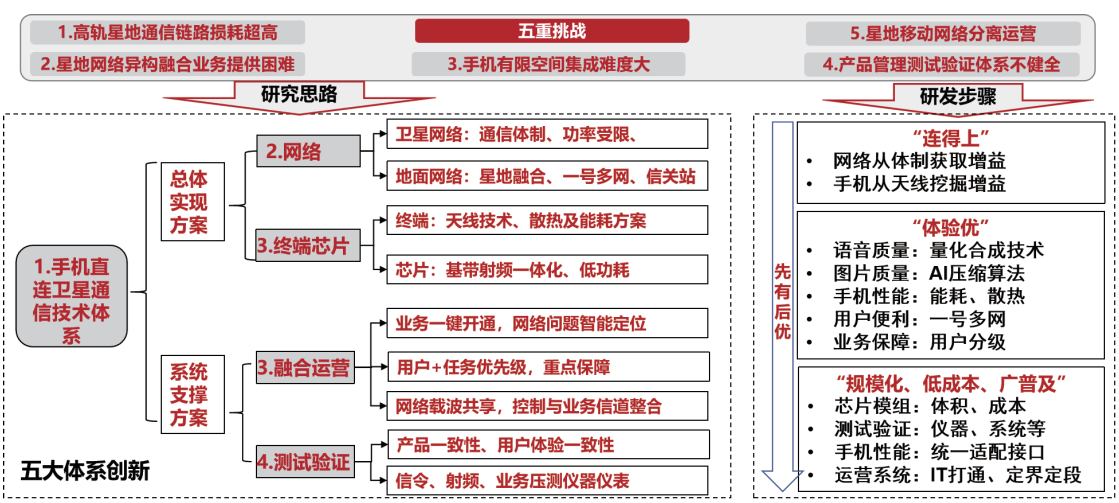
Breaking through the difficulties of ultra long distance communication with GEO satellite and building the world's first state-of-the-art space-ground integrated mobile communication network

中国电信牵头联合产业伙伴，突破手机连接高轨卫星通信的巨大技术鸿沟，全新推出了天地一体手机直连卫星通信体系，全面创新手机直连卫星通信标准、天地融合通信网络、手机直连卫星标杆产品、星地融合运营体系、产业端到端测试验证体系五大领域，实现大众智能手机“不换卡不换号”直连天通高轨卫星。该项目在全球首发大众智能手机直连卫星语音及双向短信商用服务，建成全球首个天地一体融合移动通信网络，整体处于国际先进水平，其中手机直连卫星通信技术及终端产品居国际领先，填补了业界空白。

China Telecom along with industry partners bridged the huge technical gap of mobile phones' direct communication with GEO satellite. It newly released the communication system “space-ground integrated direct phone connection to satellite” and made holistic innovation on 5 large areas including direct phone connection to satellite communication standard, space-ground integrated communication network, direct phone connection to satellite flagship products, space-ground integrated operation framework, and end-to-end industrial testing and validation system, thereby achieving smartphone direct connection to Tiantong GEO satellite with “no change in SIM cards or phone numbers”. This project announced the global debut of smartphone direct connection to satellite for audio and bi-directional SMS commercial service. In addition, it established world's first state-of-the-art space-ground integrated mobile communication network, where direct phone connection to satellite communication technology as well as terminal products take the lead internationally and fill the blank of the industry.



2023 年度央企十大超级工程
Top 10 super projects of central SOE in 2023



五大创新体系
Five Major Innovation Systems

赋能大众，从行业拓展至手机、汽车领域，推动天通国际化运营

Empower the public, expand from the industry to the fields of mobile phones and automobiles, and promote the international operation of Tiantong

该项目一方面在灾害救援、远洋航行、野外勘探、旅游探险等无地面网覆盖场景下，为用户提供更加低成本、高可靠的便捷通信手段，另一方面大幅扩展了中国高轨卫星移动通信系统的民用基础，实现卫星通信功能从行业到大众、从人到车的规模拓展。

On the one hand, this project provides users with a low cost, high reliability convenient communication method under scenarios such as disaster rescue, ocean voyage, wilderness exploration, travel adventure, etc. On the other hand, it drastically expands the civil use foundation of China's GEO satellite mobile communication, thereby achieving the scale extension of satellite communication functionality from industry to the general public.



老挝发布会
Laos Press Conference



中国香港发布会
Hong Kong Press Conference

截至 2025 年 5 月，华为、荣耀、小米、OPPO、vivo、中兴、三星等主流手机品牌推出直连天通卫星智能手机款型达 41 款，累计终端出货量超 2500 万台，带动终端产业链销售收入超千亿；中国电信手机直连卫星业务累计发展用户 516.8 万户，累计创收 4.25 亿元。

By May 2025, the number of smartphones with direct connection to Tiantong Satellite capability announced by major phone brands such as Huawei, Honor, Xiaomi, OPPO, vivo, ZTE, Samsung, etc. has reached 41, along with a terminal shipment of more than 25 millions, which produced a sales income more than 100 billion. China Telecom direct phone connection to satellite service has accumulated to 5.168 million subscribers with a 425 million Chinese yuan accumulated income.

借助手机直连卫星关键技术创新，中国电信先后于 2024 年 5 月 8 日在中国香港、2025 年 5 月在老挝落地直连卫星业务，推动中国卫星系统国际化运营，为海内外基础设施的高质量互联互通搭建桥梁。

Through critical technology innovation of direct phone connection to satellite, China Telecom has announced direct phone connection to satellite service in Hong Kong on May 8, 2024 and in Laos on May 2025, respectively. This promoted the international operation of China's satellite system, thereby providing the bridge for high quality interconnection between domestic and overseas infrastructures.

引领直连卫星技术创新，构建卫星产业发展新模态

Leading the innovation of direct satellite technology and building a new mode of satellite industry development

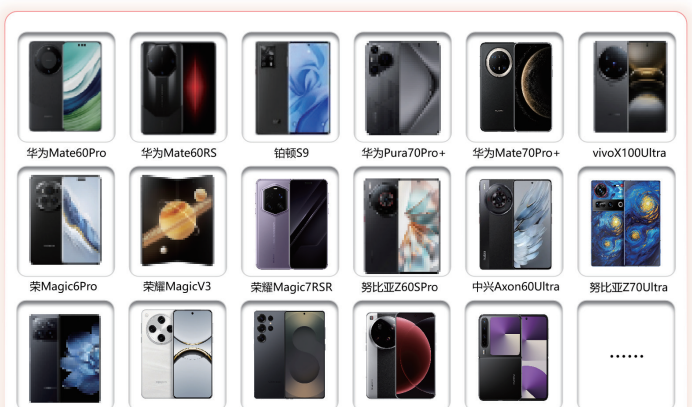
在引领技术创新方面，该项目通过在通信标准、网络架构、标杆产品、运营体系、测试体系五大领域的全面创新，形成了一系列手机直连知识产权体系，项目授权发明专利 101 项、登记软著 40 项、发表论文 16 篇。相较于国际上其它运营商仅能提供卫星 SOS 短信功能，该项目已成功向全球提供手机直连卫星整体解决方案。

In leading innovation of technology, this project has formed a series of direct phone connection intellectual property system via holistic innovation in 5 areas including communication standards, network structure, flagship products, operation framework and testing system. It authorized 101 invention patents, 40 registered software copyright and 16 published papers. In comparison to other service operators in the world which can only provide satellite SOS SMS functionality, this project has successfully provided a holistic solution to enterprises for direct phone connection to satellite worldwide.

在推动产业发展方面，该项目通过发挥地面移动通信产业规模效益，以地带天、天地融合，以技术创新驱动卫星终端芯片的低成本、规模化量产，有力促进天地一体产业融合、卫星应用降本增效，带动直连卫星终端、芯片实现低成本、规模化量产，相较于天通行业终端每年 6-7 万台销售规模，手机直连带动产业增长达数百倍，预计 2025 年支持直连卫星功能的终端销量将超 3000 万台，接近中国每年手机产量的 1/10，并从中高端领域向千元机扩展。



专利授权
Authorized patents



消费级卫星终端
Consumer grade satellite terminal

In promoting industry development, this project utilized the advantage of scale in terrestrial mobile communication industry to integrate ground with space to drive the mass production and reduction in cost of satellite terminals with technology innovation. It strongly advanced the integration of space-ground integrated industry and reduced costs while enhancing efficiency in satellite applications. This drives the low-cost, large-scale production of direct-to-satellite terminals and chips. Compared with the annual sales volume of 60,000 to 70,000 in the Tiantong industrial terminal market, direct phone connection to satellite is expected to boost industry growth by several hundred times. It is estimated that by 2025, sales of terminals supporting direct phone connection to satellite functionality will exceed 30 million—nearly 10% of China's annual mobile phone output—expanding from the mid-to-high-end segment to entry-level smartphones priced around 1000 Chinese yuan.



“通导感管”一体化低空智联网技术体系
An Integrated "Communication, Navigation, Sensing and Management" Low-Altitude Intelligent Network Technological System

低空智联网关键技术研究与应用

Key Technologies and Applications of Low-Altitude Intelligent Network

中国移动集团有限公司
China Mobile Communications Group Co., Ltd.

亿航智能设备（广州）有限公司
EHang Intelligent Equipment (Guangzhou) Co., Ltd.

丰翼科技（深圳）有限公司
Phoenix Wings Shenzhen Co., Ltd.

引言

低空智联网是推动低空经济高质量发展和高水平安全的关键，本成果从技术、标准、产品、应用四方面实现低空智联网全方位体系化创新，赋能生活方式、生产方式、社会治理等领域低空数智化创新。

Introduction

The Low-Altitude Intelligent Network (LAIN) is pivotal in driving the high-quality development and high-level security of the low-altitude economy. This achievement delivers comprehensive and systematic innovation in LAIN across four dimensions: technology, standards, products, and applications, enabling digital and intelligent innovations in lifestyles, industrial production and social governance.

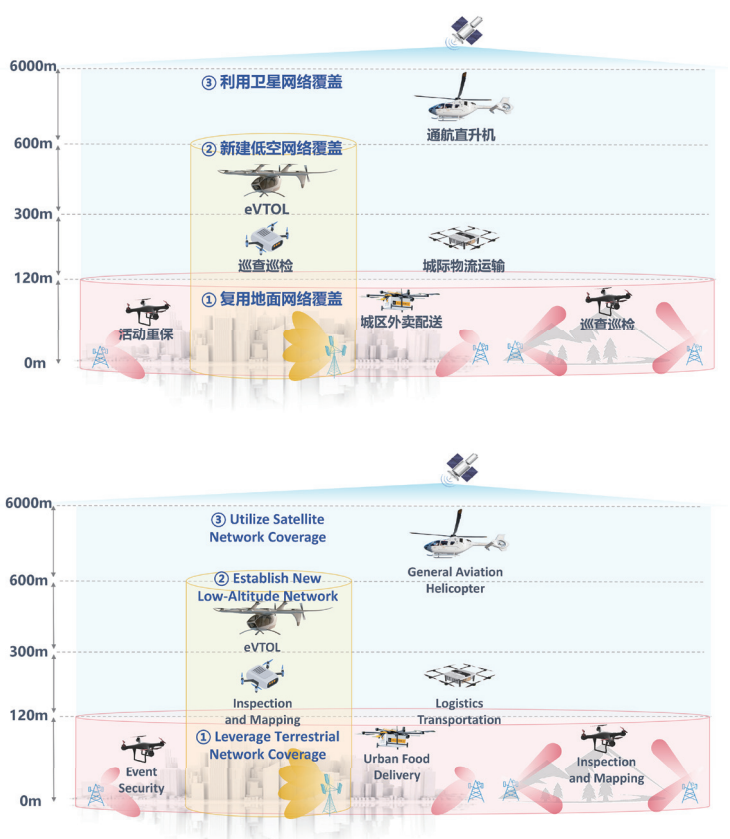
领跑低空智联网技术创新、规模试验与应用示范

Leading Technology Innovation, Large-Scale Trials and Application Demonstrations in LAIN

本成果秉承“空地协同、通感融合、安全可信”的核心理念，打造全球首个“通、导、感、管”一体的低空智联网技术体系，提出低空鱼鳞新型组网、通感一体混合波形、通感算智融合架构等标志性技术，攻克低空广域连续覆盖难、空地组网干扰大、可靠保障要求高、实时安全监管难等全球性难题，主导 3GPP、ITU 等标准 33 项，申请专利 300 余项。

联合产业研制 4 款通感一体站，部署超 700 站，打造首批规模低空试验网，实现 600 米高度低空通信连续覆盖和 300 米高度低空感知连续覆盖，研发“中移凌云”低空综合服务平台，实现超 200 款无人机、eVTOL 接入，累计轨迹数量过亿，打造城市外卖配送、跨海物流运输、载人观光飞行等世界级低空应用标杆，为低空智联网在全球范围的商用提供先行实践，荣获 2024 未来网络领先科技成果等 10 余项奖项。

Guided by the core principles of "air-ground coordination, communication-sensing integration, and security-trustworthiness", this achievement has established the world's first LAIN technological system encompassing capabilities of communication, navigation, sensing and management, introducing landmark technologies including novel fish-scale networking, hybrid communication-sensing waveforms and a converged network architecture of communication, sensing, computing and intelligence. These technologies address global challenges including difficulties in achieving wide-area con-



低空三维立体通信覆盖
3D Low-Altitude Communication Coverage

tinuous coverage, significant air-ground interference, stringent reliability requirements, and real-time safety supervision in low-altitude operations. This project has led the development of 33 standards such as 3GPP and ITU, resulted in over 300 patents.

In collaboration with industry partners, four types of integrated communication and sensing base stations were developed, with more than 700 units deployed, forming the first large-scale low-altitude trial network. This network achieves continuous communication coverage up to 600-meter height and continuous sensing coverage up to 300-meter height. This project has developed the "CMCC Lingyun" low-altitude service platform, supporting over 200 types of drones and eVTOLs with more than 100 million flight trajectories processed. It has enabled world-class application benchmarks such as urban food delivery, cross-sea logistics and aerial sightseeing, providing pioneering practical experience for the global commercialization of LAIN. The project has been recognized with more than 10 awards, including the 2024 Future Network Leading Technology Achievement Award.



“中移凌云”低空综合服务平台
"CMCC Lingyun" low-altitude service platform

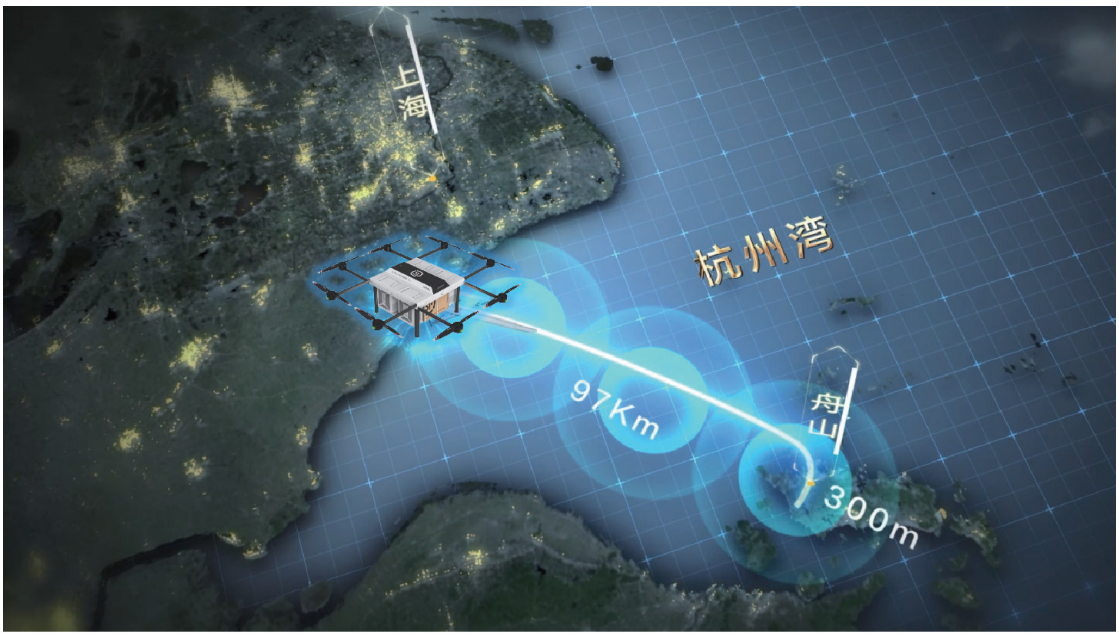
赋能生活方式、生产方式、社会治理领域低空数智化创新
Empowering digital and intelligent innovations in lifestyles, industrial production and social governance

本成果在低空物流、低空出行、低空消防等十大场景试点应用，打造载人观光飞行、跨海物流运输等示范标杆，助力低空应用深入赋能社会民生。

观光出行方面，丰富低空旅游新体验。基于亿航 EH216-S 无人驾驶航空器，通过 4G/5G 网络、GNSS 全球导航卫星系统与地面指挥调度系统实时联动，在广州、合肥、太原等景区完成载人观光飞行。

物流运输方面，构建交通物流新范式。在舟山与上海之间实现全球首次百公里级 5G-A 通感一体跨海航线低空网络覆盖，助力无人机跨海运输，舟山海鲜 1 小时可达上海，2 小时可上餐桌，实现科技服务融入日常生活。

综合治理方面，打造社会治理新模式。在重庆打造森林防火无人机监测系统，实现火情识别、实时上报。在突发山火中实现紧急支援，巡查森林面积 520 平方公里，有效减少一线投入和作业风险。



舟山到上海跨海低空物流运输
Zhoushan-Shanghai Cross-Sea Low-Altitude Logistics Transport



广州低空载人观光出行
Guangzhou Low-Altitude Manned Sightseeing Flights

This achievement has been piloted in ten major scenarios including low-altitude logistics, transportation and firefighting, establishing application benchmarks such as aerial sightseeing and cross-sea logistics. It enables the low-altitude applications to profoundly empower society and citizens.

Enabling New Aerial Sightseeing Experiences. Using EHang's EH216-S autonomous aerial vehicles, 4G/5G mobile networks, GNSS and ground control systems, manned sightseeing flights have been successfully conducted in scenic areas across Guangzhou, Hefei,

and Taiyuan.
Redefining Transportation Paradigms. Between Zhoushan and Shanghai, the world's first 100-kilometer5G-A integrated communication-sensing network allows fresh seafood to reach Shanghai within an hour and dinner tables within two hours.
Upgrading Social Management. In Chongqing, a drone-based forest fire monitoring system has been deployed, capable of automatic fire detection and alerting. In a recent wildfire response, drones flew over 520 km² of forest, reducing personnel risk and boosting emergency response efficiency.

推动低空经济高质量、规模化发展
Driving High-Quality and Large-scale Development of the Low-Altitude Economy

引领低空智联网技术创新发展。打造全球首个“通、导、感、管”一体的低空智联网技术体系，主导完成3GPP 网联无人机国际标准，技术方案写入标准数量位于全球运营商之首，牵头完成网联无人机相关行业标准立项 18 项，在多省市完成规模试验，打造跨海物流、载人观光等标杆应用，荣获 2024 未来网络领先科技成果、中国国际数字经济博览会优秀成果等 10 余项奖项，为低空智联网技术在全球范围的规模商用提供先行实践和应用示范。

带动低空经济产业规模化发展。本成果助力打造集“广域可靠通信、智能精准导航、多维立体感知、高效可控监管”于一体的低空智联网新型信息基础设施，将加速推动低空经济上游装备面向无人化、网联化、智能化演进，并赋能下游低空应用数字化升级，面向更多行业、更广领域、更深层次拓展，催生多元低空产业生态，支撑低空经济高质量、规模化发展。

Leading Technological Innovation in LAIN. The project has established the world's first integrated LAIN technological system encompassing capabilities of communication, navigation, sensing and management. It has led the development of international standards for connected drones in 3GPP, and initiated 18 industry standards within CCSA. Large-scale trials have been successfully conducted across multiple provinces, with pilot applications implemented in cross-sea logistics and aerial sightseeing. The project has been honored with over 10 awards, including the 2024 Leading Scientific Achievement of the Future Network and the China International Digital Economy Expo Excellence Award. These efforts lay a strong foundation for global commercialization of LAIN.
Promoting the Large-scale Development of the Low-Altitude Economy. This breakthrough facilitates the creation of next-generation in-



formation infrastructure integrating "wide-area reliable communication, intelligent precision navigation, multi-dimensional sensing, and efficient regulatory control", accelerating the evolution of upstream UAV equipment toward unmanned, connected, and intelligent while empowering downstream digital upgrades and expanding low-altitude application scenarios to a broader level. This fosters a diversified low-altitude industry ecosystem, and promotes the high-quality and large-scale development of the low-altitude economy.



中国移动在 2024 MWC 发布低空智联网创新成果
China Mobile Release Low-Altitude Intelligent Network Innovations at MWC 2024



GLM 大模型建设体系
GLM Large Models Development System

GLM 大模型关键技术及规模化应用

Key Technologies and Large-scale Applications of GLM Large Models

清华大学
Tsinghua University

北京智谱华章科技股份有限公司
Beijing Knowledge Atlas Technology Joint Stock Company Limited

引言

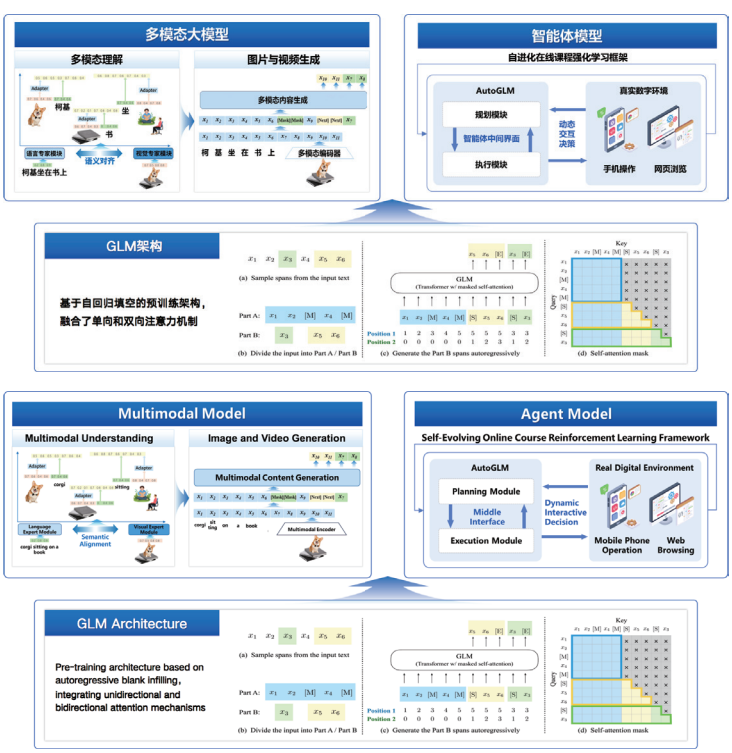
本项目建立了新一代认知大模型技术体系，研发了 GLM 系列模型，主要性能指标对齐国际先进水平，系列模型开源开放，实现了规模化的应用，产生了广泛的国际影响，取得了显著的科技、经济和社会效益。

Introduction

This project established a new-generation technology system for cognitive large model, developed the GLM series of models, and the main performance indicators are aligned with the international advanced levels. The series of models are open-source and achieved large-scale applications. The project has generated extensive international influence and achieved significant scientific, economic, and social benefits.

建立了认知大模型技术体系，主要性能指标对齐国际先进水平

Established a Cognitive Large Model Technology System, with Key Performance Indicators Aligned with International Advanced Levels



GLM 大模型技术体系
GLM Large Models Technology System

本项目针对大模型框架设计、内容理解生成、复杂规划能力等方面的挑战，建立了新一代认知大模型技术体系，主要性能指标对齐国际先进水平。

在模型架构方面，提出基于自回归填空的通用预训练架构 GLM，在自回归生成过程加入掩码注意力机制，提升大模型鲁棒性，降低幻觉性。

在多模态模型方面，提出基于视觉专家的多模态理解与生成算法，深度对齐语言和多模态信号，实现大模型的多模态认知与交互。

在智能体模型方面，研发了基于深度推理的自主工具使用智能体技术，实现了通用图形界面、手机和电脑端任务的智能规划和执行。

To address challenges such as large model framework design, content understanding and generation, and complex planning, this project has established a new-generation technology system for cognitive large model, and the main performance indicators are aligned with the international advanced levels.

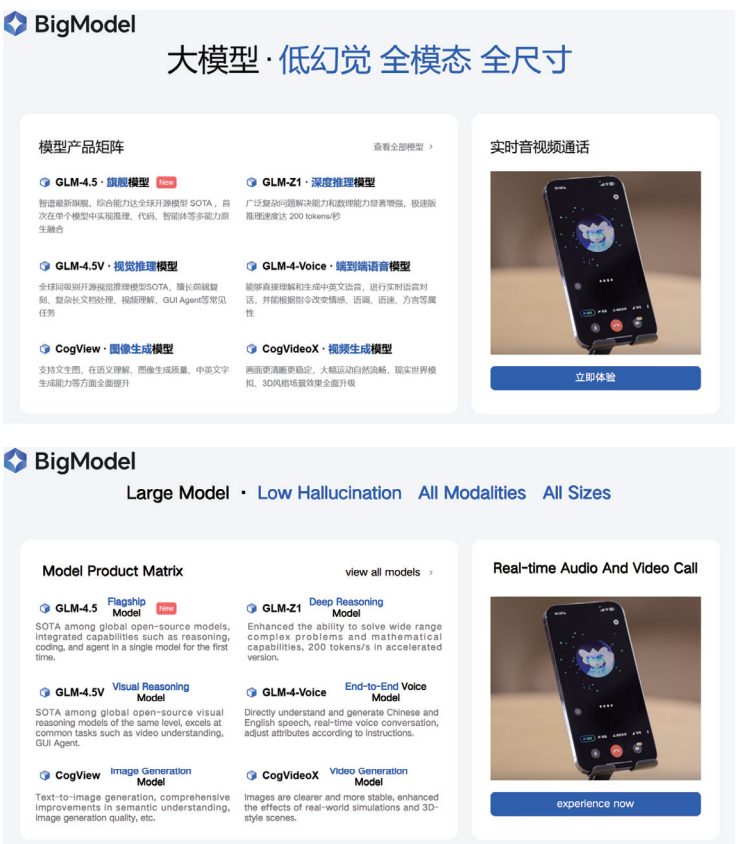
In terms of model architecture, a general pre-training architecture GLM based on autoregressive blank infilling was proposed. A masked attention mechanism is integrated into the autoregressive generation process to enhance the robustness and reduce hallucination of large model.

In terms of multimodal models, a multimodal understanding and generation algorithm based on visual experts is proposed, which deeply aligns language and multimodal signals to achieve multimodal cognition and interaction in large models.
In terms of agent models, an autonomous tool-using agent technology based on deep reasoning has been developed, enabling the intelligent planning and execution of tasks across general graphical interfaces, mobile phones, and computers.

建立了 GLM 系列模型和多样的服务模式，实现了规模化应用

Established GLM Series of Models and Diverse Service Patterns, Achieved Large-Scale Applications

本项目建立了基座模型、对话模型、多模态模型、智能体模型等 GLM 系列模型，提供语言、图像、视频等多模态内容理解与生成，以及智能体自主执行服务。研发了对话模型 ChatGLM，并构建了生成式 AI 服务助手“智谱清言”。建立了模型即服务（MaaS）的一站式大模型开发平台，通过 API 调用、云端微调、云端私有化部署等方式提供服务。日均 API 调用超万亿字。项目关键技术应用广泛，系列产品及服务在互联网、金融等 20 余个行业万余家单位实现了规模化应用，帮助行业做出成功的大模型应用，促进其实现智能化升级。实现了良好的科技、经济和社会效益。



大模型 MaaS 平台
Large Model MaaS Platform

This project developed a series of GLM models, including foundation models, dialogue models, multimodal models, and agent models. These models provide services for multimodal content understanding and generation (encompassing text, image, video, etc.), as well as autonomous execution services by agents. The project has developed the dialogue model ChatGLM and built the generative AI service assistant “Zhipu Qingyan”. A one-stop large model development platform based on Model as a Service (MaaS) has been established, which provides services through API calls, cloud-based fine-tuning, cloud-based private deployment, and other methods. The daily average API calls exceed1 trillion characters. The key technologies of the project have been widely applied. A series of products and services have achieved large-scale applications in over 10,000 organizations across more than 20 industries, including banking, telecommunications, government services, and e-commerce. This has helped industries develop successful large model applications, promoted their intelligent upgrading. The project has achieved significant scientific, economic, and social benefits.

践行大模型开源理念，促进技术繁荣发展，获得国际高度认可

Practicing the Philosophy of Large Model Open-Source to Foster Technological Development, Gained High International Recognition

项目重视大模型生态发展，开源 40 余个模型，GitHub Star 数超 15 万，衍生 1000 余项开源项目，促进各领域技术发展。率先开源 ChatGLM-6B 系列模型，发布后累计 4 周位列 Hugging Face 全球大模型趋势榜榜首。团队在 Hugging Face 评出的 2023 年全球最受欢迎 15 家机构中排名第 5，是中国唯一上榜单位。国际顶刊《Nature》在“China’s ChatGPT: why China is building its own AI chatbots”文章中介绍了 ChatGLM 模型在构建中文大语言模型方面的实践，在国际范围内引发了广泛关注。项目团队受邀在国际人工智能顶会 ICLR2024 及 WWW2024 做了特邀报告。

The project emphasizes the development of the large model ecosystem. It has open-sourced over 40 models, which have garnered more than 150,000 stars on GitHub. They have spawned of over 1,000 open-source projects, fostering technological development in various fields. We took the lead to open-source the ChatGLM-6B series of models, which ranked first on the global large model trend list of Hugging Face for 4 weeks. Additionally, our team ranked 5th among the “The top 15 most-liked organizations on Hugging Face” in 2023, it is the only Chinese organization on the list. The international top journal Nature introduced the practices of the ChatGLM model in developing Chinese large language models in the article “China’s ChatGPT: why China is building its own AI chatbots”, which has attracted widespread attention globally. Furthermore, our team delivered invited reports at top international AI conferences, including ICLR 2024 and WWW 2024.



GLM 系列模型开源生态建设

Open-Source Ecosystem Development of the GLM Series of Models



诺基亚面向具身智能生成式智能体仿真训练平台 (NGAST)
NGAST: Nokia Generative AI Agent Simulation Training Platform for Embodied Intelligence

工业 AI 的未来：诺基亚 NGAST 平台
The Future of Industrial AI: Nokia NGAST Platform

上海诺基亚贝尔股份有限公司
Nokia Shanghai Bell Co., Ltd.

上汽通用汽车有限公司
SAIC General Motors Corporation Limited

引言

诺基亚 NGAST 平台利用生成式 AI、智能体和数字孪生技术，以少量真实数据高效训练工业智能体，赋予人形机器人等具身智能在制造等行业中的泛化能力，加速工业数字化转型。

Introduction

Leveraging generative AI, AI Agents and digital twin technologies, Nokia NGAST platform efficiently trains industrial AI agents with minimal real-world data. This empowers embodied intelligence, such as humanoid robots, with the generalization capabilities needed to accelerate digital transformation across manufacturing and other industries.

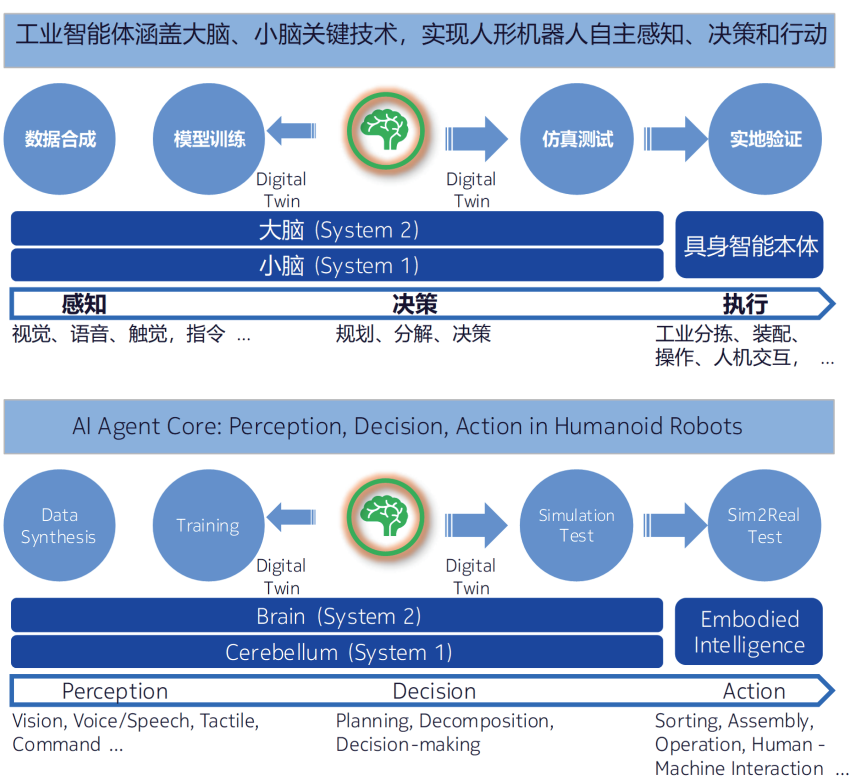
融合数字孪生和工业智能体技术，加速人形机器人工业应用
Accelerating humanoid robot adoption with digital twins and AI Agents

诺基亚 NGAST 平台攻克了传统训练依赖大量人工遥操作数据的技术瓶颈，实现了核心创新与国际领先。它融合生成式 AI、大模型及数字孪生技术，通过少量高质量数据将训练集扩增百倍甚至千倍，显著降低数据采集成本与时间，并使仿真训练流程效率提升 10 倍以上。该平台还实现了面向具身智能的智能体多模态感知融合与自主决策，大幅增强了工业智能体跨场景、多任务的技能泛化和场景适应能力。平台具备良好的扩展性，能支持多种具身智能和灵巧手，推动人形机器人成功应用于核心制造领域，成为以人形机器人为代表的具身智能进入工业制造实践的关键技术支撑。该方案在 2025 世界移动通信大会上获得 GTI 大奖，获得业界的高度认可。

Nokia's NGAST platform has overcome the significant challenge of needing amounts of TeleOp data for training. It achieves this through a core innovation that sets it apart in the industry.

By integrating Generative AI, LLM, and digital twin technology, the platform uses a small amount of high-quality data to expand training datasets by hundreds or even thousands of times. This drastically cuts data collection costs and time, while also increasing simulation training efficiency by over 10 times.

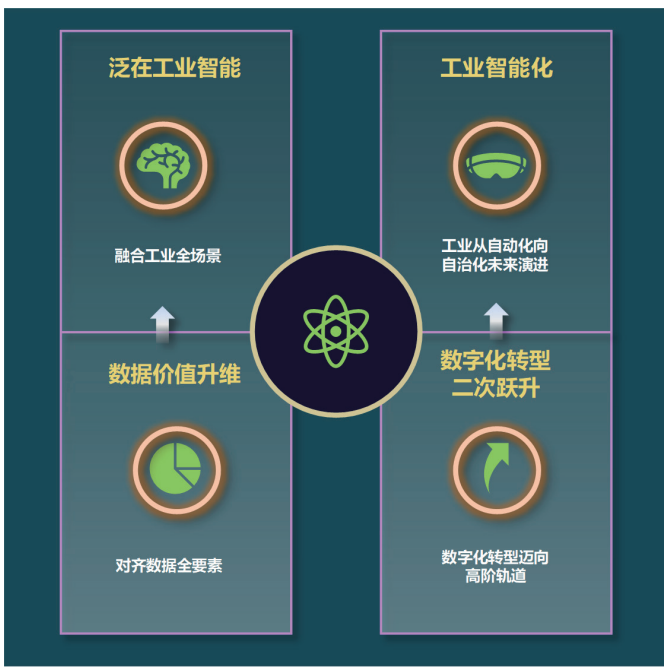
The platform also enables embodied intelligence to have multi-modal perception and autonomous decision-making. This greatly enhances the ability of industrial AI agents to generalize skills and adapt to various tasks and scenarios.
With its strong scalability, the platform can support various types of embodied intelligence and robots. This makes it a crucial technical enabler for the successful application of humanoid robots in key manufacturing sectors. The solution was highly recognized by the industry, receiving the GTI Award at the 2025 Mobile World Congress.

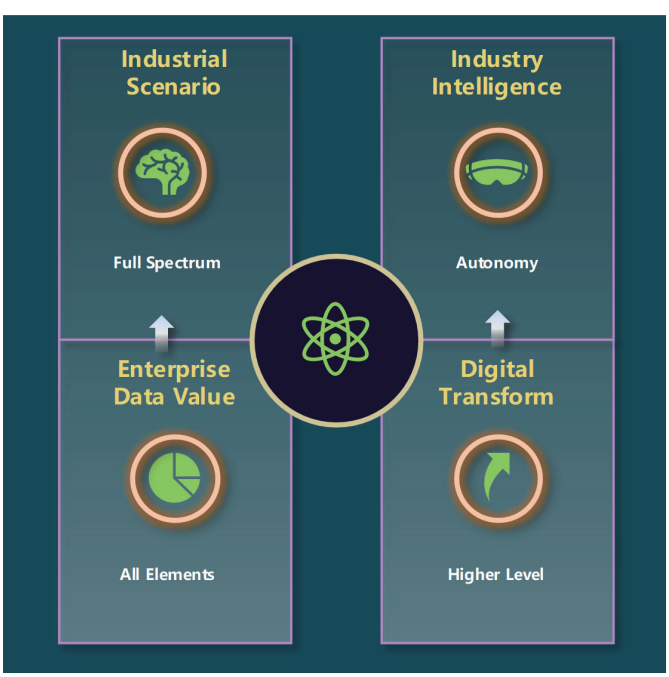


诺基亚 NGAST 平台
Nokia NGAST platform

诺基亚 NGAST 平台成功应用，积极拓展全球合作伙伴，前景广阔

Nokia NGAST, successful application, expanding global partnership





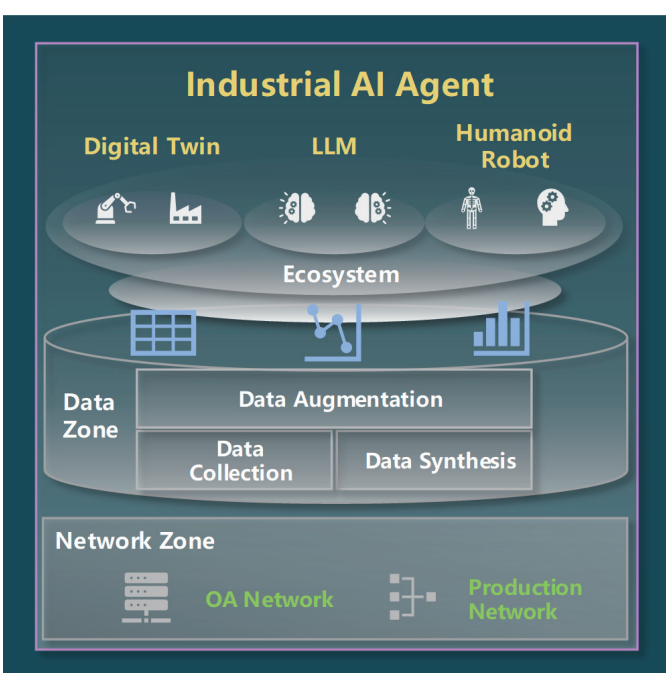
诺基亚 NGAST 平台应用前景广阔
Nokia NGAST: Broad Application Prospects

诺基亚 NGAST 平台正在积极拓展全球合作伙伴，以上汽通用凯迪拉克应用为代表，展现出显著的经济和生态潜力。在经济效益方面，该平台通过生成式技术将训练效率提升 10 倍以上，大幅降低数据采集成本，并预计将生产效率提升 30%-50%。此外，平台训练的工业智能体可胜任一些环境严苛场景，如汽车制造中的玻璃底漆涂覆工序，预计可减少 30% 的风险作业时间，同时提升制造柔性，提升员工生产制造环境，提高员工满意度。在社会效益方面，平台催生了工业智能机器人工程师等高技能新兴岗位，预计岗位需求增长 30%-50%，带动劳动力结构优化。在生态效益方面，智能体精准高效的作业减少了能源消耗和废品率，推动绿色生产。

With its successful experience at SAIC-GM Cadillac, the Nokia NGAST platform is actively expanding global partnerships. The platform demonstrates significant economic potential by boosting training efficiency over 10 times and increasing production by 30%-50%, while also reducing costs and risk in high-risk tasks. Furthermore, it creates new, high-skilled jobs with an expected growth of 30-50%, while promoting green manufacturing by reducing energy consumption and waste.

工业智能化核心引擎，催生高技能岗位，构建开放生态
Core Engine for Industrial AI: Creating High-Skilled Jobs and Building an Open Ecosystem





诺基亚 NGAST 平台是工业智能化核心引擎
Nokia's NGAST Platform: The Core Engine for Industrial AI

诺基亚 NGAST 平台作为工业智能化的核心引擎，对技术进步和产业结构优化具有深远影响。NGAST 平台突破了工业智能体训练中的数据和成本瓶颈。通过生成式 AI 技术，显著降低了数据采集成本和时间，并极大地提升了智能体的泛化能力和环境适应性，推动智能体具备在复杂动态环境中自主感知、决策和执行任务的能力，为具身智能的大规模应用奠定坚实基础。预计到 2035 年，仅汽车行业就将部署超过 100 万智能体。同时，平台催生了工业智能机器人工程师等新兴高技能岗位，构建了涵盖人形机器人、AI、数字孪生等上下游的开放协同产业生态系统，全面提升了产业链的整体技术水平。让工业从自动化向自治化跨越成为可能。

As a core engine for industrial AI, the Nokia NGAST platform is having a profound impact on technology and industry structure. The platform overcomes data and cost bottlenecks in AI agent training by using generative AI to drastically cut data collection time and costs. This greatly enhances an agent's generalization and adaptability, providing a solid foundation for large-scale embodied intelligence deployment in complex environments.

It is expected to drive the deployment of over one million AI agents in the automotive sector alone by 2035. By creating new, high-skilled jobs and an open ecosystem, it makes the leap from industrial automation to full autonomy possible.

诺基亚 NGAST 平台斩获 2025 年 GTI 创新奖，彰显工业 AI 领导力

Nokia NGAST Platform: 2025 GTI Innovation Award Winner and Industrial AI Leader

诺基亚工业智能体项目荣获 2025 年 GTI 创新奖，彰显了其在工业 AI 领域的领导力。核心贡献在于诺基亚 NGAST 平台，它融合生成式 AI 和数字孪生技术，成功突破了数据瓶颈和高成本难题，显著提升训练效率，赋予具身智能卓越的泛化能力，为引领工业自治化未来奠定了坚实基础。

Winning the 2025 GTI Innovation Award, the Nokia Industrial AI Agent project demonstrates leadership in the field. Its core, the Nokia NGAST platform, leverages generative AI and digital twins to overcome data bottlenecks and high costs. This significantly boosts training efficiency, giving embodied intelligence excellent generalization and laying a solid foundation for the future of industrial autonomy.



诺基亚 NGAST 平台荣获 2025 年 MWC GTI 创新移动服务与应用奖
Nokia NGAST Platform: 2025 MWC GTI Innovative Mobile Service and Application Award Winner





剧本驱动多模协同的高拟真数字人技术
Script-driven multimodal collaboration hyper-realistic digital human technology

剧本驱动多模协同的高拟真数字人技术

Script-driven Multimodal Collaboration Hyper-realistic Digital Human Technology

百度
BAIDU

引言

剧本驱动多模协同的高拟真数字人技术于 2025 年 4 月首发，突破了多模态实时协同、复杂动态交互等技术难题，实现了数字人“神形音容话”的高度统一和直播内容的稳定高效输出。基于该技术已生产超过 10 万个数字人，覆盖电商、教育、法律等数十个行业，助力开播成本降低 80%，直播转化率提升 31%。

Introduction

The script-driven multimodal collaboration hyper-realistic digital human technology, released in April 2025, has made breakthroughs in key challenges such as real-time multimodal collaboration and comprehensive dynamic interactions. It delivers hyper-realistic digital human live-streaming characterized by high expressiveness, strong emotional impact, and free interaction among people, objects and environments, as well as the stable and efficient live-streaming. To date, over 100,000 digital humans have been produced using this technology, covering industries such as e-commerce, education, and law. It has helped reduce the cost of starting a live broadcasting by 80% and increased conversion rates by 31%.

剧本驱动多模协同的高拟真数字人技术
Script-driven multimodal collaboration hyper-realistic digital human technology

该成果攻克了数字人领域的多重技术难题。针对适配行业多风格剧本生成、高保真语音合成、双人协同语音交互及超长时长下数字人“音 - 容 - 话”一致性等挑战，百度提出了五项创新技术：剧本驱动的多模协同技术，实现了神形音容的高度拟真；融合多模规划与深度思考的剧本生成，提升了直播内容的吸引力和知识深度；动态决策的实时交互，保障了与用户交互的自然流畅；文本自控的语音合成，显著提升了语音的自然度和表现力；高一致性超拟真数字人长视频生成，解决了长时间ID保持及复杂交互难题。这些创新不仅突破了行业瓶颈，也推动了数字人技术向更高水平发展，具有技术领先性和广泛的应用前景。

To confront the challenges such as multi-style script generation, high-fidelity voice synthesis, dual-anchor interaction and voice-appearance-language consistency of digital human over extended durations, there are 5 innovative techniques of the script-driven multimodal collaboration hyper-realistic digital human technology, including script-driven multimodal collaboration to ensure highly realistic voice-appearance-language of digital human, script generation integrating Multimodal Planning and Deep Reasoning to upgrade the content attraction and the depth of knowledge of the live broadcasting, real-time interactive technology with dynamic decision-making to guarantee the natural and smooth interaction with users, text-controllable speech synthesis to achieve more natural voice, and high-consistency, hyper-realistic long video generation for digital humans to solve long-term identity preservation and complex interactions between humans, objects, and environments. These techniques have broken the industrial bottlenecks and led the digital human technology to higher level.



剧本驱动多模协同的数字人技术创新
Technological innovation of script-driven multimodal collaboration digital human

成功打造超 10 万数字人，引领数字人行业发展
Producing over 100,000 digital humans and leading the development of digital human industry

基于剧本驱动多模协同的高拟真数字人技术，已成功打造超 10 万个数字人，广泛覆盖电商、教育、法律等多个行业。

该技术助力商家开播成本大幅降低 80%，同时直播转化率显著提升 31%。

运用该技术打造的两位企业家形象数字人，在百度优选成功完成长达 6 小时的超拟真直播，观播人数 1300 万，GMV 突破 5500 万，充分展现了其吸引观众、提升流量与销售额的强大能力，为电商平台和商家带来显著经济效益。

目前，该技术已在百度电商的明星、图书、健康等多类直播中落地，且线上表现优异，效果超越真人主播，展现出广阔的应用前景和市场潜力。

Based on the script-driven multimodal collaboration hyper-realistic digital human technology, over 100,000 digital humans have been produced and applied in industries as e-commerce, education and law, etc.

It has helped reduce live-streaming startup costs by 80% and increase conversion rates by 31%.

Notably, using this technology, the live-broadcasting featuring digital versions of two entrepreneurs on Baidu Youxuan, had completed a 6-hour hyper-realistic broadcast that attracted 13 million viewers and achieved GMV exceeding 55 million RMB. The result shows that the technology can effectively attract a large audience, boost live-stream traffic and sales, and bring significant economic benefits to e-commerce platforms and merchants.

Currently, this technology has been adopted in Baidu's e-commerce live-streams such as celebrity, books, and health. It has delivered outstanding online performance, outperforming real people in live-broadcasting and demonstrating broad application prospects and market potential.



数字人直播超越真人
Digital humans outperforming real people in live-broadcasting

攻克多模协同难题，引领数字人技术发展
Overcome the challenge of multimodal coordination and lead the development of digital human technology

技术进步方面，该成果重点攻克多模态协同难题，实现数字人在语音、语言、视觉多模态高度匹配，为数字人研究提供新思路，推动感知、认知技术融合创新，提升数字人内容生成与交互能力，引领数字人技术向更高水平发展。

产业结构方面，该成果打破了传统直播对真人主播的依赖，为直播行业带来了新的模式。数字人主播可以根据不同的剧本和场景进行灵活切换，满足用户多样化的需求，提升了用户的观看体验。此外，该技术的应用还促进了就业结构的优化。一方面，为数字人技术研发、运营、维护等领域创造了新的就业岗位；另一方面，也为传统主播提供了转型和提升的机会，促使他们不断学习和掌握新的技能，以适应行业的发展变化。

In terms of technological progress, this technology has overcome the challenge of multimodal coordination of digital humans in live-streaming, achieving high-level synchronization and coordination in language, voice, actions, and expressions. This script-driven multimodal coordination technology provides new ideas and methods for research in digital human technology, promoting the integration and innovation of perception, understanding, and expression to achieve a better content generation and user interaction.

In terms of industrial structural adjustment, this technology has changed the way that the e-commerce live-streaming heavily relies on real-person anchor and faces limited anchor resources and constrained live-streaming time. The application of this technology has made digital human anchors a new force in the live-streaming industry, enabling 24/7 uninterrupted live streaming without considering the time and space. Furthermore, the digital human anchors can switch freely according to different scenarios to satisfy user demands and improve user experience. This innovative technology promotes the change of employment structure as well. On one side, it creates new positions in digital human R&D, promotion, operation and maintenance; on the other side, it provides transformation opportunities for human anchors to improve their skills and capabilities to catch up with the rapid industry growth.



位于之江实验室的浙江新型算力中心
Zhejiang Province's New Computing Center Located at Zhejiang Lab

南湖计算框架
Nanhu Computing Framework

之江实验室
Zhejiang Lab

之江实验室
ZHEJIANG LAB

引言

南湖计算框架是一套算存网高效协同的大规模智算框架，推动人工智能基础模型训练与 GPU 类型解耦。

Introduction

Nanhu Computing Framework is a large-scale intelligent computing framework that enables efficient collaboration among computing, storage, and networking resources. It advances the decoupling of AI foundational model training from specific GPU types.

算存网高效协同，适配多品牌加速卡，支持万亿参数模型训练
Supporting efficient collaboration across computing, networking, and storage resources, supporting multi-brand heterogeneous accelerators and providing trillion-parameter large language model training capacity

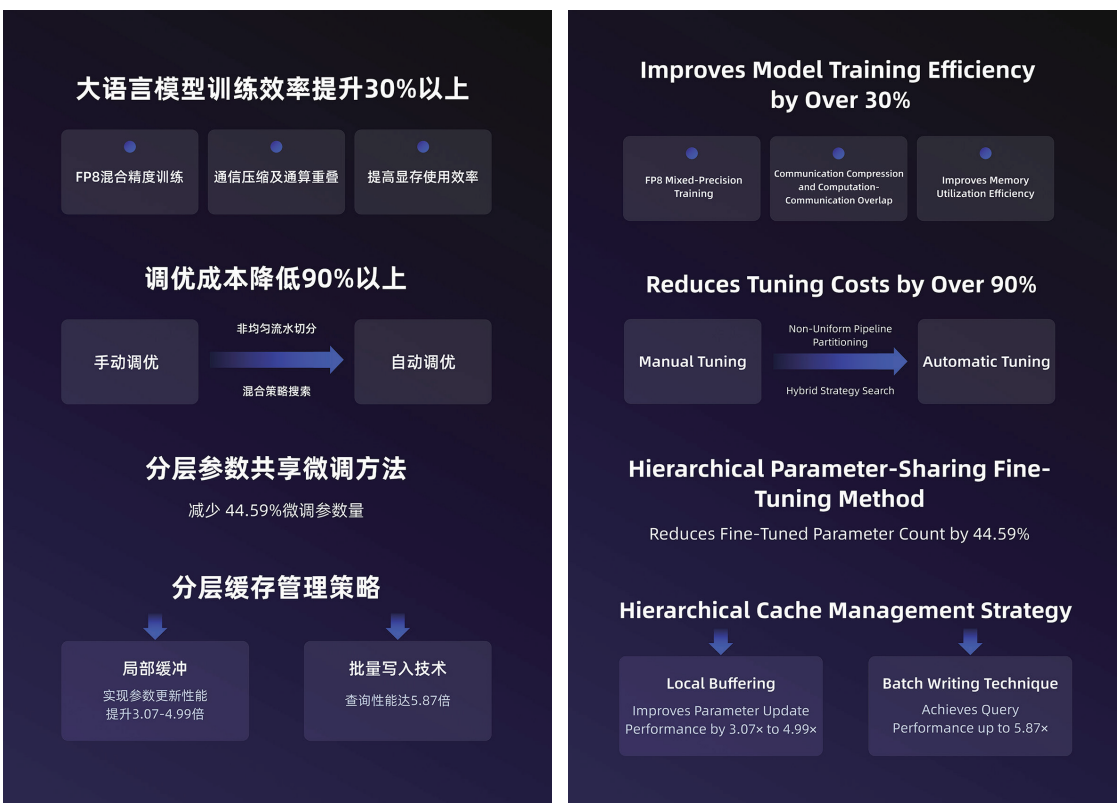
南湖计算框架支持多种类型智算硬件的大语言模型训练。它首创异构集群模型训练自动调优框架，利用较小规模的 CPU 资源求解最优策略，节省传统大语言模型训练策略调优所花费的大量智算加速卡计算资源。支持自适应的非均匀流水切分、混合训练策略自动搜索，调优成本降低 90% 以上。该框架首次提出分层参数共享精调方法，在保证模型效果的前提下，减少 44.59% 精调参数量，降低微调阶段的计算资源需求，实现更有效地捕获本地和全局级别的信息。它首创分层缓存管理策略和批量写入技术，

在更新性能方面比持久化存储系统最先进的内存存储高 3.07 倍到 4.99 倍，大幅降低数据处理中的读写开销，对大语言模型训练过程中的参数更新实现显著加速。

Nanhu Computing Framework supports large language model training across various types of accelerators. It introduces the first automatic tuning framework for heterogeneous cluster model training, addressing the issue of extensive accelerator resource consumption during strategy tuning for large language models. The search for optimal training strategies consumes only smaller-scale CPU resources instead. It supports adaptive uneven pipeline partitioning and automatic hybrid training strategy search, reducing tuning costs by over 90%.

For fine-tuning, the framework proposes a hierarchical parameter-sharing method that reduces fine-tuned parameter counts by 44.59% while maintaining model performance, significantly lowering computational resource demands during fine-tuning and better capturing both local and global information.

It pioneers a hierarchical cache management strategy and batch writing techniques, achieving 3.07× to 4.99× improvement in update performance compared to the most advanced persistent storage memory systems, significantly reducing read-write overhead in data processing and accelerating parameter updates during large language model training.



南湖计算框架对大模型训练性能提升
Nanhu Computing Framework's performance improvement for large model training

突破异构加速卡协同瓶颈，实现多异构加速卡卡间高速通信，训练效率大幅提升

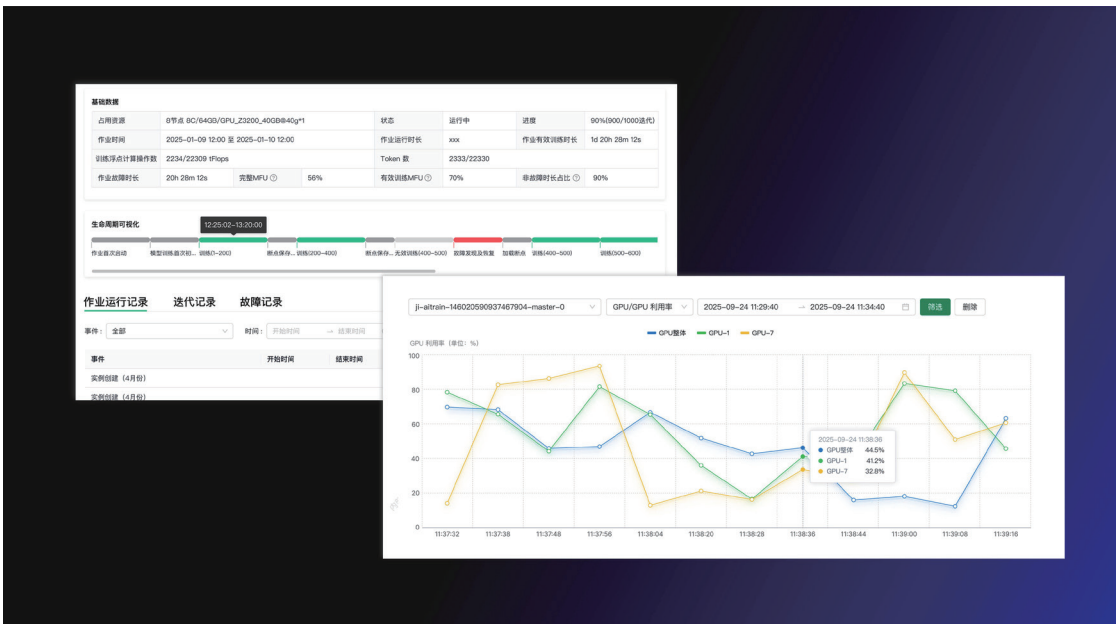
Facilitating cross-brand heterogeneous collaboration, providing high-speed communication across heterogeneous accelerators and achieving significant improvement in model training efficiency without model quality compromise

南湖计算框架全面兼容主流品牌的多种加速卡，攻克跨品牌异构协同难题。该框架首次实现多异构加速卡卡间 GPU Direct RDMA 高速直联集合通信，从而构造统一的南湖集合通信库，实现异构加速卡间高速通信，满足大规模异构算力协同调度、高带宽与低延迟的需求。同时，项目团队完成中国《智能计算异构加速器跨机互连测试方法》国家标准立项。该框架通过重构集合通信架构，首次实现通信对计算资源零占用，使得卡间 AlltoAll 集合通信带宽提升至传统集合通信库的 1.85 倍。它支持多种加速卡 FP8 混合精度训练，结合通信、显存优化，在确保模型质量不降的前提下，模型训练效率提升 30% 以上。

Nanhu Computing Framework achieves full compatibility with multiple mainstream accelerator brands, facilitating cross-brand heterogeneous collaboration. It is the first to achieve GPU Direct RDMA high-speed interconnect collective communication among multiple heterogeneous accelerators, which enables the construction of Nanhu Collective Communication Library providing high-speed communication across heterogeneous accelerators. The framework provides the capacity for large-scale heterogeneous compute scheduling with high bandwidth and low latency. We initiated the proposal of the national standard “Intelligent computing cluster - Test method of computing node interconnection.” By reconstructing the collective communication architecture, the framework consumes zero computing resource on accelerator during communication, boosting AlltoAll collective communication bandwidth by 1.85× compared with traditional communication libraries. It supports FP8 mixed-precision training across multiple accelerator types. Through communication and memory optimizations, it achieves over 30% improvement in model training efficiency without model quality compromise.



新型算力中心智算集群
Intelligent Computing Cluster of the New Computing Center



南湖计算框架的故障检测能力
The fault detection capability of Nanhu Computing Framework

实现万卡级高可用智能运维，支撑异构集群的万亿参数大模型高效训练

Achieving high-availability intelligent operations and maintenance at 10,000-GPU-scale cluster , supporting efficient training of trillion-parameter large models on heterogeneous clusters

南湖计算框架实现万卡规模集群秒级故障检测，万卡集群可用率跃升至 97%，实现故障智能感知与智能排障，大语言模型训练有效时长占比提升至 98.1%。 该框架已成功应用于万亿参数大语言模型训练，支持异构加速卡混合训练，同时具备高兼容性、高稳定性和低成本优势，将推动异构集群的高效协同与产业应用。

Nanhu Computing Framework enables fault detection within seconds which raises 10,000-GPU-scale cluster availability to 97%, Through intelligent fault detection and automated troubleshooting, the effective training time ratio reaches 98.1% for large language models training tasks.

The framework has been successfully applied to the training of trillion-parameter large language models, supporting heterogeneous accelerator hybrid training with advantages in high compatibility, stability, and cost efficiency. It will promote efficient collaboration and industrial applications within heterogeneous clusters.



应用具身智能基座大模型的全球首个真正商用的银河通用机器人在售货
The world's first truly commercialized Galbot robot, powered by an embodied AI foundation model, is deployed in retail sales

合成数据和真实数据驱动的 VLA 具身智能大模型
Synthetic and Real Data-driven VLA Embodied Intelligence Large Model

北京银河通用机器人有限公司
Beijing Galbot Co.,Ltd.

北京大学前沿计算研究中心
Center on Frontiers of Computing Studies, Peking University

香港大学
The University of Hong Kong

引言

聚焦具身领域“训练数据缺乏”和“模型泛化能力不足”两大核心瓶颈，银河通用创新性地开启了“大规模仿真合成数据预训练，真实数据后训练”新范式。项目构建了涵盖数据生成、模型训练、应用部署的全链条一体化技术体系。

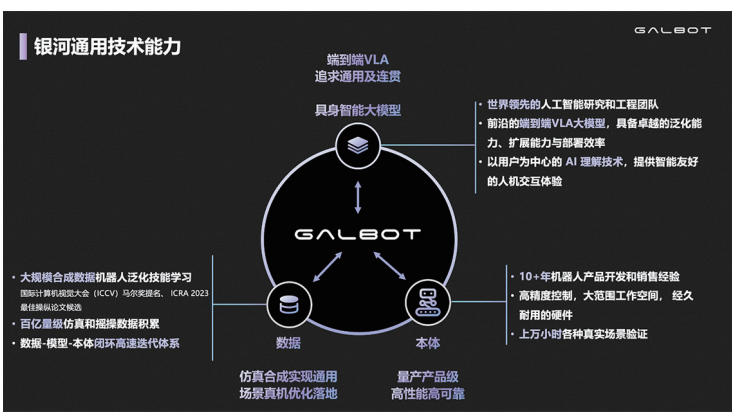
Introduction

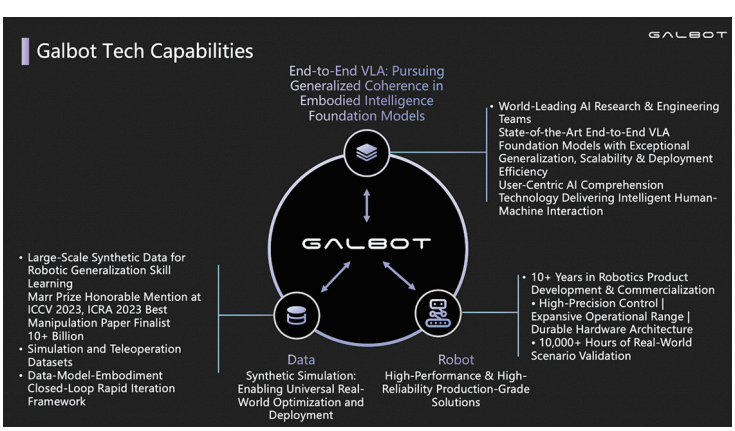
Focusing on the two core bottlenecks in the field of embodied intelligence—"the scarcity of training data" and "insufficient model generalization capability"—this project innovatively initiates a new paradigm of "large-scale synthetic simulation data for pre-training, complemented by real-world data for post-training." Starting from fundamental research and extending to cross-industry practical applications, the project independently develops key technologies such as physics-realistic simulation, Real2Sim2Real, and end-to-end Vision-Language-Action (VLA) models. This effort establishes a comprehensive, integrated technical system encompassing data generation, model training, and application deployment.

合成数据与真实数据双轮驱动的具身智能基座大模型
Embodied AI Foundation Model Dual-Driven by Synthetic and Real Data

针对具身智能数据少和泛化性差两大瓶颈，银河通用创新性地提出“大规模仿真合成数据预训练 + 少量真实数据后训练”的虚实数据融合训练新范式，从物理求解器底层出发构建物理真实的仿真数据合成管线，融合真实数据采集系统，并搭建了一套行业内国际领先的“数产 - 标注 - 审核 - 训练 - 测试”的自动化工具链，以应用落地需求为优化目标，低成本高效率地闭环迭代数据生产和模型训练。项目产出了全球领先的高质量具身智能数据集，包括十亿规模的灵巧手抓取大数据集 DexGraspNet 2.0、覆盖 77 万个三维物体资产的空间智能大数据 SpatialNet，以及超大规模零部件数据集 GAPartNet 等。

在此基础上，项目研发了全球首个端到端具身抓取大模型 GraspVLA，其预训练完全基于十亿级“视觉 - 语言 - 动作”合成数据，具备强大的 Sim2Real 能力，可在千变万化的真实场景中实现零样本泛化抓取，并支持通过少量真实样本后训练完成从通用模型到专家模型的快速适配；项目还训练了全球首个具身智能领域纯视觉“FSD”导航大模型 NaVid，并以此为基础模型发布了首个产品级导航大模型 TrackVLA。





银河通用机器人的技术创新能力
Galbot' Capacity for Applied Innovation

Addressing the two major bottlenecks of scarce data and poor generalization in embodied intelligence, Galbot has innovatively proposed a novel virtual-real data fusion training paradigm: "large-scale simulated synthetic data for pre-training + a small amount of real-world data for post-training." Starting from the underlying physics solver, the project constructs a physics-realistic simulation data synthesis pipeline, integrates a real-world data acquisition system, and has built the industry's advanced and comprehensive automated toolchain for "data production-labeling-review-training-testing." This system closed-loop iterates data production and model training with low cost and high efficiency, optimized for application deployment goals. The project has yielded multiple high-quality embodied intelligence datasets crucial for global strategic needs, including the billion-scale dexterous hand grasping dataset DexGraspNet 2.0, the spatial intelligence big data SpatialNet covering 770,000 3D object assets, and the ultra-large-scale components dataset GAPartNet.

Building upon this foundation, the project developed the world's first end-to-end embodied grasping foundation model, GraspVLA. Its pre-training was entirely based on billions of "Vision-Language-Action" synthetic data points, endowing it with powerful Sim2Real capability. It achieves zero-shot generalized grasping in ever-changing real-world scenarios and supports rapid adaptation from a general model to an expert model through post-training with minimal real samples. Furthermore, the project trained the world's first pure vision "FSD" navigation foundation model for embodied intelligence, NaVid, and based on this foundation model, released the first product-level navigation foundation model, TrackVLA.



功能性灵巧抓取大数据
Functional Dexterous Grasping Big Data

跨领域的具身智能应用
Cross-Domain Applications of Embodied Intelligence

银河通用坚持做“会干活、可实用”的智能机器人，具备高实用性的 7 自由度双臂 + 全向轮折叠升降结构，在商业、工业和家庭、医疗领域广泛应用。公司由美团、宁德时代、中网投、国家开发银行、北汽产投、上汽恒旭、香港投资公司 HKIC 等累计投资超 24 亿元，成就估值超百亿独角兽。目前，公司已在北京开设 15 家由机器人运营的自主配货仓，每家约 40 平方米的门店配备超 5,000 种药品、6,000 个货道，数万盒药品均由 Galbot 单“人”管理。也在新中关大融城开业第一家由机器人运营的智慧零售店，支持咖啡及自制饮料、饮料零食、文创周边、药品等多品类商品售卖落地，计划于年底实现“十城百店”计划；银河通用作为唯一机器人合作平台承办了国际人工智能奥林匹克竞赛，组织来自 63 个国家 80 多支参赛队在银河通用的软硬件平台上完成这一国际大赛，也刚刚在世界人形机器人运动会中获得自主干活的场景赛金牌；公司和德国博世、韩国现代、宁德时代、赛力斯、极氪汽车等工业巨头开展合资、投资和深入的工业应用合作；公司还将机器人服务带到宣武医院、华西医院等医疗场景。公司在北京、深圳、苏州、香港四地设有研发中心，公司已入选工业和信息化部 AI 标委会成员单位，已在世界机器人大会、服贸会、国际智能机器人与系统会议（IROS）、中关村论坛、北京电视台春晚等露出。银河通用屡次登上《新闻联播》、《央视新闻》及其他媒体，入选英伟达全球 14 家人形机器人合作伙伴。



银河太空舱：全球首个城市级人形机器人常态化运营示范区
Galaxy Store: The World's First Urban-Level Humanoid Robot Regular Operation Demonstration Zone

Galbot adheres to the principle of developing "practical and functional" intelligent

robots. Its robots feature a highly utilitarian design with 7-DOF dual arms and an omnidirectional wheel foldable lift structure, enabling widespread application across commercial, industrial, household, and medical fields. The company has secured cumulative investments exceeding RMB 2.4 billion from leading entities such as Meituan, CATL, China Internet Investment, China Development Bank, BAIC Capital, SAIC Hengxu, and Hong Kong Investment Corporation (HKIC), ranking first in the domestic embodied intelligence sector and achieving unicorn status with a valuation over RMB 10 billion.

Currently, the company has established 15 autonomous robotic distribution warehouses in Beijing. These facilities are compatible with various complex shelf structures, including open shelving, precision retrieval systems, and drawers. Each approximately 40-square-meter store is equipped with over 5,000 types of medicines and 6,000 cargo lanes, with tens of thousands of medicine boxes managed solely by a single Galbot robot. Galbot has also launched its first intelligent retail store operated by robots at the New Zhongguan Darongcheng, supporting the sale of multiple product categories such as coffee, self-made beverages, snacks, cultural and creative products, and medicines. It plans to realize the "Ten Cities, Hundred Stores" initiative by the end of the year.

As the exclusive robotic partner platform, Galbot hosted the International Artificial Intelligence Olympiad, organizing over 80 teams from 63 countries to complete the international competition on its software and hardware platform. The company also recently won the gold medal in the autonomous task scenario competition at the World Humanoid Robot Games. Furthermore, Galbot has established joint ventures, investments, and in-depth industrial application collaborations with industrial giants such as Bosch, Hyundai, CATL, Seres, and Zeekr.

The company has extended its robotic services to medical scenarios, including Xuanwu Hospital and West China Hospital. It has conducted multiple live demonstrations and reported to senior Chinese leaders, including Premier Li Qiang, Vice Premier Ding Xuexiang, Chairman of the National Development and Reform Commission Zheng Shanjie, Beijing Municipal Party Secretary Yin Li, and Director of the National Data Administration Liu Liehong.

With R&D centers in Beijing, Shenzhen, Suzhou, and Hong Kong, Galbot has been selected as a member unit of the AI Standardization Committee under the Ministry of Industry and Information Technology. The company has published nearly 100 cutting-edge academic papers on embodied foundation models globally and holds 11 authorized utility model patents and 6 software copyrights, all of which have been successfully translated into practical applications. Its achievements have been showcased at events such as the World Robot Conference, the China International Fair for Trade in Services (CIFTIS), the International Conference on Intelligent Robots and Systems (IROS), the Zhongguancun Forum, and the Beijing TV Spring Festival Gala.

Galbot has been featured multiple times on programs like "CCTV News Broadcast" and "CCTV News," as well as other media outlets, and has been selected as one of NVIDIA's 14 global humanoid robot partners.



银河通用机器人在工业流水线的应用
Galbot' Applications in Industrial Production Lines

具身智能大模型对产业升级的积极影响
Embodied Intelligence Large Models as a Driving Force for Industrial Upgrading

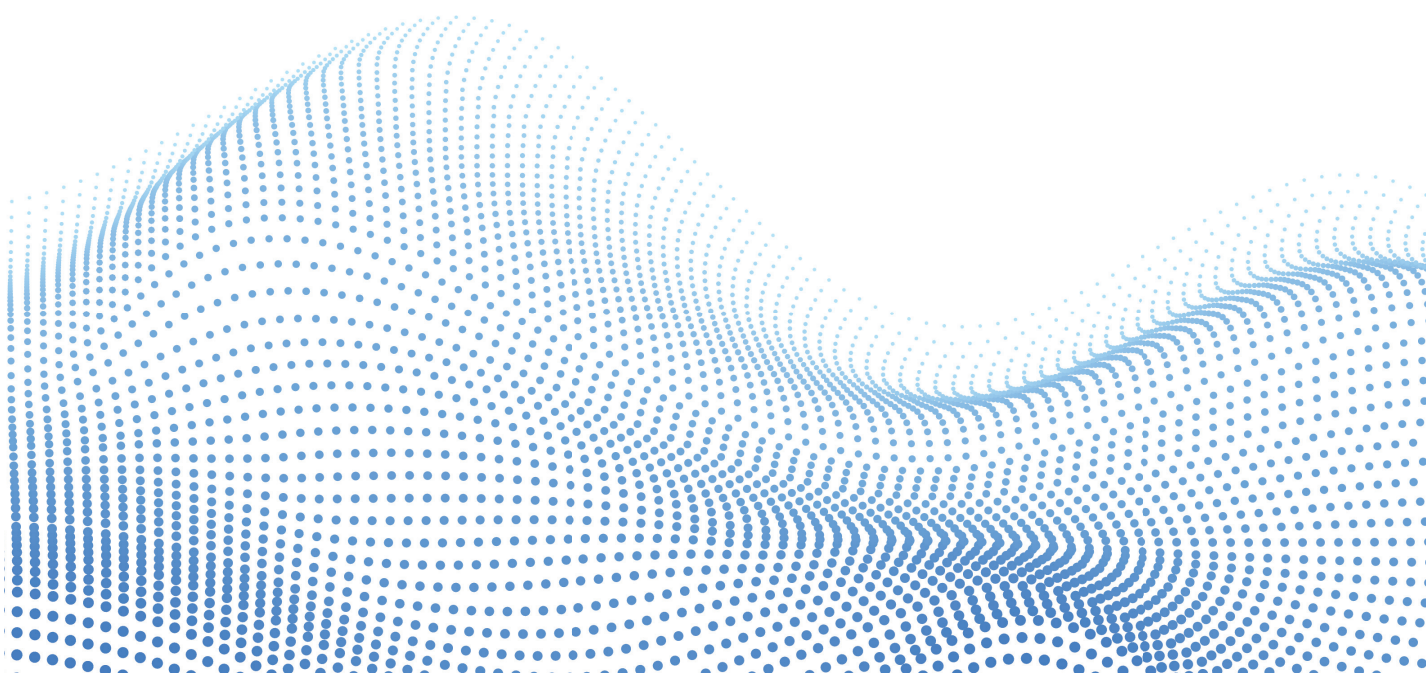
相比当前传统机器人技术只能按照固定程序做简单重复性任务，公司有跨代能力提升，能力上具备硬件、数据、算法技术闭环，可使通用服务机器人实现与人一样泛化操作能力。公司在全球首创三层级大模型系统，核心思想是通过三维视觉小模型实现反应速度快、泛化能力强具身智能技术。其中底层为硬件层；中层是具身智能技能模型，通过三维视觉和仿真数据 Sim2Real 学习到一系列技能，包括可泛化自动建图、可泛化地图导航、物体抓取、关节类物体操作、移动抓取操作、叠衣服、挂衣服等技能；上层是任务规划模型，令 GPT-4V、Emu2 等多模态大模型做任务规划者调用中间层小模型。公司已有 Sim2Real 技术实现从虚拟到真实迁移，摆脱现实条件限制，描绘任意场景和物体，赋予机器人更强泛化能力，克服数据采集与处理高成本与低效能这一世界难题，并提出世界最大灵巧手数据集 DexGraspNet 与超大零件数据集 GAPartNet。三层级大模型系统基于两大数据集通过三维视觉获得零部件点云，进行感知 + 位姿估计 + 动作组合，实现跨场景、跨物体材质、跨形态、跨物体摆放、依据人类语音指令进行开放语义泛化抓取，目前成功率已达 95%，未来预期成功率可达 99.9% 以上。通过“理论 - 技术 - 标准”三级转化，支撑家庭服务机器人精准操作、工业柔性装配等十大场景，形成 6 项行业标准，推动具身智能在智慧零售、工业制造、应对老龄化社会服务与智能制造升级中的规模化落地。三大方向构成“操作 - 导航 - 交互”能力三角：灵巧手模型解决工具功能实现难题，导航系统扩展环境自主认知边界，语言驱动打通人机意图鸿沟，共同推动机器人从“机械执行”向“主动进化”转型，标志着人工智能从数据驱动迈向“物理交互驱动”的新纪元。

In contrast to current traditional robotic technologies that are limited to performing simple, repetitive tasks based on fixed programs, the company has achieved a generational leap in capabilities through a closed-loop integration of hardware, data, and algorithmic



银河通用机器人在零售分拣上的应用
Galbot have achieved significant applications in retail sorting

technologies, enabling general-purpose service robots to possess human-like generalization abilities in operation. The company has pioneered a globally innovative three-layer large model system, whose core concept is to achieve embodied intelligence with rapid response and strong generalization capabilities via a 3D vision small model. The system is structured as follows: the bottom layer is the hardware layer; the middle layer consists of embodied skill models that learn a series of skills—including generalized automatic mapping, generalized map navigation, object grasping, articulated object manipulation, mobile grasping, folding clothes, and hanging clothes—through 3D vision and Sim2Real simulation data; the top layer is a task planning model that employs multimodal large models such as GPT-4V and Emu2 as task planners to invoke the small models in the middle layer. The company's Sim2Real technology enables seamless transfer from virtual to real environments, overcoming real-world constraints by depicting arbitrary scenes and objects, thereby significantly enhancing the robot's generalization capabilities and addressing the global challenge of high-cost and low-efficiency data collection and processing. It has also introduced the world's largest dexterous hand dataset, DexGraspNet, and the massive parts dataset, GAPartNet. Leveraging these two datasets, the three-layer large model system uses 3D vision to obtain point clouds of components, enabling perception, pose estimation, and action combination to achieve cross-scenario, cross-material, cross-form, and cross-placement generalized grasping based on human voice commands, with a current success rate of 95% and an expected future rate exceeding 99.9%. Simultaneously, the company continues to refine its end-to-end multimodal large model, which directly outputs actions. This model maintains high computational efficiency while ensuring high-precision and highly reliable operations across various environments, ultimately achieving superior perception and performance in diverse scenarios and with complex material objects. Through a "theory-technology-standard" three-level transformation framework, it supports precise operations in household service robots and industrial flexible assembly, among ten major scenarios, and has established six industry standards, promoting the large-scale application of embodied intelligence in smart retail, industrial manufacturing, services for an aging society, and smart manufacturing upgrades. Three key directions form an "operation-navigation-interaction" capability triangle: dexterous hand models solve the challenge of tool functionality implementation, navigation systems expand the boundaries of environmental autonomous cognition, and language-driven interaction bridges the gap between human intent and machine execution. Together, these advancements drive the transformation of robots from "mechanical execution" to "active evolution," marking the dawn of a new era in artificial intelligence transitioning from data-driven to "physical interaction-driven" paradigms.





人工智能开源软件平台 ROCm™
Open-Source AI Software Platform ROCm™

人工智能开源软件平台 ROCm
Open-Source AI Software Platform ROCm

超威半导体公司（AMD）
Advanced Micro Devices, Inc.

引言

AMD ROCm™（Radeon™ Open Compute Platform）是业内知名的人工智能开源软件平台，通过支持异构硬件、优化平台工具、提升开发者友好程度以及拓展合作伙伴等方式，助力 AI 产业生态建设。

Introduction

AMD ROCm™(Radeon™ Open Compute Platform)is a renowned industry-leading open-source artificial intelligence software platform. It contributes to fostering the AI industry ecosystem by supporting heterogeneous hardware, optimizing platform tools, enhancing developer-friendliness, expanding partnerships.

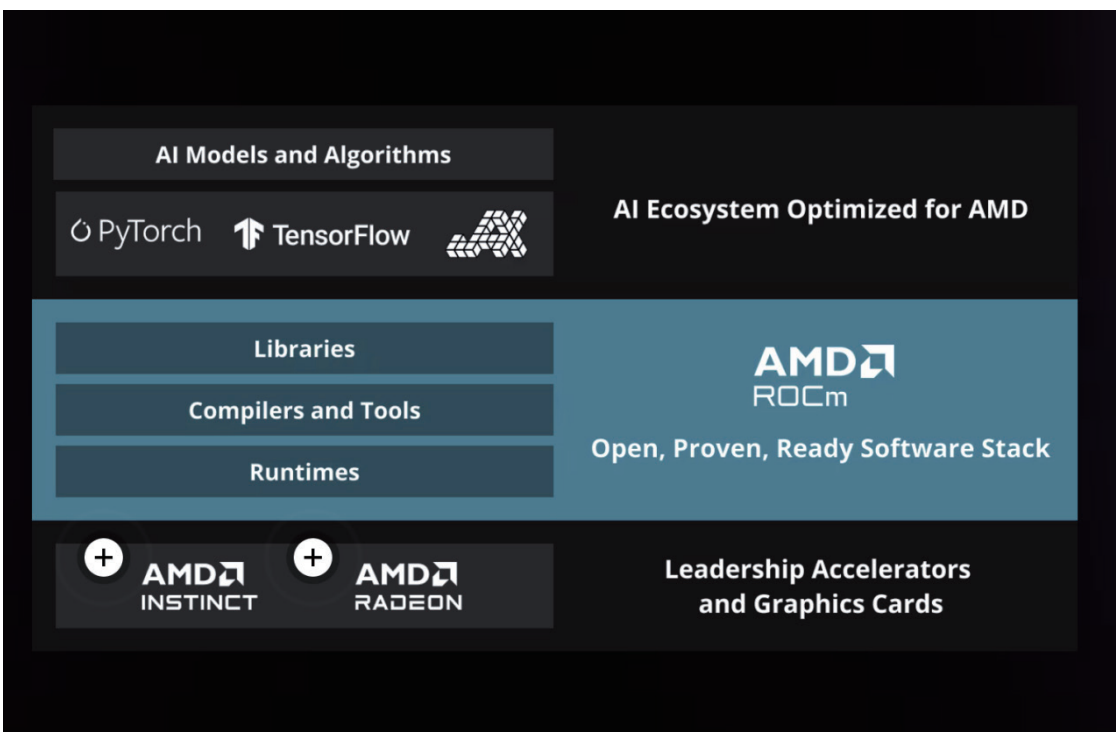
全面优化的 GPU 软件栈和一应俱全的开发人员工具集
Optimized GPU Software Stack and Comprehensive Developer Tool Set

AMD ROCm 是一个开放式软件栈，包含多种驱动程序、开发工具和 API，可为从底层内核到最终用户应用的 GPU 编程提供助力。ROCm 已针对生成式 AI 和 HPC 应用进行了优化，而且能够轻松将现有代码迁移到 ROCm 软件。

AMD ROCm 软件为开发人员和研究人员带来了一系列工具，能够实现灵活管理、质控和监控等功能。

AMD ROCm™ is an open software stack including drivers, development tools, and APIs that enable GPU programming from low-level kernel to end-user applications. ROCm is optimized for Generative AI and HPC applications, and it is easy to migrate existing code into ROCm software.

ROCm includes a comprehensive set of tools to provide developers and researchers with flexible management, quality control, and monitoring capabilities.



ROCm 支持加速器和 GPU, 优化 AI 生态
ROCm supports accelerators and GPUs, optimizing the AI ecosystem

ROCm 面向 AI 工作负载提供优化方案，并支持包含众多开放式框架、模型和工具的 AI 软件生态系统

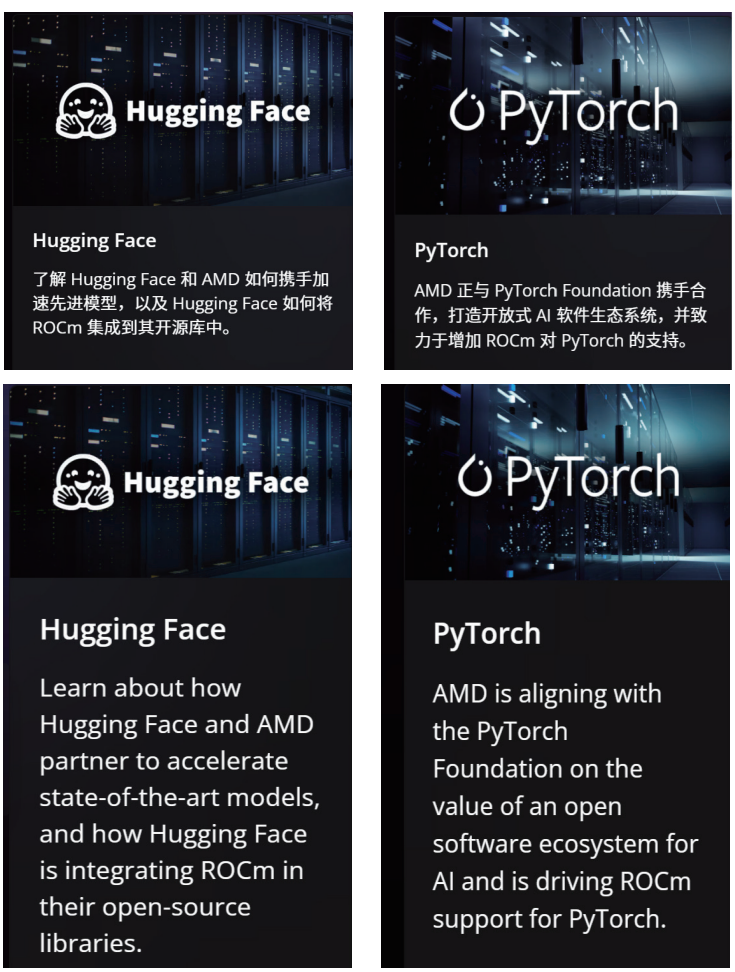
ROCm optimizes AI workloads and supports the broader AI software ecosystem, including open frameworks, models, and tools

ROCm 加快 AI 部署速度，主流模型如 Llama、Deepseek 可在发布当天直接运行。与开源社区合作紧密，已有超 210 万个 Hugging Face 模型可在 ROCm 上运行。最新发布的 ROCm 7 预览版本在推理性能上较 ROCm 6 平均提升 3.5 倍，训练性能平均提升 3 倍，支持如 DeepSeek R1 等模型的高效推理。

ROCm 7 增强了分布式推理与企业级优化兼备功能，其中新增功能包含支持开源框架的分布式推理，卓越的企业就绪型 AI 工具，具备编排和端点集成功能，支持大型模型，并兼容新型数据类型 FP6 和 FP4，提升灵活性与性能。借助 HIP 7.0，增强代码可移植性等功能。

ROCm accelerates AI deployment, allowing mainstream models such as Llama and DeepSeek to run on the day of release. Through close collaboration with the open-source community, over 2.1 million Hugging Face models are now supported on ROCm software. The newly released ROCm 7 preview offers an average 3.5x improvement in inference performance and an average 3x improvement in training performance compared to ROCm 6, enabling efficient inference for models like DeepSeek R1.

ROCm 7 enhances capabilities integrating distributed inference and enterprise-grade optimization. The new features include distributed inference with open-source framework support, enterprise-ready AI tools with orchestration and endpoint integration, support for large-scale models with new data types FP6 and FP4 for enhanced flexibility and performance, enhanced code portability with HIP 7.0, etc.



ROCm 携手生态伙伴，加速先进模型迭代，提升开发者体验
ROCm collaborates with ecosystem partners to accelerate state-of-the-art models and enhance developer experience

ROCm 通过开发者人员中心和产学研合作为开发者提供资源

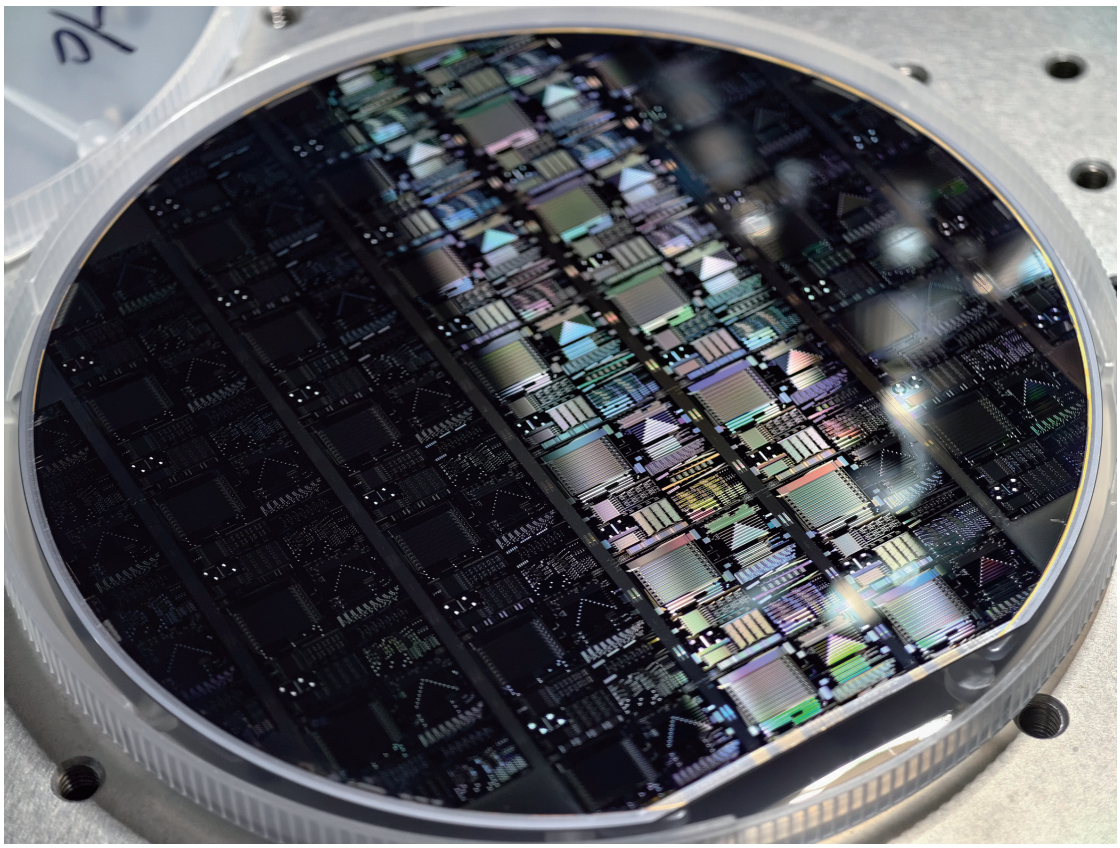
ROCm provides developers with resources through its developer hub and industry-academia-research collaboration

AMD 与 Meta、微软、DeepSeek、阿里云等全球科技与大模型公司合作，构建开放共赢 AI 生态。同时，AMD 深化产学研合作，与国内外高校交流，推广 ROCm 生态。我们走进清华大学、北京大学，斯坦福大学，麻省理工学院等顶尖学府，开展技术分享，向师生解读 ROCm 软件栈运行大模型的原理，并分享性能优化策略，推动 ROCm 生态在高校科研领域的应用。今年 7 月，中国首家 ROCm 实验室在南京软件谷揭牌。未来，AMD 将秉持“同超越，共成就”理念，携手客户与伙伴，践行人工智能行动计划，赋能千行百业。

AMD collaborates with global tech and large model companies such as Meta, Microsoft, DeepSeek, and Alibaba Cloud to build an open and mutually beneficial AI ecosystem. At the same time, AMD is deepening industry-academia-research cooperation by engaging with universities both domestically and internationally to promote the ROCm ecosystem. We have visited top institutions such as Tsinghua University, Peking University, Stanford University, and MIT to conduct technical sharing sessions, explain the principles behind running large models on the ROCm software stack, and share performance optimization strategies— helping to drive ROCm adoption in academic research. In July this year, China’s first ROCm software lab was inaugurated in Nanjing Software Valley. Looking ahead, AMD will uphold the philosophy of “Together We Advance,” working together with customers and partners to implement the AI action plan and empower industries across the board.



AMD 在中国建立 ROCm 实验室，推进 AI 产业生态建设
AMD established ROCm Lab in Nanjing, China, advancing AI industry ecosystem development



上海交通大学无锡光子芯片研究院首片 6 英寸薄膜铌酸锂光子芯片晶圆，同时实现了超低损耗、超高带宽的高性能薄膜铌酸锂调制器芯片的规模化量产

The first 6-inch thin-film lithium niobate (TFLN) photonic chip wafer developed by Chip Hub for Integrated Photonics Xplore (CHIPX), enabling mass production of ultra-low loss, ultra-high bandwidth TFLN modulator chips

实用化大规模高速可编程光量子计算芯片关键技术与应用

Key Technologies and Applications of Industrialized Large-Scale High-Speed Programmable Photonic Quantum Computing Chips

上海交通大学无锡光子芯片研究院
Chip Hub for Integrated Photonics Xplore (CHIPX)

上海交通大学
Shanghai Jiao Tong University

上海图灵智算量子科技有限公司
TuringQ Co., Ltd.

CHIPX | 上海交通大学 SHANGHAI JIAO TONG UNIVERSITY

上海交通大学 SHANGHAI JIAO TONG UNIVERSITY

TURINGQ 图灵量子

引言

上海交通大学无锡光子芯片研究院联合上海交通大学、上海图灵智算量子科技有限公司，建成中国首条光子芯片中试线，突破晶圆级薄膜铌酸锂光子芯片、多维飞秒激光直写和光电共封等技术，实现大规模高速可编程光量子芯片规模化量产，推动量子计算产业发展。

Introduction

The Chip Hub for Integrated Photonics Xplore (CHIPX), in collaboration with Shanghai Jiao Tong University and TuringQ Co., Ltd., has established China's first photonic chip pilot line. Breakthroughs have been achieved in wafer-level TFLN photonic chips, Femtosecond laser multidimensional direct writing, and Co-Packaged Optics (CPO) technologies, enabling the mass production of large-scale, high-speed programmable photonic quantum chips and advancing the quantum computing industry.

可实用化部署的超大规模、超低损耗、高速可编程光量子计算芯片

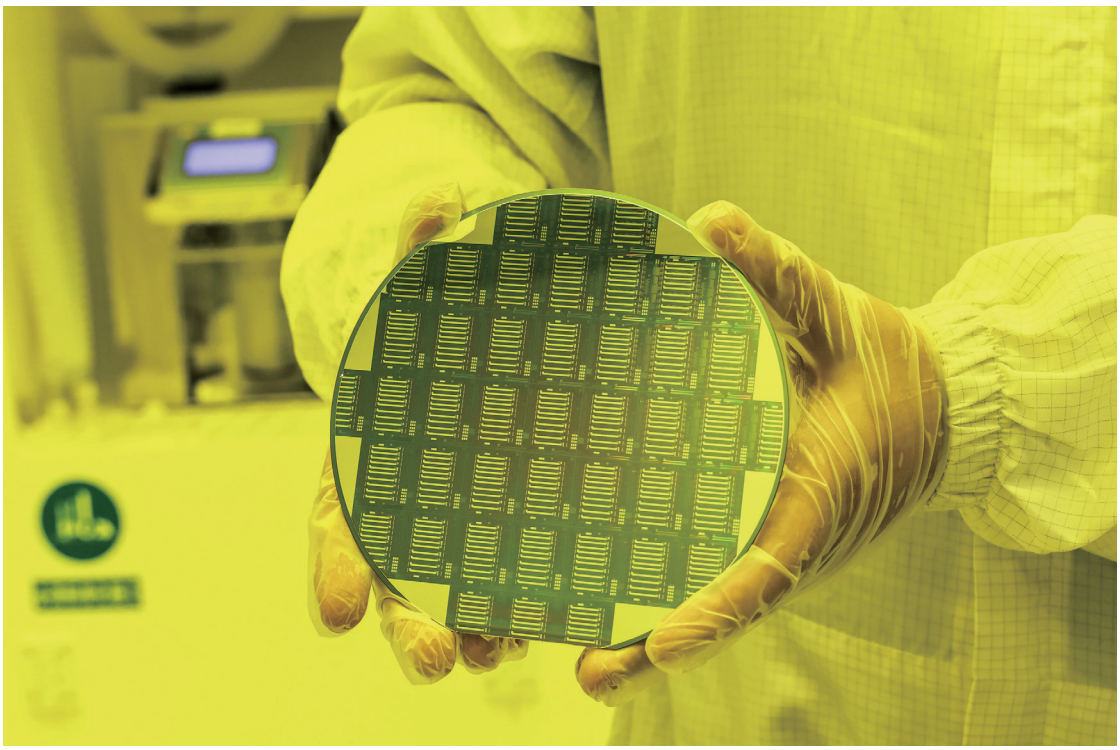
Industrialized Ultra-Large-Scale, Ultra-Low-Loss, High-Speed Programmable Photonic Quantum Computing Chips

团队依托中国首条光子芯片中试线先进纳米加工能力，研究超低损耗波导设计和多层级光子器件优化方法，突破了高精度刻蚀、低损耗耦合、高均匀性晶圆级制造及飞秒激光直写技术，实现了单片集成光子器件数量超 1000 个，器件损耗 <0.1 dB/cm；基于此实现了最大片上 56 个光子事件，突破了量子优越性范畴，成果获得“中国芯片科学十大进展奖”。团队利用薄膜铌酸锂特性，开发 GHz 级高速电光调制器，实现 32×32 薄膜铌酸锂超快可编程芯片，主频达 10GHz 级别。为了加速量子计算赋能互联网的各类应用场景，团队设计了量子 - 经典混合计算架构，支持超 10 万变元求解能力，超 100 比特张量网络模拟量子计算，实现模块化大规模混合集成系统。

Leveraging the advanced nano-fabrication capabilities of China's first photonic chip pilot line, the team researched ultra-low loss waveguide design and multi-level photonic device optimization. Breakthroughs were achieved in high-precision etching, low-loss coupling, high-uniformity wafer-scale manufacturing, and femtosecond laser direct writing technology, enabling monolithic integration of over 1000 photonic components with loss <0.1 dB/cm. This facilitated the generation of 56 photon achievement on a single chip, surpassing the quantum supremacy threshold and earning the "Top 10 Advances in Chinese Chip Science" award. Using TFLN, GHz-speed electro-optic modulators were developed, resulting in a 32×32 ultrafast programmable TFLN chip operating at 10 GHz. To accelerate the empowerment of various internet application scenarios by quantum computing, the team designed a quantum-classical hybrid computing architecture, supporting the solution of problems with over 100,000 variables and tensor network simulations exceeding 100 qubits, enabling a modular large-scale hybrid integrated system.



基于光电共封的光量子计算系统
Photonic quantum computing system based on CPO



大规模高速可编程光量子芯片实物图
Physical image of the large-scale high-speed programmable photonic quantum chip

光量子芯片加速算力供给与数智赋能，底层技术推动信息技术变革

Photonic Quantum Chips Accelerate Computational Power Supply and Data-Intelligent Empowerment, Underlying Technologies Drive IT Transformation

项目成果催生医疗研发、金融科技、光计算和光连接等互联网应用领域快速发展。在医疗健康领域，光量子芯片通过量子 - 经典混合计算架构和云平台实现蛋白质折叠预测与药物分子设计的指数级效率提升，在肿瘤靶向药研发中实现千倍效率跃升；在金融领域，以光量子芯片提供算力资源供给，结合量子算法，在风险管理、投资组合优化等方面展现出了更高时效性、更高准确性的优势。作为光量子芯片的关键技术，晶圆级薄膜铌酸锂芯片和光电共封装技术是光计算和光连接的重要支撑，其高速可编程、低功耗和大带宽的特点，推进光计算在各种场景的落地应用，并推动实现数据中心光互连，大幅降低全球数据中心的能耗需求，直接应对 AI 大模型训练、实时渲染等互联网应用的算力饥渴症结。目前基于项目的技术突破，项目参与单位图灵量子实现薄膜铌酸锂调制器等产品落地，四年完成五轮融资，估值达 40 亿元，2025 年上半年签订 1 亿元订单，实现跨越式发展。

The outcomes accelerate advances in internet-enabled fields including medical R&D, fintech, optical computing, and interconnects. In healthcare, photonic quantum chips, through the quantum-classical hybrid computing architecture and cloud platforms, enable exponential efficiency gains in protein folding prediction and drug molecule design, achieving a thousandfold efficiency leap in targeted cancer drug development. In finance, the computational power provided by photonic quantum chips, combined with quantum algorithms, demonstrates higher timeliness and accuracy in risk management and portfolio optimization. As key underlying technologies, wafer-level TFLN chips and CPO underpin optical computing and interconnect. Their high programmability, low power consumption, and large bandwidth drive adoption across diverse optical computing scenarios and advance optical interconnects in data centers, significantly reducing global energy consumption. This

directly addresses the computational power bottlenecks faced by internet applications like AI large model training and real-time rendering. Based on the project's technological breakthroughs, TuringQ has successfully commercialized products like TFLN modulators, completed five funding rounds in four years, reaching a valuation of 4 billion CNY, and secured POs worth 100 million CNY in the first half of 2025, achieving breakthrough development.



TuringQ Gen2大规模可编程光量子计算系统以大规模高速可编程光量子计算芯片为核心，集成量子光源单元、量子计算单元与探测单元三大核心组件，构建起一套高度集成且协同高效的量子计算系统。设备采用量子 - 经典混合计算架构，具备 56 光子规模，支持超 10 万变元求解能力，能够轻松应对复杂计算任务

The TuringQ Gen2 large-scale programmable photonic quantum computing system, featuring its large-scale high-speed programmable photonic quantum computing chip, integrates three core components: quantum light source units, quantum computing units and quantum detection units, forming a highly integrated and synergistically efficient quantum computing system. The device employs a quantum-classical hybrid computing architecture, features a 56-photon scale, supports solutions for over 100,000 variables, and can easily handle complex computational tasks



量生万物生物医药智能平台从生物医药各环节痛点问题出发，融合了量子计算的速度、人工智能的神经网络，形成包含合成生物学，抗原抗体设计，小分子药物设计三大板块的综合性一站式应用平台，为生物医药发展带来无限想象空间

The "TuringQ Bio Platform" biomedicine intelligence platform addresses pain points across various R&D stages. It integrates the speed of quantum computing with the neural networks of AI, forming a comprehensive one-stop platform encompassing synthetic biology, antigen/antibody design, and small molecule drug design, bringing limitless possibilities to the development of biomedicine

突破产业瓶颈，光量子计算走向中试量产，驱动算力跨越发展

Breaking Through Industrial Bottlenecks, Photonic Quantum Computing Advances to Pilot Production, Driving Leapfrog Development in Computing Power

面向后摩尔时代人类发展对算力的需求，在芯片化集成的趋势下，团队围绕实用化光量子计算技术开展研究，突破了晶圆级高速可编程铌酸锂光量子芯片等技术工艺，并建设了中国首条光子芯片中试线，基于此形成了可室温运行的光量子计算机，建设了量子智算中心，通过量子加速 AI 训练，在量子化学模拟、蛋白质设计、物流调度、金融投资组合优化与风险管控等领域全面开展算法部署与场景应用的实用化探索，为量子计算的产业发展提供了有效路径。本项目研发过程中形成的芯片设计到流片封装的全链条能力，以先进技术、工艺平台和产业放大为抓手，吸引产业链上下游企业加速集聚，构建了完整的产业生态体系，推动产业升级，并辐射多个新兴领域，并为中国光量子信息及先进半导体领域的科学与工艺建设和产业化应用提供可持续的支撑，进而为人工智能时代中国的新质互联网发展提供坚实基础。

Addressing post-Moore's Law computational demands, the team has advanced industrialized photonic quantum computing through wafer-scale programmable lithium niobate photonic quantum chips and established China's first photonic chip pilot line. This enabled the development of a room-temperature operational photonic quantum computer and a Quantum Intelligence Computing Center. Using quantum-accelerated AI training, industrialized algorithm deployment and application exploration are underway in quantum chemistry simulation, protein design, logistics scheduling, financial portfolio optimization, and risk management, providing a viable industrial pathway. The full-chain capability from chip design to packaging leverages advanced technology and scale-up to attract upstream and downstream partners, building a complete industrial ecosystem that upgrades and radiates into emerging fields. This effort sustainably supports China's photonic quantum and advanced semiconductor science and industrialization, laying a foundation for China's new-quality internet in the AI era.



“光子芯片”荣获中央广播电视总台“2024 新质生产力年度十大案例”

"Photonic Chips" were honored as one of the "Top 10 Annual Cases of New Quality Productivity in 2024" by China Media Group (CMG)


CERTIEICATE
OF COMPLETION
2023年度中国十大光学产业技术
OIT AWARDS WINNER
获奖技术
单片集成128个全同量子光源的阵列芯片
获奖单位
上海图灵智算量子科技有限公司
经中国十大光学产业技术评审委员会决定，贵司申报的技术凭借其创新性和推动性，在101个申报技术中脱颖而出，成功入选“2023年度中国十大光学产业技术”，荣获最终荣誉！
嘉宾见证
中国十大光学产业技术评审委员会
二零二四年五月
光电汇

单片集成 128 个全同量子光源的阵列芯片是目前有报道技术中能实现的最大规模的全同可扩展量子光源阵列，研究成果以“128 Identical Quantum Sources Integrated on a Single Silica Chip”为题，发表在美国物理学权威应用期刊 Physical Review Applied 上，并被遴选为“编辑推荐”（Editors' Suggestion），荣获 2023 年度中国十大光学产业技术

A monolithically integrated array of 128 identical quantum light sources represents the largest scalable platform of its kind. The research findings, titled "128 Identical Quantum Sources Integrated on a Single Silica Chip," were published in Physical Review Applied as an “Editors' Suggestion”, and awarded China's Top 10 Optical Technology in 2023



2025 福布斯中国人工智能科技企业 top50

TuringQ Co. Ltd was ranked among 2025 Forbes China Top 50 AI Tech Companies

世界互联网大会
领先科技奖获奖成果

Award-winning Achievements of World Internet Conference
Awards for Pioneering Science and Technology



01

世界互联网大会
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Awards for Pioneering Science and Technology

工程研发组

Engineering Research and Development Group



NODE——一款智能移动机器人
NODE - A mobile robot

ALTO Robotics：
实现制造业无缝自动化的机器人系统 NODE

NODE by ALTO ROBOTICS

ALTO ROBOTICS

引言

Alto Robotics 研发的 NODE 机器人，具备直观的人机交互（HMI）功能。操作人员可通过触摸屏或可穿戴设备轻松操控。NODE 机器人搭载专利型电机转向系统及高性能传感器组，适用于多品种、小批量生产场景。

Introduction

Node by Alto Robotics has intuitive human-machine interaction (HMI) and allows operators to effortlessly control the robot via touch-screen or wearable devices, requiring no specialized training. We have designed patented motorsteering wheels and a robust sensor suite, NODE achieves seamless navigation in complex environments while ensuring safe collaboration with human workers. The system is particularly suited for high-mix, low-volume production scenarios, demonstrating exceptional performance in asset handling, quality assurance, and production line setup tasks.

Alto Robotics NODE: 智能融合，效能革新
Alto Robotics NODE: Fusing AI with Adaptive Robotics for Cross-Industry Efficiency

NODE 机器人攻克了协作移动机器人领域的多项关键技术难题，并在动态、非结构化环境中实现高灵活性、高自主性与高安全性方面取得突破。传统机器人在适应性、人机交互能力及复杂场景下的高效作业能力上存在局限，NODE 将三维激光雷达、安全激光扫描仪、编码器、传感式缓冲器等先进传感设备，构建了一套能实时、可靠地进行精准导航、完成复杂操作并实现自然交互的一体化系统。该机器人采用基于 ROS 2 的软件架构，结合人工智能与多传感器融合技术，实现了灵活可扩展的感知、决策与控制集成，显著提升了导航精度与响应效率。机器人还配备 15 英寸触摸屏、触觉手柄及社交化 LED 矩阵，支持丰富的人机交互，适配多行业应用场景。同时，其即插即用的部署模式有效降低了集成复杂度。

NODE robot has overcome multiple key technical challenges in the field of collaborative mobile robots, achieving breakthroughs particularly in achieving high flexibility, high autonomy, and high safety in dynamic, unstructured environments. Traditional robots have limitations in adaptability, human-machine interaction capabilities, and efficient operation capabilities in complex scenarios. NODE has successfully integrated various advanced sensing devices such as 3D LiDAR, safety laser scanners, encoders, and sensory buffers into a unified system that can complete navigation, operation, and interaction tasks in real-time and reliably. It adopts a ROS 2-based software architecture, combined with art ificial intelligence and sensor fusion technology, to achieve flexible and scalable integration of perception, decision-making, and control, significantly improving navigation accuracy and response efficiency. The robot is equipped with a 15-inch touchscreen interaction interface, tactile handle, and socialized LED matrix, supporting human-robot interaction (HRI), and is adaptable to multi-industry application scenarios. At the same time, its plug-and-play deployment mode can effectively reduce integration complexity.



NODE 关键技术要素
Node technological enablers

NODE: 赋能 20+ 应用场景的智能交互终端
NODE: Enabling 20+ Use Cases from Logistics to Quality Control

NODE 机器人已在制造自动化、医疗健康、酒店服务等重点领域成功应用。在制造领域，其可自主完成物料运输及高精度操作任务，助力优化多品种、小批量生产流程，降低人工成本最高达 30%，提升生产吞吐量效率 25%。经济层面，模块化、即插即用设计使集成时间缩短约 40%，加快投资回报。社会层面，通过承担重复性或危险性任务，支持人员向更高价值工作岗位转型，助力营造更安全的作业环境。该公司已与达涅利、埃莱马斯特等企业共同完成了十余项概念验证。目前，其首批产品已进入生产尾声，预计将于 2025 年第四季度开始交付，并将提供不经过中间环节的直接售后服务与技术支持。

NODE robots have been successfully applied in key areas such as manufacturing automation, healthcare, and hotel services. In the manufacturing sector, they can independently complete material transportation and high-precision operation tasks, helping to optimize multi-variety, small-batch production processes, reduce labor costs by up to 30%, and improve production throughput efficiency by 25%. Economically, the modular, plug-and-play design shortens integration time by approximately 40%, accelerating return on investment. Socially, by taking on repetitive or hazardous tasks, they support the transition of personnel to higher-value job positions, helping to create a safer working environment. We have completed over 10 PoCs with companies including Danieli and Elemaster. We are completing production of our first batch and are due to start delivering by Q4 2025, offering non-intermediated aftersales and servicing support as well.



NODE 在实际场景中的应用
Node in a real-life setting

NODE：重塑全球工业自动化新格局
NODE: Redefining Global Industrial Automation

NODE 机器人，通过整合精密人工智能算法、先进传感器融合技术与模块化软件架构，攻克了协作移动机器人领域长期存在的技术难题，在自主灵活性、精准导航及人机交互方面实现突破，使机器人能够在动态、非结构化环境中安全高效运行。在产业应用层面，NODE 机器人已展现出对生产模式的重塑能力。在宝马工厂中，它将生产线换型时间从 45 分钟缩短至 12 分钟；为 DHL 提供的解决方案则成功降低运营成本 32%，并提升整体效率 58%。其通信协议已被纳入欧盟工业机器人标准体系，技术领先性获得权威认可。

在社会经济层面，NODE 机器人的部署亦带来显著效益。数据显示，每部署 10 台机器人可催生 3.2 个高技能岗位，并带动意大利相关岗位年增长率达到 17%。在意大利最大汽车制造商菲亚特的应用中，NODE 机器人助力工作场所事故发生率下降 81%，成效获国际劳工组织认可。

Node 于 2024 年荣获红点设计大奖，并于 2025 年同时摘得 iF 设计奖与意大利工业设计协会设计指数提名。

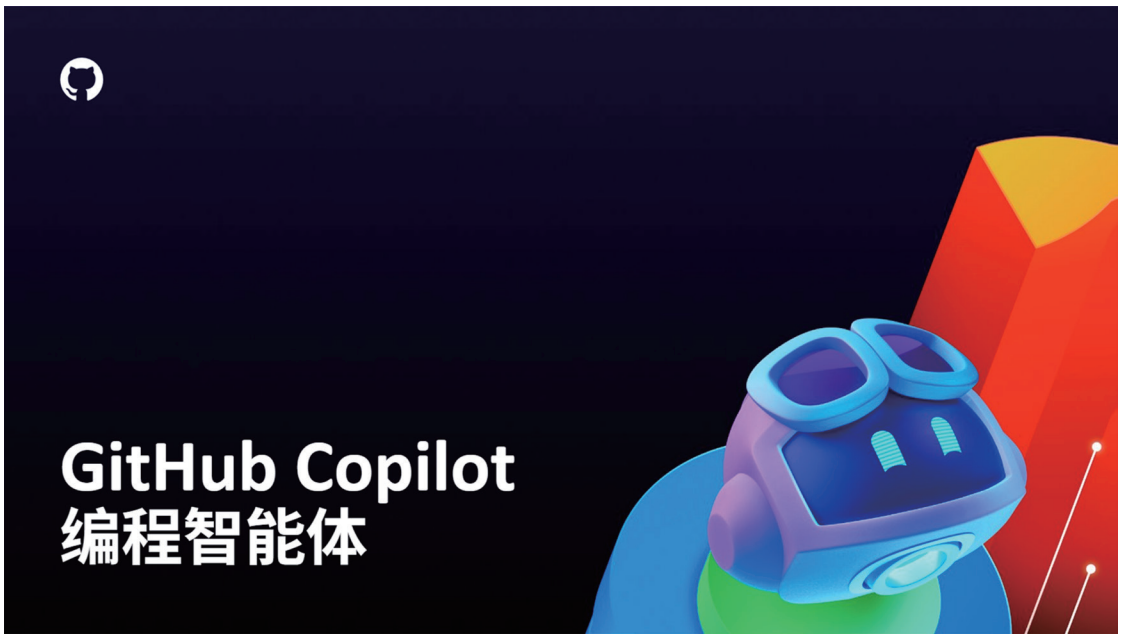
NODE robots, through integrating precise artificial intelligence algorithms, advanced sensor fusion technology, and modular software architecture, have overcome long-standing technical challenges in the field of collaborative mobile robots, pushing autonomous flexibility, precise navigation, and human-robot interaction technology to new frontiers, enabling robots to operate safely and efficiently in dynamic, unstructured environments. At the industrial application level, NODE robots are reshaping production models. In BMW factories, production line changeover time has been reduced from 45 minutes to 12 minutes; solutions for DHL have reduced operating costs by 32% and increased efficiency by 58%. Its communication protocol has been incorporated into the EU industrial robot standard system, with its technological leadership being recognized. At the socio-economic level, every 10 units deployed can create 3.2 high-skilled jobs, driving an annual growth rate of 17% for related positions in Italy. In Fiat's application, it has helped reduce workplace accident rates by 81%, recognized by the International Labour Organization.

Node won the Red Dot in 2024 and iF Design award in 2025, as well as ADI Nomination in the Design Index in 2025.



Alto Robotics 首席执行官乔迪·萨格利亚（Jody Saglia）与首席产品官萨拉·贝利尼（Sara Bellini）

Node with Alto Robotics' Founders – Jody Saglia CEO and Sara Bellini CPO



GitHub Copilot：新一代编程智能体
GitHub Copilot: New Gen Coding Agent

GitHub Copilot：新一代编程智能体

GitHub Copilot: New Gen Coding Agent

微软（中国）有限公司
Microsoft China Co., Ltd.

Microsoft

引言

GitHub Copilot 是全球信息技术行业领域第一个大型生成式 AI 编程应用。2025 年，GitHub Copilot 从程序代码辅助工具进化为能力全面且具自主性的编程智能体，由此开启了全新的“智能体网络”（Agentic Web）时代。

Introduction

GitHub Copilot is the world’s first large-scale generative AI application in the field of information technology. In 2025, it evolved from a code-assistance tool into a fully capable and autonomous programming agent, ushering in a new era known as the “Agentic Web.”

以人工智能驱动软件产业变革
AI-powered transformation of the software industry

GitHub Copilot 深度集成了 Visual Studio Code（以下简称“VS Code”）、主流 IDE 及异步编程智能体，为 GitHub Models 新增了提示词管理、轻量化评估与企业级管控等功能，彻底消除了多窗口切换的繁复低效操作，实现了跨平台无缝协作，将编程工作者引入人机互补协同、效率多倍提升的“人类智能 + 人工智能”新阶段。

目前，GitHub Copilot 可以自动分析代码库，执行各种中低复杂度的任务，如添加功能、修复漏洞、扩展测试、重构代码等等，并通过拉取请求 (PR) 提交修改，确保流程清晰、行为透明、结果可控。

凭借有助于加速开发进程的持续互动能力（典型场景如为新架构改写旧程序）、高度整合的单一使用接口、自动生成并优化代码的全方位支持，GitHub Copilot 已成为催化技术产品创新、推动软件产业变革的重要引擎。

GitHub Copilot is deeply integrated with Visual Studio Code (hereafter “VS Code”), mainstream IDEs, and asynchronous programming agents. It introduces new capabilities to GitHub Models, including prompt management, lightweight evaluation, and enterprise-grade governance. By eliminating the inefficiencies of multi-window switching, it enables seamless cross-platform collaboration—ushering developers into a new era of “Human Intelligence + Artificial Intelligence,” marked by synergistic workflows and exponential productivity gains.

Today, GitHub Copilot can automatically analyze codebases and execute a wide range of low- to medium-complexity tasks—such as adding features, fixing bugs, expanding test coverage, and refactoring code. It submits changes via pull requests (PRs), ensuring process clarity, behavioral transparency, and controllable outcomes.

With its sustained interactive capabilities (e.g., rewriting legacy programs for new architectures), unified interface, and comprehensive support for code generation and optimization, GitHub Copilot has become a powerful engine for accelerating product innovation and driving transformation across the software industry.



GitHub Copilot 全新方式予力开发者
GitHub Copilot empowers developers in new way

予力全球逾 2000 万开发者
Empowering over 20 million developers worldwide

得益于技术成熟、更新迅速、可扩展性良好，GitHub Copilot 编程智能体已被全球逾 2000 万开发者采用——仅过去一个季度新增的开发者就超过 500 万。

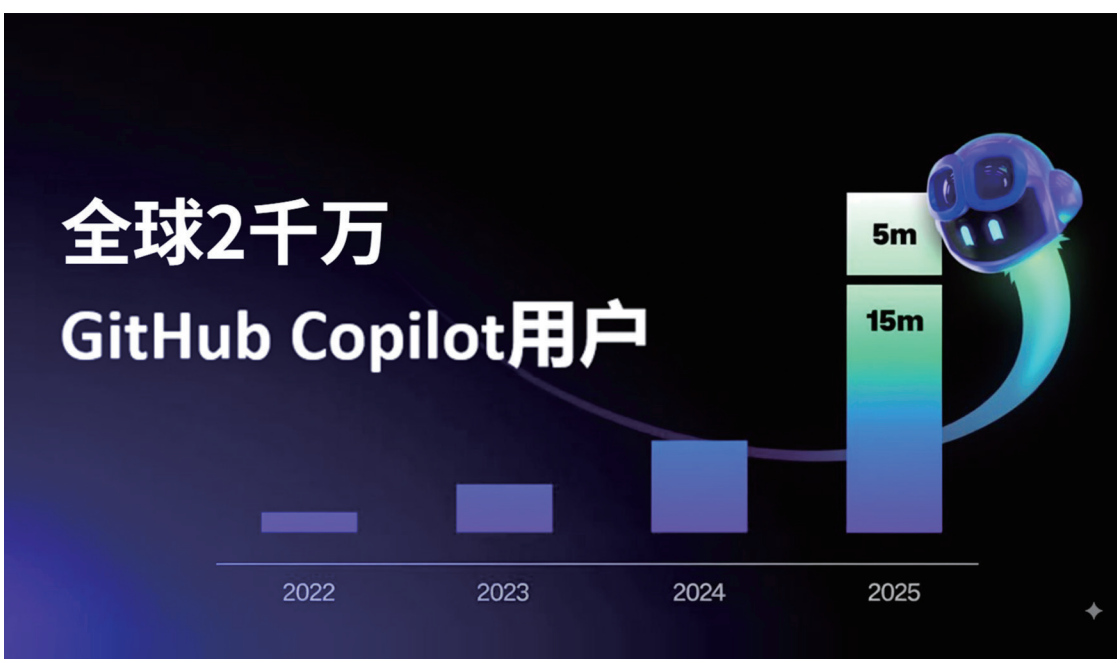
2025 年 5 月，微软决定将 GitHub Copilot Chat 扩展代码以 MIT 许可协议开源，并将其核心 AI 功能整合至 VS Code 中，自此，开发者可以自由查看、修改、分发扩展代码，企业可以根据自身需求进行定制化开发，社区可以共同参与扩展代码的更新与优化。

由于这款持续焕新的强大工具能够显著提高开发效率、改善代码质量、提供智能提示和建议、支持“多人 x 多智能体”协作，因而已被 90% 的《财富》100 强企业所使用——其企业客户的数量还在持续快速增长。

Thanks to its technical maturity, rapid updates, and strong scalability, the GitHub Copilot programming agent has been adopted by over 20 million developers worldwide—with more than 5 million new users joining in the past quarter alone.

In May 2025, Microsoft announced the open-sourcing of GitHub Copilot Chat's extension code under the MIT license, while integrating its core AI capabilities directly into Visual Studio Code. This move empowers developers to freely view, modify, and distribute the extension code; enables enterprises to tailor it to their specific needs; and invites the broader community to collaboratively update and optimize its functionality.

As a continuously evolving and powerful tool that significantly boosts development efficiency, improves code quality, offers intelligent suggestions, and supports “multi-user × multi-agent” collaboration, GitHub Copilot is now used by 90% of Fortune 100 companies—with enterprise adoption continuing to grow rapidly.



GitHub Copilot 已被全球逾 2000 万开发者采用
GitHub Copilot has been adopted by over 20 million developers worldwide

对软件开发流程及生命周期构成深远影响
Transforming how software is built, maintained, and evolved across its entire lifecycle

GitHub 是全球最大的代码托管和协作平台，拥有约 1 亿名开发者用户——其中，采用 GitHub Copilot 编程智能体的用户比例已超过 20%，且在持续增加。

GitHub Copilot 编程智能体将对软件开发流程与生命周期产生持久而深刻的影响。经济层面，它可以帮助企业降低开发成本、缩短交付周期、强化竞争力；社会层面，它能够解放开发者，使他们可以聚焦于更有价值的创新工作；生态层面，它有利于优化资源使用、减少冗余代码，提高软件的可持续性——GitHub Copilot 编程智能体的广泛应用不仅加速了企业的数字化转型，还促进了全球开发者社区的协作与发展。它是技术上的重大突破，也是推动整个软件行业蜕变的关键引擎。

GitHub is the world's largest platform for code hosting and collaboration, serving a global community of approximately 100 million developers. Among them, over 20% have adopted the GitHub Copilot programming agent—a figure that continues to rise steadily.

GitHub Copilot is poised to exert a lasting and profound influence on the software development process and lifecycle. From an economic perspective, it helps enterprises reduce development costs, shorten delivery cycles, and enhance competitiveness. Socially, it liberates developers from repetitive tasks, allowing them to focus on higher-value, innovation-driven work. Ecologically, it promotes more efficient resource utilization, reduces redundant code, and improves software sustainability.

The widespread adoption of GitHub Copilot not only accelerates digital transformation across industries but also strengthens collaboration and growth within the global developer community. It represents a major technological breakthrough and serves as a catalytic engine driving the evolution of the software industry.

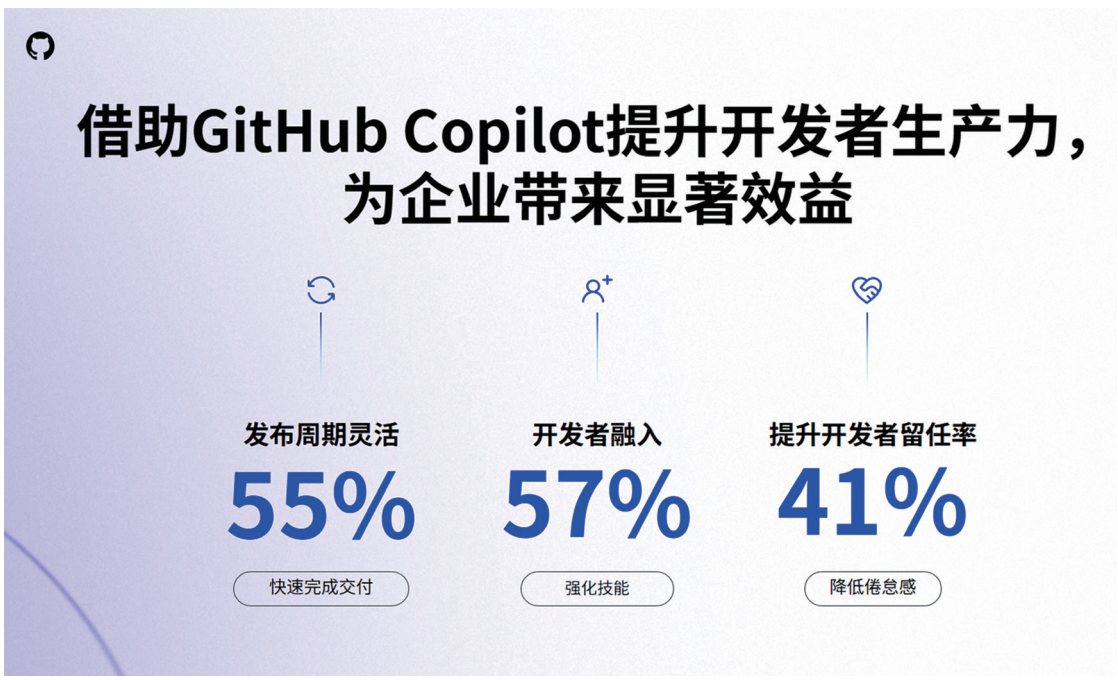


GitHub Copliot 全球最广泛采用的 AI 开发工具
GitHub Copilot is the most widely adopted AI development tool globally

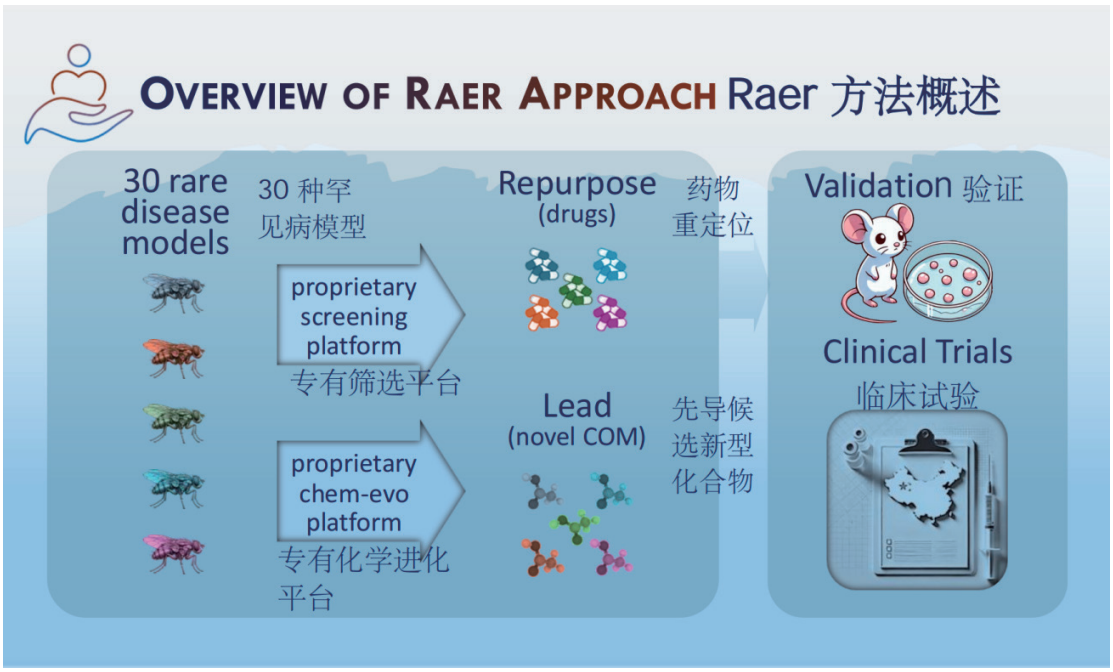
助亿万开发者投身更有价值的工作
Helping millions of developers engage in more meaningful work

调查数据显示，由 AI 生成代码较人工编写快 55%，75% 的受访者对 GitHub Copilot 支持的软件开发过程感到满意——今后，越来越多的开发者可以将才能与精力投入更有价值的创造性工作中。在人机协同的全新技术范式下，开发者的核心价值正在从“码农”转型为“代码导演”乃至“单人创业家”。

Survey data shows that AI-generated code is 55% faster than manual programming, and 75% of respondents are satisfied with the software development process supported by GitHub Copilot. Looking ahead, more and more developers will be able to channel their talent and energy into higher-value creative work. Under this new paradigm of human–AI collaboration, the core role of developers is evolving—from “code laborers” to “code directors,” and even “one person entrepreneur”.



GitHub Copilot 提升开发者生产力
GitHub Copilot enhances developer productivity



RAER 方法概述
Overview of RAER Approach

RAER Therapeutics：专注罕见病疗法的创新开发平台 RAER

RAER Therapeutics: An Innovative Development Platform Focusing on the Treatment of Rare Diseases

RAER Therapeutics

引言

RAER Therapeutics 致力于开发针对罕见病的创新疗法。我们依托独特、快速且具成本效益的药物筛选平台，探索新药及拓展已有药物的新用途，以应对疗效有限疾病领域中的大量临床需求。目前，公司已推进多个研发项目，涵盖 RAS 通路病、Tau 蛋白病及腺样囊性癌等领域。

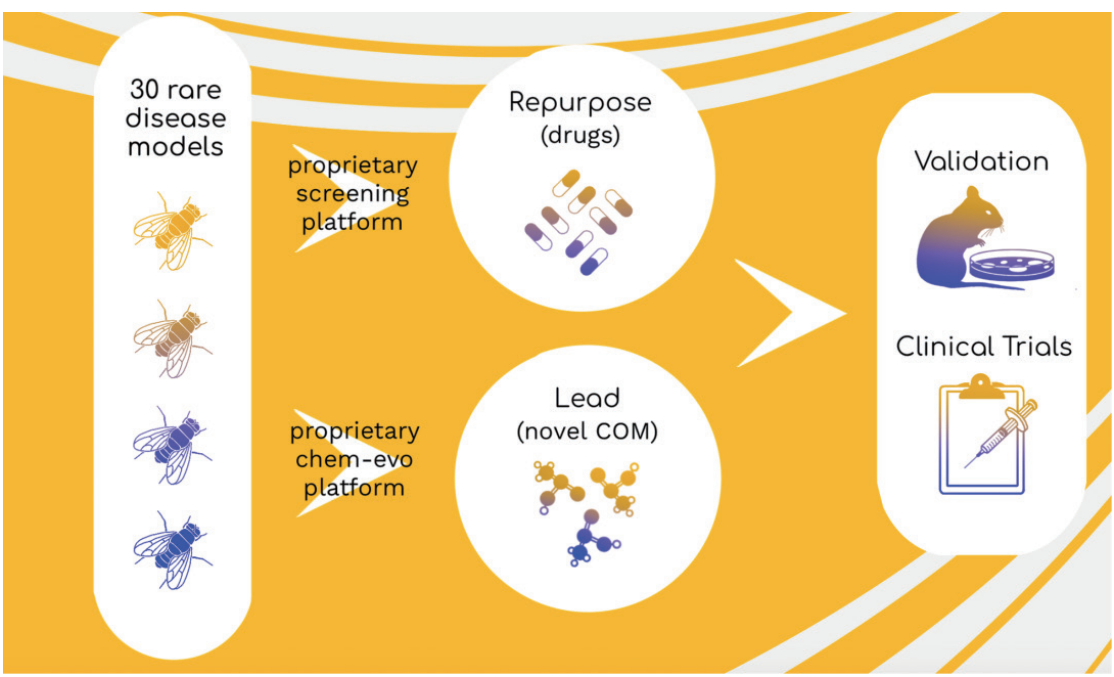
Introduction

At RAER Therapeutics, we develop innovative therapies for rare diseases. Leveraging a unique, rapid and cost-effective screening platform to develop novel and as well as repurposed leads, we address significant unmet medical needs in a market with limited effective treatments. We have advanced projects in RASopathies, TAUopathies, and Adenoid Cystic Carcinoma.

利用果蝇、小鼠等模型，筛选有潜力的重定位药物与新型在研新化合物
Utilizing Drosophila, mouse and other models to screen promising repurposed compounds and novel protected compounds

通过基因工程果蝇模型模拟病理机制并结合机器人高通量筛选，快速测试数千种化合物以识别潜在候选分子，随后在小鼠等哺乳动物模型中验证其安全性和有效性，最终推进至临床试验，这一高效且低成本的工作流程显著缩短了药物开发时间，为近 7000 种罕见疾病提供了新的治疗可能性。RAER 的工作流程涵盖从基因工程果蝇模型的构建、机器人驱动的高通量筛选、哺乳动物模型验证到最终推进临床试验的全过程。

By modeling disease mechanisms through genetically engineered Drosophila models and combining robotic high-throughput screening, this approach rapidly tests thousands of compounds to identify potential candidate molecules. These are subsequently validated for safety and efficacy in mammalian models such as mice before advancing to clinical trials. This highly efficient and low-cost workflow significantly shortens drug development timelines and offers new therapeutic possibilities for nearly 7,000 rare diseases. RAER's workflow encompasses the entire process, from constructing genetically engineered Drosophila models and conducting robotic high-throughput screening to mammalian model validation and ultimately advancing candidates to clinical trials.



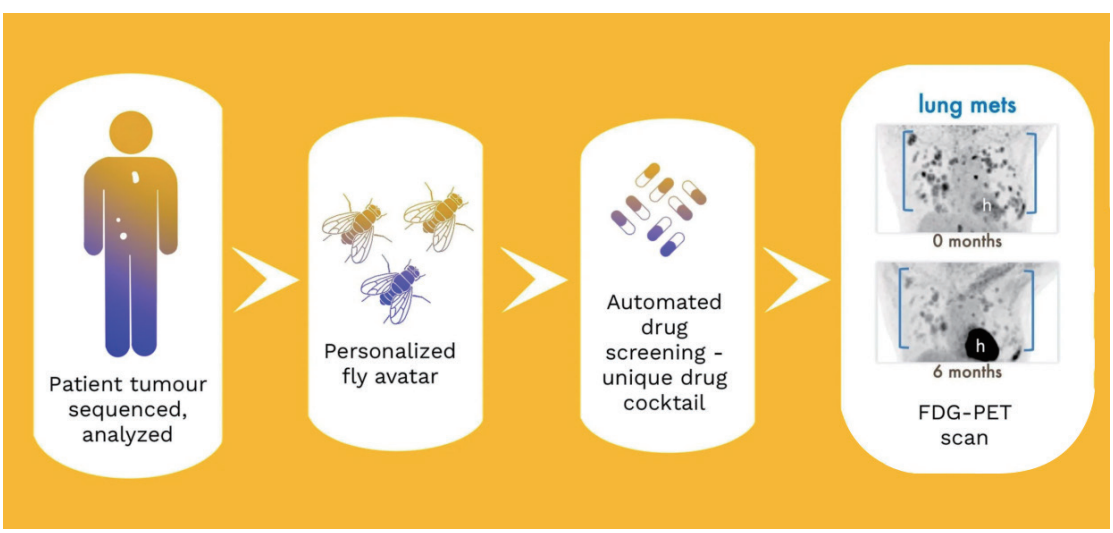
多模型筛选和验证平台
Multi-Model Screening and Validation Platform

利用果蝇、小鼠等模型，快速精准识别潜在的候选药物
Using fruit flies, mice and other models to rapidly and accurately identify potential candidate drugs

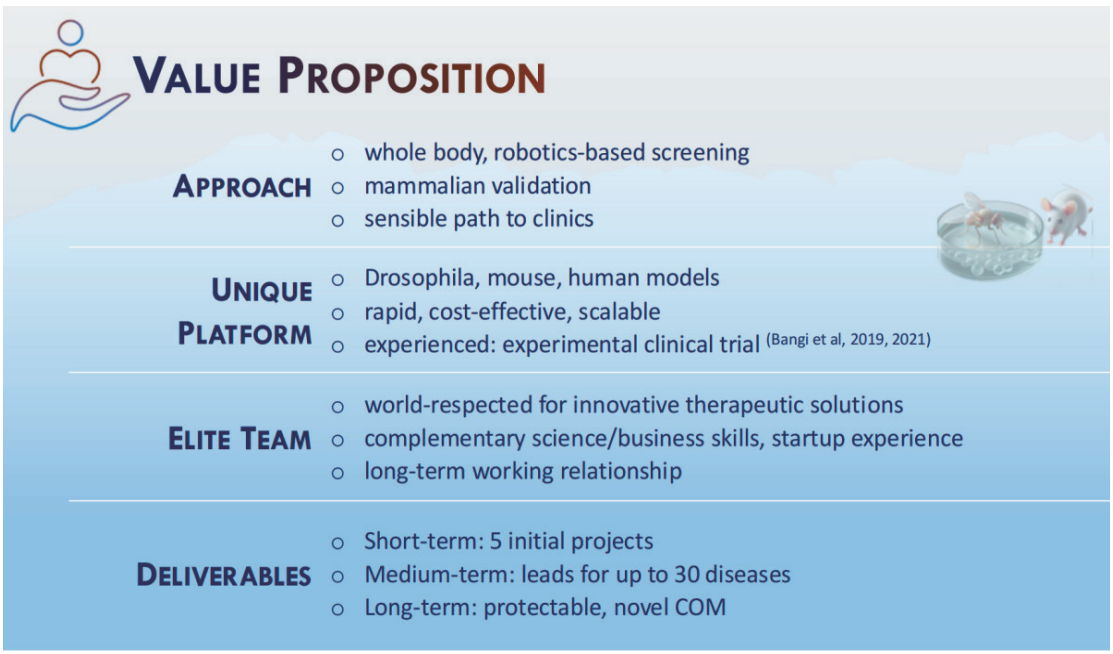
本研究系统性地确立了果蝇模型在罕见病精准药物研发中的核心地位，突破了以细胞系和小鼠模型为主导的传统筛选范式。其原创性观点认为，基于进化上保守的疾病通路，利用果蝇这一“全身性”活体模型，能够高效模拟人类复杂疾病表型，从而建立一条“从果蝇到临床”的转化路径。这为缺乏成熟动物模型的罕见病研究提供了全新的理论框架。

在研究方法上，本研究的重大创新在于构建了一套整合高通量果蝇机器人筛选、哺乳动物验证与化学进化平台的独特技术体系。该体系将低成本、大规模的果蝇初筛与严谨的临床前验证无缝衔接，显著提升了从化合物发现、先导物优化到临床候选药物确立的整体效率，开创了一种快速、低成本且可规模化的药物研发新模式。

Systematically establishing the Drosophila model as a cornerstone in precision drug discovery for rare diseases, challenging the traditional screening paradigm dominated by cell lines and mouse models. Its original perspective posits that by leveraging evolutionarily conserved disease pathways, Drosophila serves as a holistic in vivo system capable of efficiently modeling complex human disease phenotypes. This approach enables a “Fly-to-Bedside" translational path, offering a novel theoretical framework for tackling rare diseases that lack adequate animal models .In terms of research methodology, a significant innovation lies in constructing a unique technological platform that integrates high-throughput robotic screening in Drosophila, mammalian validation, and chemical evolution. This system seamlessly connects low-cost, large-scale initial screening in flies with rigorous preclinical validation, substantially enhancing the efficiency of the entire pipeline from compound discovery and lead optimization to identifying clinical candidates . It pioneers a new paradigm for drug development characterized by speed, cost-effectiveness, and scalability.



RAER 治疗公司将利用其最先进的方法来寻找其他罕见疾病的线索
RAER Therapeutics will use its cutting-edge methods to pursue leads for other rare disorders



价值主张
Value Proposition

项目获国际认可
Project Gains International Recognition

项目的研究成果发表于具有高影响力的同行评审期刊《i 科学》（Das 等人，2021 年），详细介绍了为 RAS 通路病创建的 24 种果蝇模型。该论文的发表标志着相关研究的科学严谨性与创新性已获得同行评议的高度认可。

该方法最关键的认可体现在其临床转化进展中。目前，已有腺样囊性癌患者开始接受基于该平台所发现的疗法，更大规模的临床试验也已启动，初步验证了该研究路径从实验室走向临床应用的可行性与潜力。

The research was published in the high-impact peer-reviewed journal iScience (Das et al., 2021), detailing the creation of 24 Drosophila models for RASopathies. The publication in a Cell Press journal reflects the scientific rigor and innovation of the achievement, which has gained peer recognition.

The most significant recognition of this approach lies in its clinical translation. Patients with adenoid cystic carcinoma have already received treatments discovered through this platform, and larger-scale clinical trials are currently underway, preliminarily validating its feasibility and potential in practical applications.



千帆星座组网示意
Spacesail Constellation Satellite Networking Schematic

千帆星座卫星规模化研制

Large-Scale Development and Production of the Spacesail Constellation Satellites

中国科学院微小卫星创新研究院
Innovation Academy for Microsatellites of Chinese Academy of Sciences

microsat 上海微小卫星工程中心 中国科学院微小卫星创新研究院

引言

卫星将通信的边界从地面拓展至太空，让无处不联从概念变为现实。千帆星座旨在为全球客户提供高速、实时、安全、可靠的低轨卫星互联网接入服务，正跨越高可靠高密度组网、高效率宽带通信、低成本批量制造及智能自主运行四大难题。

Introduction

Satellites are extending the frontier of communication from the ground into space, turning the concept of "ubiquitous connectivity" into reality. The Spacesail Constellation is designed to provide global customers with high-speed, real-time, secure, and reliable internet access services via low-earth orbit satellites. To achieve this ambitious vision, the constellation must overcome four major challenges: high reliability and high density networking , high-efficiency broadband communication, low-cost mass production, and intelligent autonomous operation.

掌握全链条关键核心技术，加速大规模星座商用化进程
Master key core technologies across the entire industry chain to accelerate the commercialization of large-scale satellite constellations

突破一箭 18 星的高效组网技术，通过平板结构一体化成型、高容积比多星堆叠与旋转式抛撒分离等技术创新，为星座大规模部署按下加速键。

突破高效率高集成通信载荷技术，通过捷变多波束相控阵技术、双轴偏转的馈电技术及星地协同的多维资源管理技术，为卫星通信容量提升注入了强劲动力。

突破氪工质推进、自主运维、高集成综电等系列技术，为千帆星座实现高效在轨运维与精准按需服务筑牢了“智能底座”。

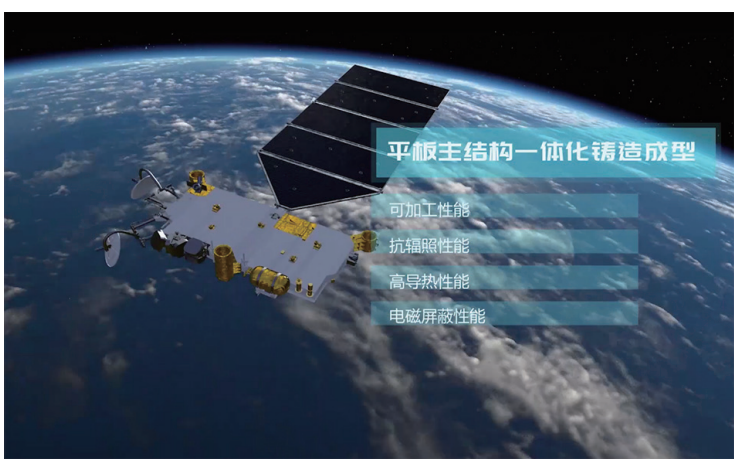
这些突破构建了全链条自主创新体系，柔性产线的应用更使研制周期缩短 60%，单产线年产能突破 300 颗，加速千帆星座大规模建设步伐。

We have made a breakthrough in high-efficiency deployment technology with the capability to launch 18 satellites on a single launch vehicle. Through innovations such as integrated flat-panel structure design, high-volume-ratio multi-satellite stacking, and rotary separation deployment, we have pressed the accelerator pedal for large-scale constellation construction.

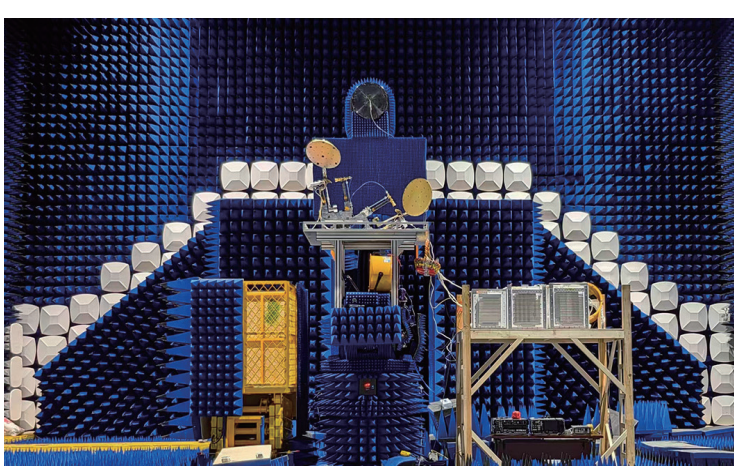
We have achieved a breakthrough in high-efficiency, highly-integrated communication payload technology. The application of agile multi-beam phased array technology, dual-axis steering feed technology, and multi-dimensional resource management technology with satellite-terrestrial coordination has injected strong impetus into the enhancement of satellite communication capacity.

We have made breakthroughs in a series of technologies, including krypton propulsion, autonomous operation and maintenance, and highly integrated electrical systems. These advancements have established a robust "intelligent foundation" for the Spacesail Constellation to achieve efficient in-orbit operation and maintenance, as well as precise on-demand services.

These breakthroughs have established an end-to-end independent innovation system. The application of a flexible production line has slashed the development cycle by 60% and increased annual production capacity to over 300 satellites, significantly accelerating the large-scale commercial rollout of the Spacesail Constellation.



平板主结构一体化铸造成型
Integrated Flat-Panel Architecture Design



卫星通信载荷无线对接测试
Wireless Interface Test Solution for Satellite Communication Payloads

带动上下游升级，形成产业生态，激活千亿市场
Driving Upstream and Downstream Upgrades, Fostering an Industrial Ecosystem, and Unlocking Hundred-Billion-Dollar Market Value

依托千帆星座商业化组网与全链条自主创新体系建设，不仅实现核心技术产业化落地与规模化应用，更带动砷化镓芯片、特种复合材料等上下游企业技术升级，形成完整产业协同生态。

经济效益上，协同产业链共同推动卫星制造成本下降，带动商业航天产业转型升级，支撑千帆星座围绕交通、电力能源、应急防灾、科教文卫、矿业、农业、个人用户等典型应用场景持续开展全球市场拓展与提供商用服务，惠及数亿级人口、激活千亿级市场空间；其技术创新推动全球卫星互联网产业从“单点突破”迈向“协同跃升”，既具备服务全球通信的高市场价值，更有助力全球信息基础设施互联互通、保障人类共同信息权益的重要社会价值。

Leveraging the commercialized network deployment of the Spacesail Constellation and the establishment of a fully self-reliant innovation chain, we have not only achieved the industrialization and large-scale application of core technologies but also driven technological upgrades in upstream and downstream enterprises, such as gallium arsenide chips and special composite materials, forming a comprehensive and synergistic industrial ecosystem.

In terms of economic benefits, collaboration across the industrial chain has collectively contributed to reducing satellite manufacturing costs, fostering the transformation and upgrading of the commercial aerospace industry. This supports the Spacesail Constellation in continuously expanding into global markets and providing commercial services across key application scenarios, including transportation, power and energy, emergency response and disaster prevention, education, science, culture, healthcare, mining, agriculture, and individual users. These efforts benefit hundreds of millions of people and activate a market worth hundreds of billions. The technological innovations behind it are propelling the global satellite internet industry from "isolated breakthroughs" to "collaborative leaps" , demonstrating not only high market value in serving global communications but also significant social value by enhancing the interconnection of global information infrastructure and safeguarding humanity's shared information rights.



卫星互联网互联万物
Satellite Internet: Interconnecting All Things

构建星地一体融合网络，打造 6G 时代核心竞争力
Building an Integrated Space-Ground Network to Forge Core Competitiveness in the 6G Era

千帆星座立足“星地融合、全域智联”的愿景，支撑远洋船舶航行大洋也可实现随遇接入、民航飞机万米高空也可无缝高速通信、智慧农场依托实时精准感知与控制实现丰产丰收、偏远地区莘莘学子也能享受全球前沿教育资源……

千帆星座的不断突破是构建空天地一体星地融合网络的关键举措，也将为推进 6G 标准、消除数字鸿沟、构建人类命运共同体做出卓越的贡献。

千帆星座通过技术—产业—应用的全链条突破，其成熟度体现在规模化部署能力与市场化应用实效，经济效益直指千亿级市场，社会效益覆盖国家安全与民生福祉，该成果不仅重塑了全球商业航天的竞争格局，更为全球和平利用太空、拓展互联疆域贡献了关键力量。

Rooted in the vision of "Space-Ground Integration and Comprehensive Intelligent Connectivity," the Spacesail Constellation enables always-on connectivity for ocean-going vessels navigating remote seas, seamless high-speed communications for commercial aircraft at cruising altitudes, and data-driven precision for smart farms—achieving optimal yields through real-time monitoring and control. It also bridges educational divides, allowing students in remote regions to access world-class learning resources.

The continuous breakthroughs of the Spacesail Constellation represent a critical step toward building an integrated space-air-ground network. These advances will also contribute significantly to the development of 6G standards, bridging the digital divide, and advancing the shared future of humanity.

Through the innovation across technology, industry, and application, the maturity of the Spacesail Constellation is demonstrated by its scalable deployment capabilities and tangible market impact. Economically, it targets a market valued in the hundreds of billions, while its social benefits extend to national security and public well-being. These achievements are not only reshaping the global commercial aerospace landscape but also contributing vital momentum to the peaceful use of space and the expansion of global connectivity.



卫星互联网构建空天地海一体化通信网络

Satellite Internet Constructs an Integrated Space-Air-Ground-Sea Communication Network



通义千问大模型：卓越性能，开源开放
Qwen: Open Foundation Model with Outstanding Performance

通义千问：开源开放的基础大模型

Qwen: An open-source foundational large language model

阿里云计算有限公司
Alibaba Cloud Computing Co., Ltd.

引言

通义千问是阿里云打造的全球领先开源大模型，以“全模态、全尺寸”布局和持续技术突破为核心竞争力，得到全球开发者广泛共建与采用，衍生模型超17万、下载量破6亿，成为开源生态中最活跃、最具影响力的大模型。

Introduction

Qwen, developed by Alibaba Cloud, stands as a globally leading open-source large language model. Anchored in a comprehensive “full-modality, full-scale” strategy and continuous technological breakthroughs, Qwen has garnered extensive adoption and collaborative contributions from developers worldwide. With over 170,000 derivative models and more than 600 million downloads, it has emerged as the most active and influential large model within the global open-source ecosystem.

构建高效自适应大模型训练新范式
Establishing a New Paradigm for Efficient and Adaptive Large Model Training

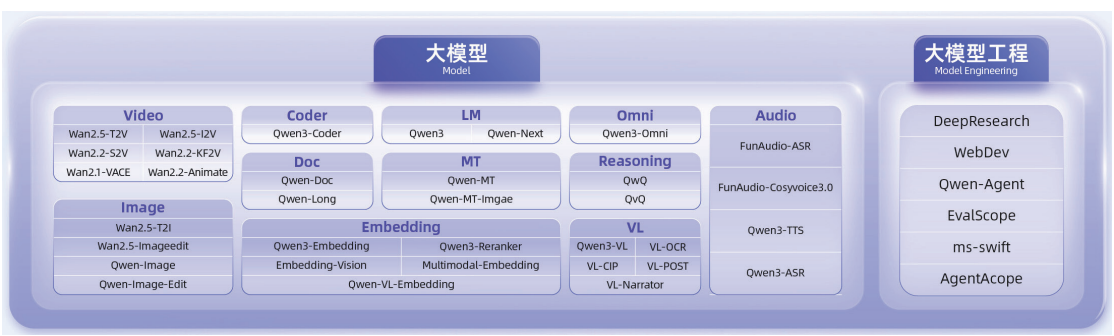
为攻克大模型数据质量、训练算法、训练效率三大瓶颈，通义千问团队首创“语义驱动—评估牵引—资源协同”三位一体的训练体系。在数据层面，构建自进化引擎，通过智能管理、价值洞察与自动化生成，让数据从被动输入变为主动进化燃料，效率提升超 40%。在算法层面，建立评估驱动的自适应训练飞轮，动态发现模型弱点，智能调整内部结构分工，并精炼关键环节优化策略，使数学、代码等专业任务性能跃升 12% 以上。在算力层面，打造资源感知的高效训练架构，从模型切分、数据调度到硬件适配，实现全链路智能协同，千卡集群资源利用率提升 22%，训练成本显著降低。成功研发并开源了从 0.6B 到 235B 参数，覆盖文本、视觉、音频、代码等多模态的完整模型矩阵，在多项权威基准上全面比肩或超越国际顶尖闭源产品。

To overcome the critical bottlenecks in data quality, training algorithms, and training efficiency, the Qwen team pioneered an integrated “Semantics-Driven, Evaluation-Guided, Resource-Coordinated” training framework.

In terms of data, the team built a self-evolving data engine that leverages intelligent curation, value-aware analysis, and automated generation to transform raw data from a passive input into an active driver of model evolution—boosting data utilization efficiency by over 40%.

In terms of algorithms, an evaluation-driven, adaptive training flywheel was developed to dynamically identify model weaknesses, intelligently reconfigure internal module responsibilities, and refine optimization strategies for key components. This has yielded performance improvements of over 12% on specialized tasks such as mathematical reasoning and code generation.

In terms of computing infrastructure, a resource-aware, high-efficiency training architecture was engineered to enable intelligent coordination across the full stack—from model parallelization and data scheduling to hardware adaptation. This architecture has increased resource utilization by 22% in thousand-GPU clusters and significantly reduced overall training costs.



通义大模型家族
Tongyi Qwen and Wan Model Family

服务千行百业 AI 应用规模化落地
Accelerating AI Adoption Across Industries at Scale

通义千问系列大模型已实现大规模产业成熟落地，服务企业客户超 105 万家，覆盖科研、金融、汽车、消费电子、政务、传媒等关键领域，形成显著经济与社会双重效益。在科研端，赋能国家天文台、青藏高原所等机构，在太阳耀斑预测、生态监测等前沿课题取得突破，推动科研范式智能化升级。在产业端，“通义灵码”生成超 30 亿行代码，成为主流编程助手；招商银行、重庆政务“渝小智”等案例实现业务效率与服务质量双提升；比亚迪、宝马、一汽等车企借助其构建智能座舱与 AI 引擎，重塑人车交互体验。消费电子领域，雷鸟、荣耀等品牌将其深度集成至终端，提升亿级用户交互智能度。文化传媒方面，央视春晚 AI 视觉生成、主流媒体智能编辑平台等应用，彰显其文化赋能与创意革新价值。通义千问不仅降低 AI 使用门槛，更成为产业智能化基座，其开源模式加速技术普惠，创造广泛社会价值与市场增量空间。

The Qwen series has achieved mature, large-scale industrial deployment, serving over 1.05 million enterprise customers across key sectors including scientific research, finance, automotive, consumer electronics, government services, and media—generating substantial economic and societal impact.

In scientific research, Qwen empowers institutions such as the National Astronomical Observatories and the Institute of Tibetan Plateau Research, enabling breakthroughs in frontier domains like solar flare prediction and ecological monitoring, thereby driving an intelligent transformation of scientific methodologies.

In industry, “Tongyi Lingma” has generated over 3 billion lines of code, establishing itself as widely used AI programming assistant. Use cases such as China Merchants Bank and Chongqing’s government AI assistant “Yu Xiao Zhi” have demonstrably enhanced both operational efficiency and service quality. Leading automakers—including BYD, BMW, and FAW—are leveraging Qwen to build intelligent cockpits and AI engines, redefining human-vehicle interaction.

In consumer electronics, brands like RayNeo and Honor have deeply integrated Qwen into their devices, elevating intelligent interaction for hundreds of millions of users.

In media and culture, applications such as AI-powered visual generation for CCTV’s Spring Festival Gala and intelligent editing platforms for major media outlets highlight Qwen’s capacity to empower cultural innovation and creative expression.

By significantly lowering the barrier to AI adoption, Qwen has become a foundational platform for industrial intelligence. Its open-source model accelerates technology democratization, creating broad social value and expansive market opportunities.



通义已服务全球 105 万企业级客户，覆盖行业包括互联网、消费电子等

Tongyi Qwen models have been used by 1,050,000+ global enterprises from industries like Internet and consumer electronics

通义大模型凭借持续创新和开源开放，得到全球开发者认可

Global Recognition Through Continuous Innovation and Open Collaboration

通义千问以“全尺寸、全模态”开源战略，重塑全球大模型协作格局，累计开源模型超 300 个，下载量突破 6 亿次，衍生模型超 17 万，稳居全球开源模型榜首，成为全球开发者首选基座模型。其开源极大降低研发门槛，激发全球创新活力——斯坦福、伯克利等顶尖机构基于 Qwen 训练出低算力高性能模型，学术引用数千次，成为多模态与长上下文研究的重要基线。Qwen3 发布 3 小时 GitHub 获 1.7 万星，刷新开源热度纪录，印证其全球开发者认可度。生态协同层面，与英伟达、高通、苹果等全球头部厂商深度适配，MLX 框架支持 iPhone/Mac 本地高效运行，推动大模型在消费电子与边缘设备的广泛部署。Qwen3 模型支持 119 种语言和方言，这一广泛的多语言能力为国际应用开辟了新的可能性，让全球用户都能受益于这些模型的强大功能。Gartner 等国际机构均将阿里云列为生成式 AI 全球领导者，彰显中国开源力量对全球 AI 发展的重要贡献。

Guided by a strategy of continuous innovation and open-source empowerment, we have established Qwen as a leading global large model, fostering a vibrant developer ecosystem with extensive international adoption. Its “full-scale, full-modality” open-source strategy is reshaping global collaboration in large model development. To date, Alibaba Cloud has released over 300 open-source models, amassed more than 600 million downloads, and inspired over 170,000 derivative models—solidifying Qwen’s position as the world’s leading open-source base model and the preferred choice for developers globally.

This open approach has dramatically lowered R&D barriers and catalyzed global innovation: top-tier institutions such as Stanford and UC Berkeley have built low-compute, high-performance models based on Qwen, which have been cited thousands of times in academic literature and serve as key baselines in multimodal and long-context research.

The release of Qwen3 garnered 17,000 GitHub stars within three hours—a record-breaking milestone that underscores its global developer endorsement.

On the ecosystem front, Qwen has achieved deep hardware-software co-optimization with global leaders including NVIDIA, Qualcomm, and Apple. Support for Apple’s MLX framework enables efficient on-device inference on iPhones and Macs, accelerating the deployment of large models in consumer electronics and edge devices. Furthermore, Qwen3 supports 119 languages and dialects, unlocking new possibilities for international applications and ensuring users worldwide can benefit from its advanced capabilities.

International research firms such as Gartner have recognized Alibaba Cloud as a global leader in generative AI—highlighting the significant contribution of China’s open-source initiatives to the advancement of global AI.



通义在开源模型数量、衍生模型数量、模型下载量等方面，已是全球最大的开源模型家族

Tongyi Qwen has become the world’s largest open-source model family in terms of the number of open-source models, derivative models, and model downloads

世界互联网大会
领先科技奖收录成果

Collection of World Internet Conference
Awards for Pioneering Science and Technology



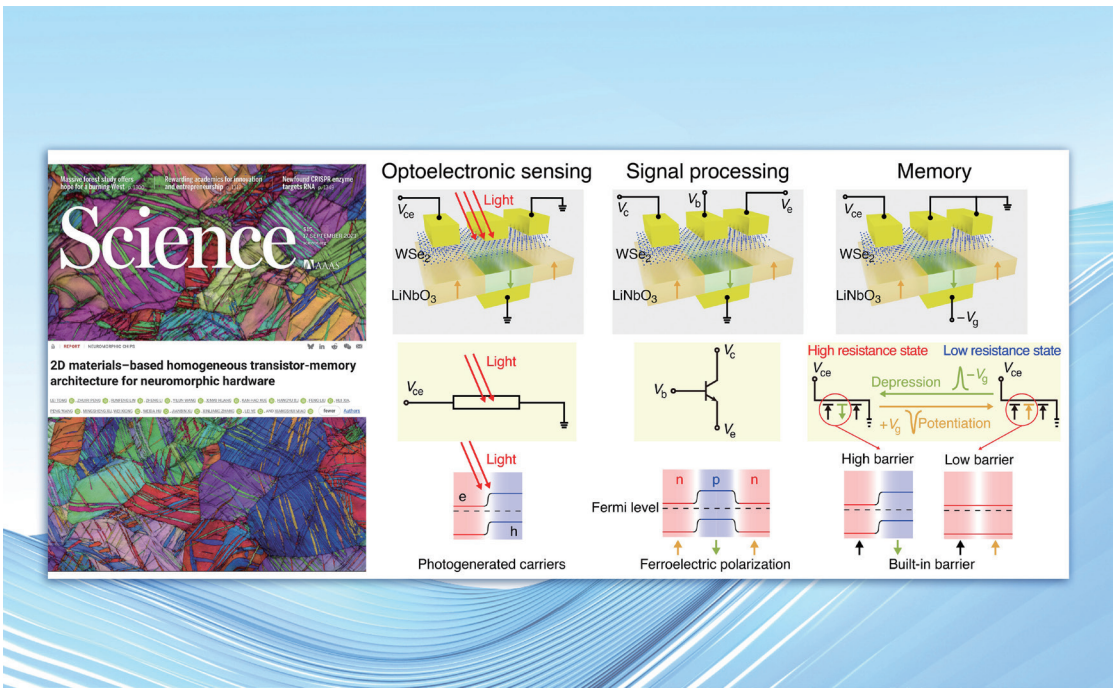
02

世界互联网大会
领先科技奖收录成果

Collection of World Internet Conference
Awards for Pioneering Science and Technology

基础研究组
Basic Research Group





首款感存算一体类脑芯片登上 Science 期刊
World's first sensing-memory-computing integrated neuromorphic chip featured in Science

类脑芯片的感存算一体机制及性能调控方法

Mechanism and modulation method of sensory-memory-computing fusion in neuromorphic chips

华中科技大学
Huazhong University of Science and Technology

引言

针对目前类脑芯片存算与感知分离的问题，项目组提出将感知与存算一体化的类脑处理新路径，突破了感知与存算分离导致的带宽瓶颈，显著降低了功耗和延时，为类脑智能技术体系提供底层架构和硬件基础支撑。

Introduction

On account of the critical issue of separated sensing and memory- computing components in current neuromorphic chips, a novel approach integrating perception with memory-computation functionality was proposed. This method overcomes the bandwidth bottleneck caused by the segregation between sensing and memory-computing units, substantially reduces power consumption and latency, and establishes a hardware-supported foundational architecture for neuromorphic intelligence technology.

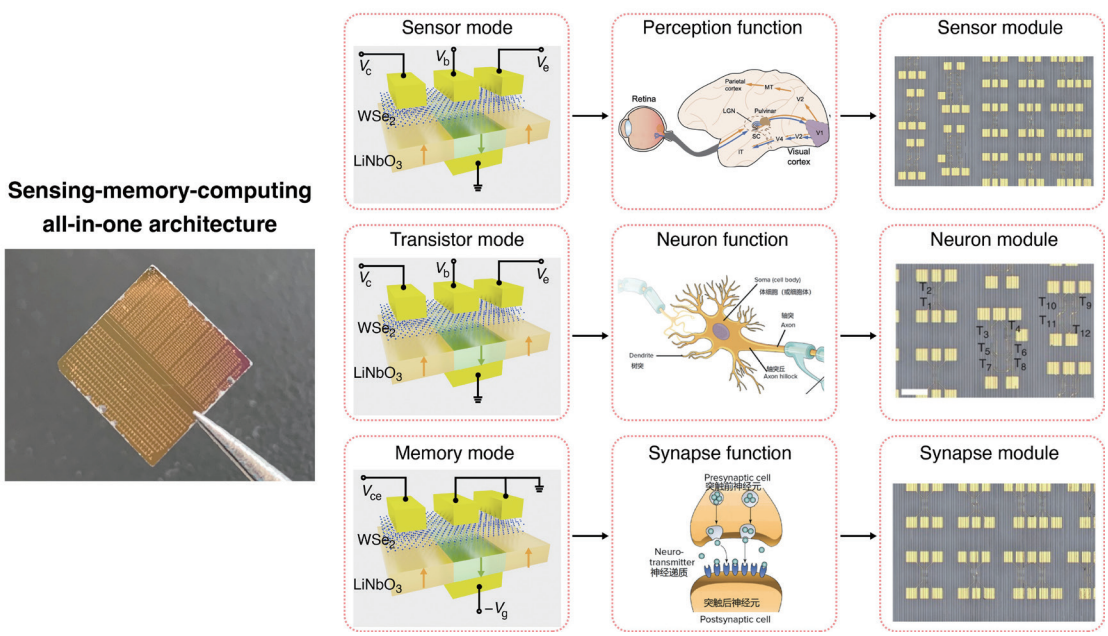
提出将感知与存算一体化的类脑芯片新架构
Proposing a new neuromorphic chip architecture integrating perception with in-memory computing

实现类脑智能是人类长期以来一直追求的梦想，类脑神经形态芯片是类脑智能的基石和引领者，其存算一体架构的科学意义在于突破冯·诺依曼架构瓶颈，但目前仍依赖外部传感模块完成感知信号的转换和传输，致使信息处理低能效、高延时。由于感知要求器件电导动态变化，而存算则要求器件电导处于稳态，在同一器件中实现感知与存算一体化极为困难。

团队发现光—电—力耦合场诱导材料的电子和离子迁移、相变及极化现象，揭示多外场耦合与材料物性相互作用规律，率先提出多外场耦合的类脑感存算一体机制，阐明异质界面工程的器件性能调控新原理，创立原创性的类脑感存算一体理论框架，构建类脑回路连接可塑的类脑芯片新架构。

Brain-inspired intelligence has long been a dream pursued by humanity. Neuromorphic chips serve as the cornerstone and pioneer of brain-inspired intelligence. Their memory-computing integrated architecture shows scientific significance in breaking through the limitations of the von Neumann architecture. However, their reliance on external sensing modules for the conversion and transmission of perceptual signals, leads to low energy efficiency and high latency in information processing. Since perception requires dynamic conductance modulation whereas memory and computation demand stable conductance states, integrating these conflicting requirements within the same device is extremely challenging.

The team discovered that opto-electro-mechanical coupling fields can induce electron/ion migration, phase transition, and polarization phenomena in materials, revealing the interaction mechanisms between multi-field coupling and material properties. A neuromorphic sensing-memory-computing integration mechanism was proposed based on multi-field coupling, elucidating new principle for regulating device performance through heterogeneous interface engineering. An original theoretical framework was established for sensing-memory-computing integration. Meanwhile, a novel neuromorphic chip architecture featuring the synaptic plasticity of brain-like circuit connections was constructed.



多外场耦合的感存算一体类脑芯片新架构

Novel multi-field coupled sensing-memory-computing integrated neuromorphic chip architecture

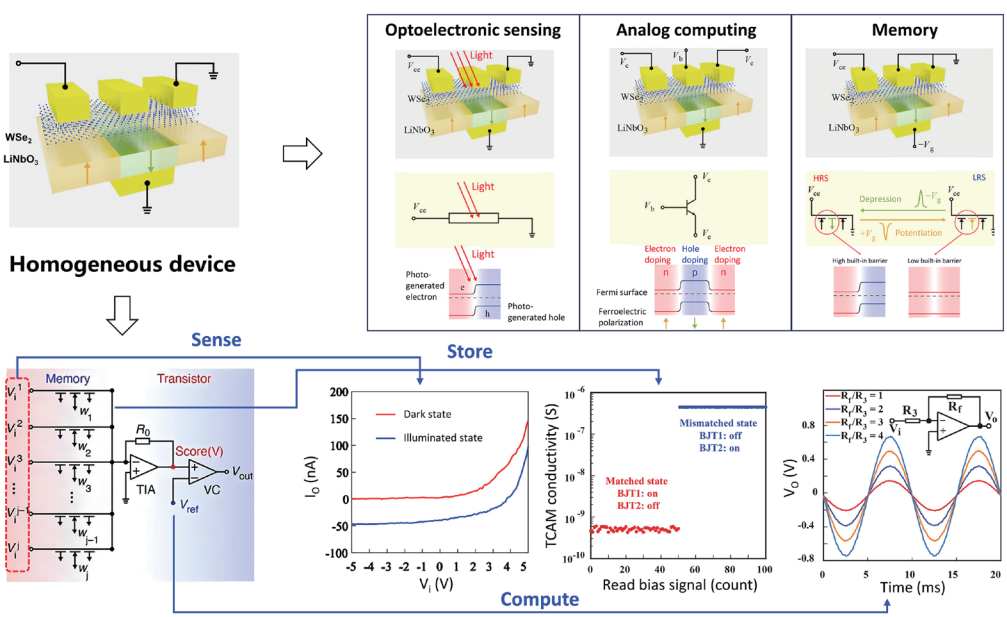
开创感存算一体类脑芯片新范式
Pioneering a new paradigm in sensing-memory-computing integrated neuromorphic chips

团队基于感存算一体架构，提出采用铁电材料与二维沟道材料耦合的器件结构。固定的铁电极化等效为非易失栅极电场对二维材料沟道进行电学掺杂，从而构建结型晶体管（BJT）器件，用于实现感知功能；铁电畴的极化翻转调制能够改变 BJT 的结区内建势垒，采用同一器件实现存算功能。

团队设计和制备基于上述器件的交叉阵列，根据任务的动态需求使器件在感知的神经元模式与存算的突触模式间切换，于存算链路中集成光电双模态感知功能，构建脑回路连接可塑的感存算一体类脑芯片新范式，研制出感知—存储—计算一体化集成的类脑芯片，其单位面积能耗仅 58.44 μW/mm²，延时仅为 27 μs，与国际同期感知与存算分离架构的先进芯片相比，能耗降至 ~1/8，延时降至 ~1/6。

Based on the sensing-memory-computing integrated architecture, the team proposed a device structure coupling ferroelectric materials with the two-dimensional channel materials. The fixed ferroelectric polarization equivalently acts as a non-volatile gate electric field to electrically dope the channel of the 2D material, thereby constructing a bipolar junction transistor (BJT) device that implements sensing functions. Ferroelectric domain switching modulates the built-in potential barrier in the BJT junction region, enabling the same device to perform memory and computing functions.

The team designed and fabricated cross-bar arrays based on the aforementioned devices, allowing them to switch between neuronal mode for sensing and synaptic mode for memory-computing according to dynamic task assignment. By integrating dual-mode optical and electrical sensing functions into the memory-computing pathway, a novel paradigm for sensing-memory-computing integrated neuromorphic chips was established with the synaptic plasticity of brain-like circuit connections. This as-developed neuromorphic chip achieves fully integrated sensing, memory, and computing capabilities, demonstrating a remarkably low energy consumption of 58.44 μW/mm² and a latency of merely 27 μs. Compared to state-of-the-art international chips with separated sensing and memory-computing architectures, this design reduces energy consumption to approximately 1/8 and cuts latency to about 1/6.



基于同一器件实现感存算一体类脑芯片

Sensing-memory-computing integrated neuromorphic chip based on same device

发表 Science 论文，开辟了国际类脑芯片的新方向
Publication in Science: Pioneering a New Direction for International Neuromorphic Chip Research

相关研究工作发表在 Science 等国内外高水平学术期刊和 IEEE 顶级会议上，被斯坦福大学、IBM 研发中心等 94 个国家 / 地区的 386 家研究机构学者广泛引用，引领了国际感存算一体芯片研究。自我们 2021 年提出感存算一体概念以来，论文得到广泛引用和跟随。成果荣获 2021 年中国半导体十大研究进展、2022 年世界人工智能大会青年优秀论文奖，入选 2021 年中国国家基金委成果巡礼。

Science 期刊副主编 Yury Suleymanov 评价：感存算一体架构“使多样化的神经形态功能成为可能，提供片上神经形态系统性能提升的潜力”；同期 Science 展望文章指出：“为感存算一体化芯片的量产提供更为可行的路线…大大降低了类脑神经形态芯片制造的门槛”；Nature Electronics 副主编 Matthew Parker 评价：“实现了兼具存储与模拟信号处理功能的同质晶体管”。

The related research has been published in high-impact academic journals such as Science and premier IEEE conferences, receiving extensive citations by scholars from 386 research institutions across 94 countries/regions, including Stanford University and IBM Research Centers, demonstrating its pioneering role in international sensing-memory-computing integrated chip research. Since the concept was first introduced by the team in 2021, and has been widely cited and followed. This groundbreaking work was honored with the 2021 Top Ten Semiconductor Research Advances in China, the Outstanding Youth Paper Award in 2022 World Artificial Intelligence Conference and was featured in the 2021 NSFC Achievements Showcase by the National Natural Science Foundation of China.

Science Deputy Editor Yury Suleymanov evaluated that the sensing-memory-computing integration architecture "promising diverse neuromorphic functionalities and offering potential improvements in neuromorphic systems on-chip." A Science Perspective article published concurrently noted that it "shape a more feasible route for the mass production of sensory-computation-memory integrated chips… substantially lower the bar for the manufacturing of neuromorphic chips." Nature Electronics Deputy Editor Matthew Parker commented that it "developed a homogenous transistor design that can be used for both memory and analogue signal processing."



感存算一体类脑芯片概念被广泛引用和跟随

Widely cited and followed concept of sensing-memory-computing integrated neuromorphic chip



Novascan 的项目优势
Advantages of Novascan

Novascan：
使用一次性设备进行癌症实时检测和分层

Transforming the assessment and treatment of cancers

NovaScan

引言

NovaScan 开发的“肿瘤电信号检测器”，通过扫描身体部位的电信号变化，可精准区分肿瘤组织与健康组织。该技术不受个体差异影响，其准确性媲美显微镜，稳定性高。

Introduction

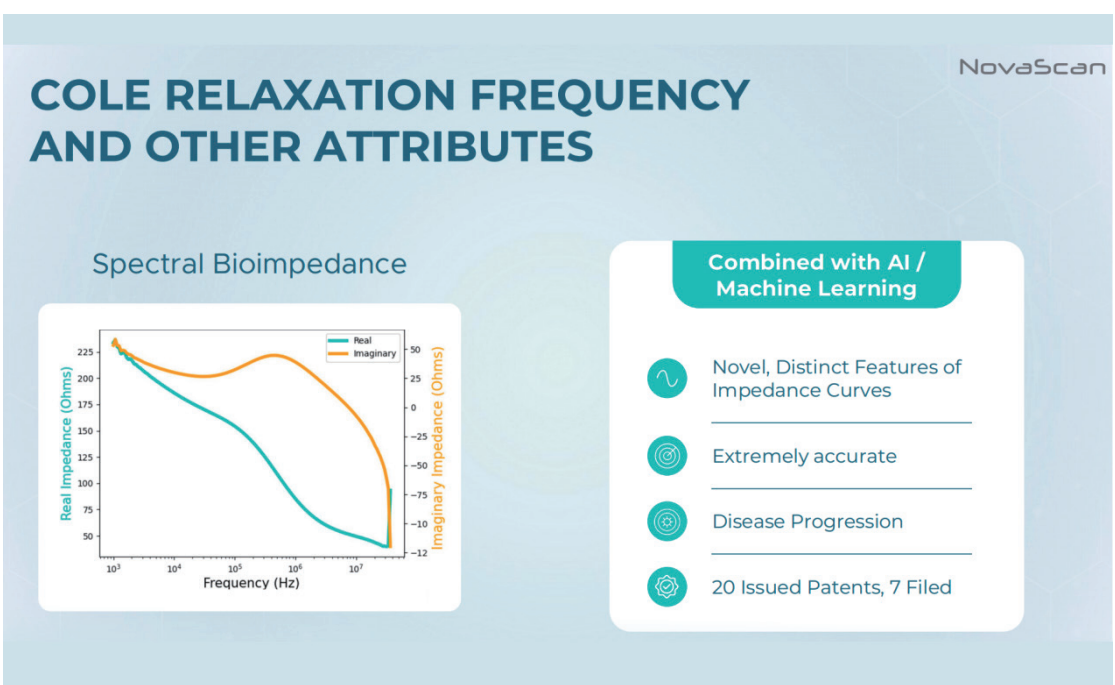
The "tumor electrical signal detector" developed by NovaScan can quickly distinguish between tumor and healthy tissue by scanning changes in the electrical signals of body parts. Unaffected by individual differences, the technology offers accuracy comparable to microscopy and high stability.

人工智能赋能光谱阻抗技术：无创癌症检测新路径
AI-Powered Spectroscopic Impedance: A Novel Pathway for Non-Invasive Cancer Detection

NovaScan 通过开发基于频谱生物阻抗与人工智能的无创定量检测技术，攻克了实时癌症检测中的多项关键难题。与传统定性化、有创的检测方法不同，NovaScan 平台能够在细胞层面快速、精准地测量组织电特性，并借助与恶性转化相关的独特科尔弛豫频率偏移，实现对癌症的有效识别。

NovaScan 的主要成果包括：一是完成多癌种临床验证，灵敏度达 91%-100%、特异度达 80%-100%；二是成功研发两款核心系统——用于实时活检分析的 nsCanary ™系统，以及用于术中切缘成像的 MarginScan ™系统。该技术获得 20 项授权专利支持，覆盖基于循环游离因子的检测方法与人工智能驱动的诊断成像等核心领域。

NovaScan has addressed several key technological challenges in the field of real-time cancer detection by developing a non-destructive quantitative testing method based on spectral bioelectrical impedance and AI. Unlike traditional cancer detection methods, which are often qualitative and invasive, the NovaScan platform enables rapid and precise measurement of tissue electrical properties at the cellular level. It identifies cancer by detecting unique Cole Relaxation Frequency (CRF) shifts associated with malignant transformation.Key achievements of NovaScan include: 1) successful multi-cancer clinical validation, demonstrating sensitivity of 91%-100% and specificity of 80%-100%; and 2) the development of two core systems: the nsCanary™ system for real-time biopsy analysis and the MarginScan™ system for intraoperative margin assessment . This technology is supported by 20 granted patents covering core areas such as circulating factor-based detection techniques and AI-driven diagnostic imaging.



科尔弛豫频率及其他属性
COLE RELAXATION FREQUENCY AND OTHER ATTRIBUTES

基于生物电阻抗频谱与人工智能的无创实时癌症检测方法
AI-powered, non-invasive real-time cancer detection method based on CRF electrical characteristics

该成果提出以科尔弛豫频率为核心的新型生物物理标志物，建立了细胞膜电容特性与癌变状态之间的定量关系，有效解决了传统组织病理学方法依赖形态学观察所存在的主观性强、耗时久等问题。

在研究方法上，该研究创新性地融合了光谱生物阻抗技术与人工智能分析，实现了无需染色、无损伤样本的高通量电生理检测，显著提升了恶性肿瘤识别的准确性与效率。

多项临床试验表明，该系统性能稳定，灵敏度达 91%–100%，特异度达 80%–100%，已成功应用于胰腺癌、肺癌、乳腺癌等多癌种的早期诊断与术中切缘评估，为临床实践提供实时决策支持。

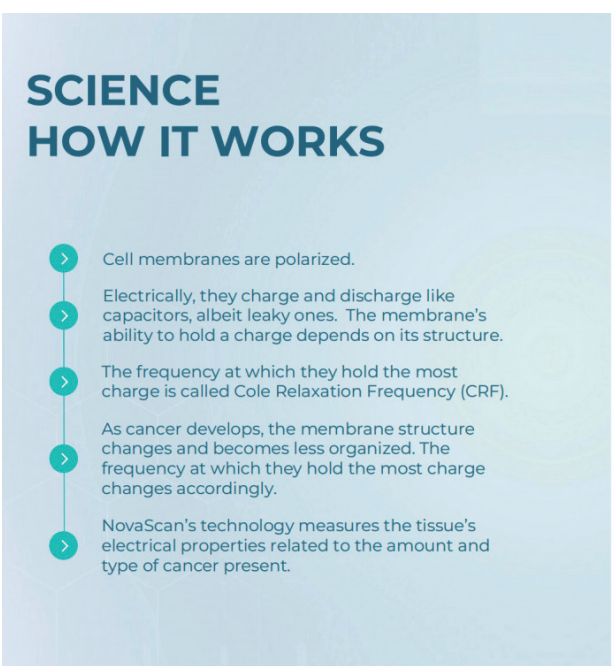
该研究的学术价值在于跨学科融合与方法创新，推动了生物电阻抗技术在肿瘤精准诊断领域的发展，相关成果已发表于多个高影响力国际期刊。在社会经济层面，该技术显著降低了检测成本与时间，提升了医疗资源利用效率，展现出显著的临床应用价值与产业化潜力。

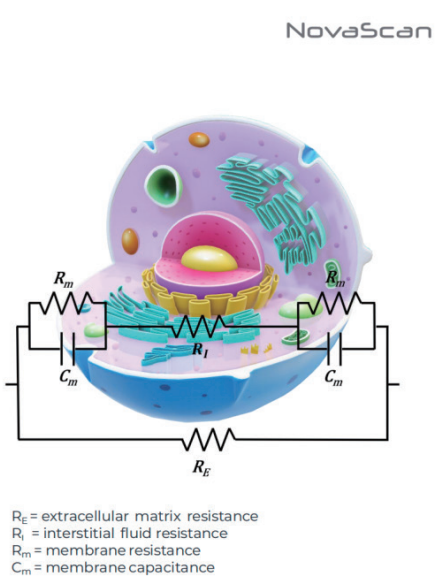
This work introduces Cole-relaxation-frequency (CRF) as a novel biophysical biomarker, establishing for the first time a quantitative link between membrane capacitance and neoplastic status. By replacing morphological inspection with an objective electrical metric, it eliminates the subjectivity and long turnaround times inherent to conventional histopathology.

Methodologically, spectral bio-impedance was seamlessly integrated with AI analytics to deliver high-throughput, label-free and non-destructive electrophysiological screening, dramatically raising both accuracy and speed in malignant-tissue recognition.

Multi-centre clinical trials show robust system stability, delivering 91%–100% sensitivity and 80%–100% specificity. The platform has already been deployed for early diagnosis and intra-operative margin assessment in pancreatic, lung and breast cancers, providing real-time decision support in the operating room.

Academically, the cross-disciplinary fusion and methodological innovation advance the application of bio-impedance technology in precision oncology, with resultant papers published in high-impact international journals. Socio-economically, the approach cuts testing cost and time, improves healthcare resource efficiency, and offers strong potential for clinical adoption and commercial scale-up.



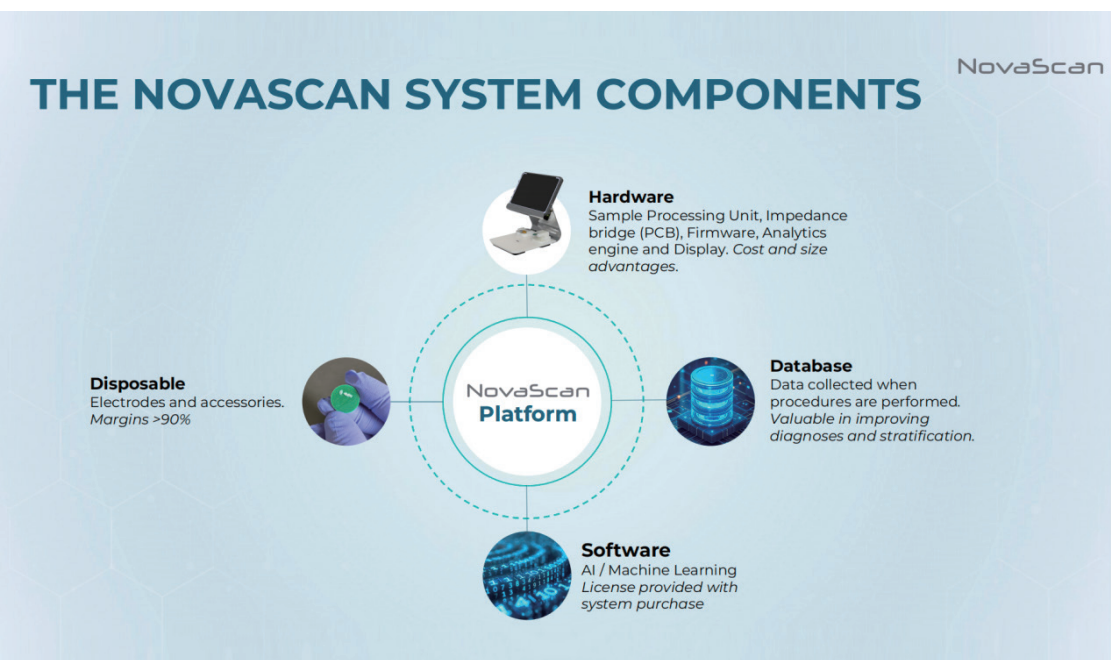


科学原理
SCIENCE HOW IT WORKS

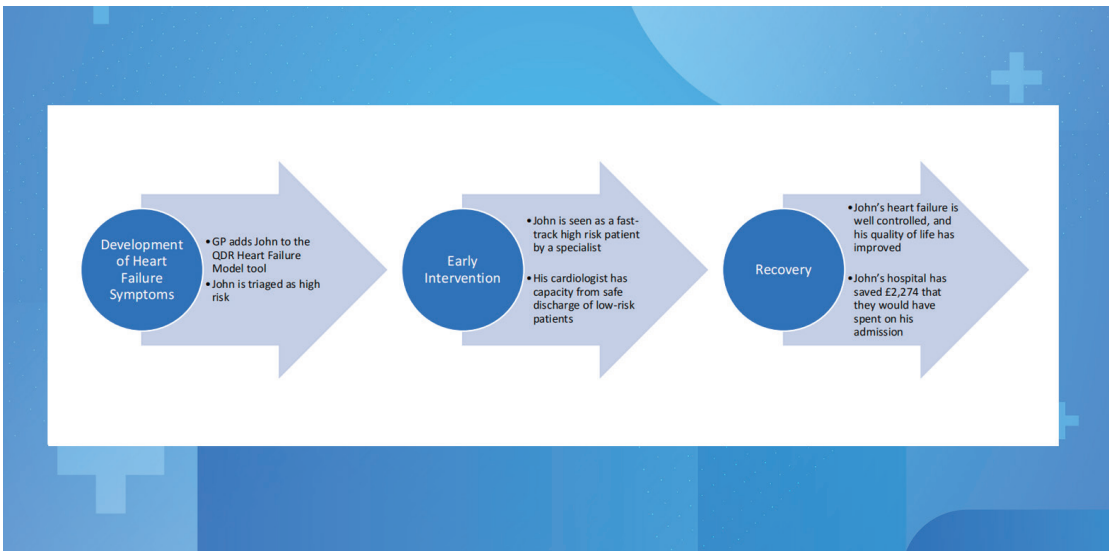
癌症无创定量新方法获国际认可
International Recognition for a Novel Non-Invasive, Quantitative Cancer Detection Method

通过基于科尔弛豫频率的生物阻抗谱与人工智能融合，开创了无创、实时、定量诊断癌症的新方法，其科学价值与临床效果已获得国际科学界的多项公开认可。核心研究成果多次发表于《Journal of Medical Physics》《JPCRR》（Journal of Patient-Centered Research and Reviews） 及《JAAD》（Journal of the American Academy of Dermatology）等国际权威期刊，涵盖乳腺癌、肺癌到皮肤癌等多个癌种的临床验证。专利内容涵盖 CRF 在癌症检测、组织电特性图谱生成及癌症复发预测等方面的应用，相关技术已进入美国 FDA 医疗器械审批程序。

By integrating Cole Relaxation Frequency (CRF)-based bioelectrical impedance spectroscopy with AI, a novel non-invasive, real-time, and quantitative method for cancer diagnosis has been pioneered. Its scientific value and clinical efficacy have received multiple public recognitions from the international scientific community. Core research findings have been consistently published in internationally authoritative journals such as Journal of Medical Physics, JPCRR(Journal of Patient-Centered Research and Reviews), and JAAD(Journal of the American Academy of Dermatology), encompassing clinical validations across various cancers including breast cancer, lung cancer, and skin cancer. The patent portfolio covers applications of CRF in cancer detection, tissue electrical property mapping, and cancer recurrence prediction. The related technology has entered the medical device approval process of the US FDA.



NOVASCAN 系统组件
THE NOVASCAN SYSTEM COMPONENTS



治疗疗程
New Pathway

QDR HEALTH：
为临床医生和患者提供精准诊断和管理的心脏病学平台

The Heart Failure Model

QDR Health Ltd.

QDR HEALTH
Digital HF

引言

QDR Health 研发了心力衰竭精准数字分诊工具。该工具可对高危人群实施分诊，辅助开展早期干预，有效减少住院人次、并发症发生及死亡病例，降低医疗成本。目前，该工具相关成果已获学术界认可，并得到多方合作支持。

Introduction

QDR Health has developed a precise digital tool for triaging heart failure, capable of triaging high-risk groups, aiding early intervention, reducing hospitalizations, complications, and deaths, and lowering costs. Its achievements have received academic recognition and it has the support of multiple partnerships.

QDR Health：精准分级分诊的数字工具
QDR Health: Precision Graded Triage Digital Tool

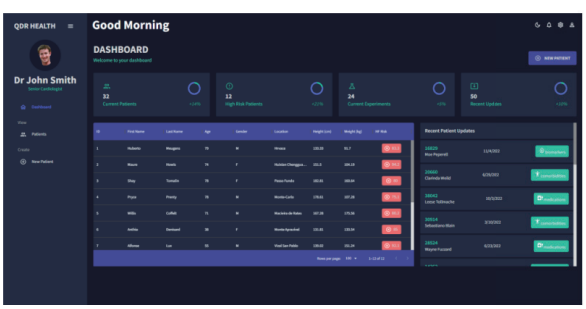
QDR Health 成功攻克了心力衰竭领域的两项核心技术难题：一是提升现有生物标志物的检测准确性与效率；二是缓解因病例数量持续增长给临床医师带来的资源压力。公司开发出基于数字生物标志物的分级分诊工具，可在临床实践中辅助实现对心衰患者的高效分级与分诊，为早期干预提供关键支持。该工具的核心算法基于全球规模最大的初级医疗数据库开发，相关研究成果已在欧洲心脏病学会年会进行展示，并正式发表于《欧洲心脏杂志》。目前，公司已与多家国际机构建立合作关系，共同推动该技术的临床验证与落地应用。

QDR Health has overcome two core technical challenges in the field of heart failure: First, enhancing the accuracy and efficiency of existing biomarkers; second, addressing resource constraints faced by clinicians due to increasing patient caseloads. The company has developed a digital biomarker-based graded triage tool that can efficiently assist in clinical stratification of heart failure patients, supporting early intervention. This achievement's algorithm is built on the world's largest primary care database. Related research results have been presented at the European Society of Cardiology (ESC) Congress and published in the European Heart Journal. The company has established partnerships with multiple global institutions to advance technology validation and application.

How we help John

A Digital Biomarker which accurately triages heart failure for clinicians at the point of use.

- Large scale triage and monitoring for referral and waiting lists for convenience
- Available at the point of use, saving patients and clinicians' time
- Reducing burden of care for clinicians as low-risk patients can be safely discharged



The Heart Failure Model

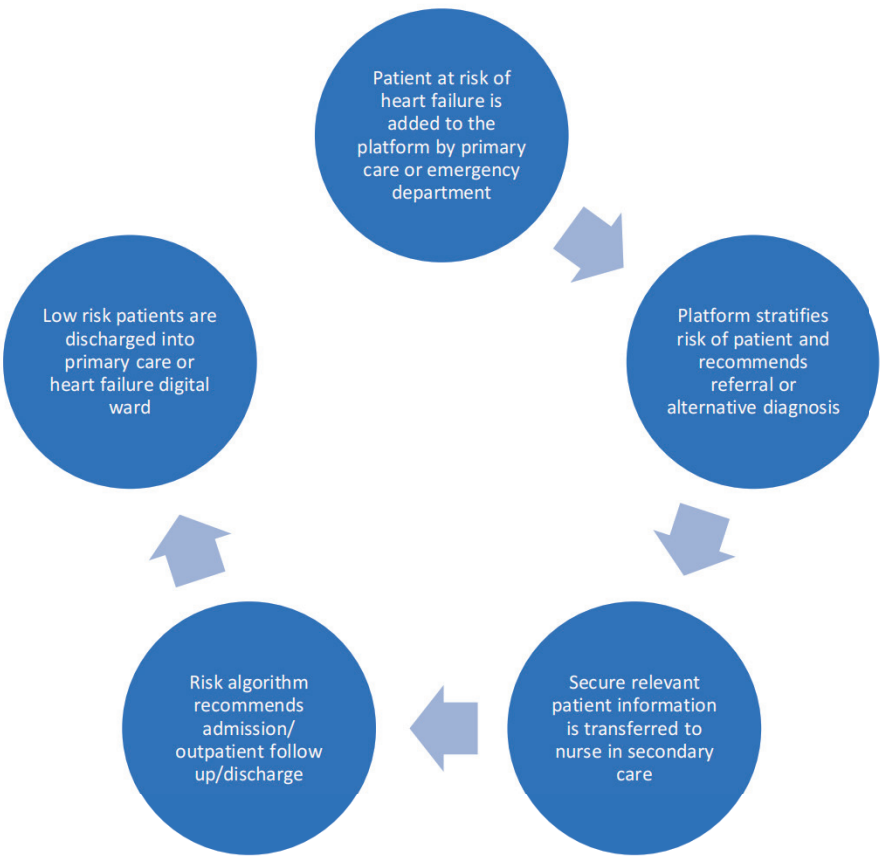
案例展示
How we help John

QDR Health 推动心力衰竭管理模式从被动应对向主动预防转变
QDR Health is driving a shift in heart failure management from reactive response to proactive prevention

该成果提出一种基于数字生物标志物的心力衰竭精准分级分诊新方法，有效克服了现有生物标志物准确性不足、效率偏低的问题，为心衰早期干预提供了新的理论依据。在研究方法上，创新性地采用英国基本医疗保健数据库构建核心算法，结合大规模分级分诊与持续监测技术，在临床实践中实现了高效干预，有力推动了心力衰竭管理模式从被动应对向主动预防的转变。

This achievement proposes a novel method for achieving precision graded triage of heart failure through digital biomarkers, which helps address existing issues of insufficient accuracy and low efficiency in current biomarkers, providing theoretical support for early

intervention in heart failure. In terms of research methodology, it innovatively employs the UK primary care database to construct algorithms, integrates large-scale triage and monitoring technologies, achieves efficient intervention in clinical application scenarios, and drives a shift in heart failure management from reactive response to proactive prevention.



工作原理
How it works

研究获国际权威认可，共建全球合作网络
Research has gained international authoritative recognition and established a global collaboration network

该成果在国际科学界获得高度公认，相关研究成果已在欧洲心脏病学会（ESC）会议上进行展示，并发表于权威期刊《欧洲心脏杂志》。研发团队与国际顶尖专家开展深度合作，邀请伦敦大学学院、华威大学等机构学者组建顾问委员会，为研发工作提供专业指导。研发团队参与由全球公立及私立卫生机构共同发起的 P4 精准医疗加速计划，联合国际合作伙伴推进心力衰竭领域研究。此外，依托全球规模最大的初级医疗数据库构建的算法及相关创新成果，对心脏病学与数字健康交叉学科发展产生积极推动作用。

The achievement has received high recognition in the international scientific community, with related research results presented at the European Society of Cardiology (ESC) conference and published in the authoritative journal "European Heart Journal". The research

team has conducted in-depth cooperation with top international experts, inviting scholars from institutions such as University College London and Warwick University to form an advisory committee, providing professional guidance for the research and development work. The team has participated in the P4 precision medicine acceleration program jointly initiated by global public and private health institutions, collaborating with international partners to advance research in the field of heart failure. Additionally, relying on algorithms built from the world's largest primary care database and related innovative achievements, it has positively promoted the development of cross-disciplinary fields between cardiology and digital health.

Progress

In one year, we have been able to build, test and validate our platform

Our algorithms have been built on the largest primary care database in the world, maintained by the UK government

Our work has been presented at the ESC and published in the European Heart Journal

We are a part of the British Heart Foundation's Cardio Stars Programme in Collaboration with Panacea Innovation.

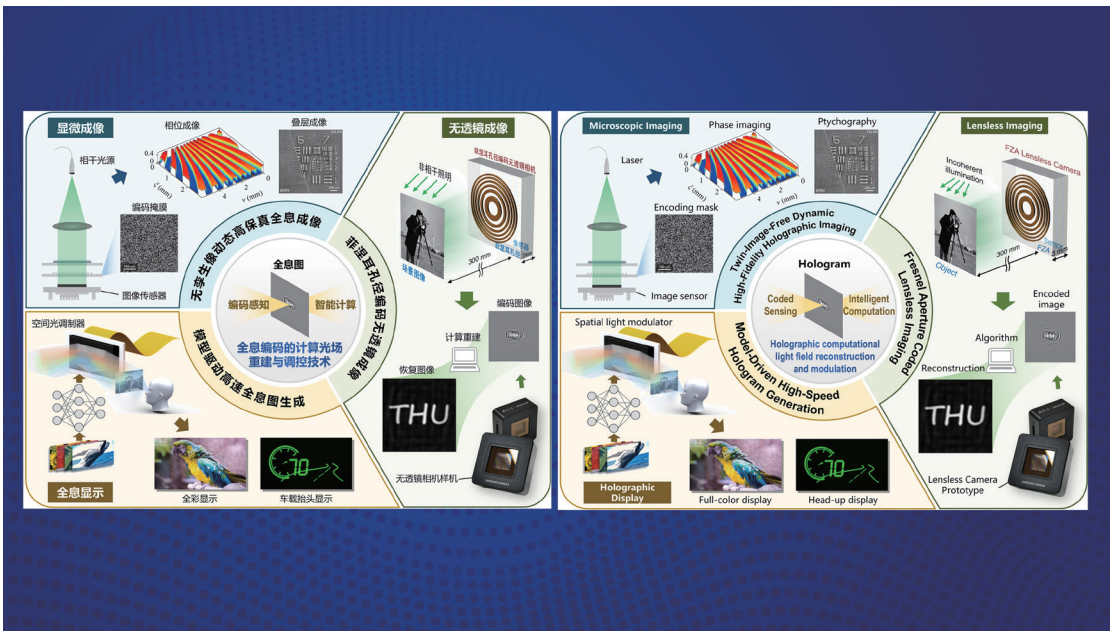
We are partnered with principal health innovation institutions across three regions in the United Kingdom, which total 16.7 million people with 65 hospitals in total.

We are a part of the P4 Precision medicine accelerator – a programme partnered with public and private health institutions globally

We are a part of the National Health Service Clinical Entrepreneur Programme, which supports the scale of healthcare innovations

项目进程

Project progress



全息编码的计算光场重建与调控技术在成像和显示领域的应用
Applications of holographic encoding based computational light field reconstruction and modulation in imaging and display

全息编码的计算光场重建与调控技术

Holographic encoding based computational light field reconstruction and modulation

清华大学
Tsinghua University

引言

全息技术是获取与重建多维光场的重要手段。受限于采集器件，难以实现高通量光场重建与调控。项目组聚焦高维光场获取与重建，构建了编码感知与智能计算协同的全息编码理论体系，提供了智能化光学信息处理新方案。

Introduction

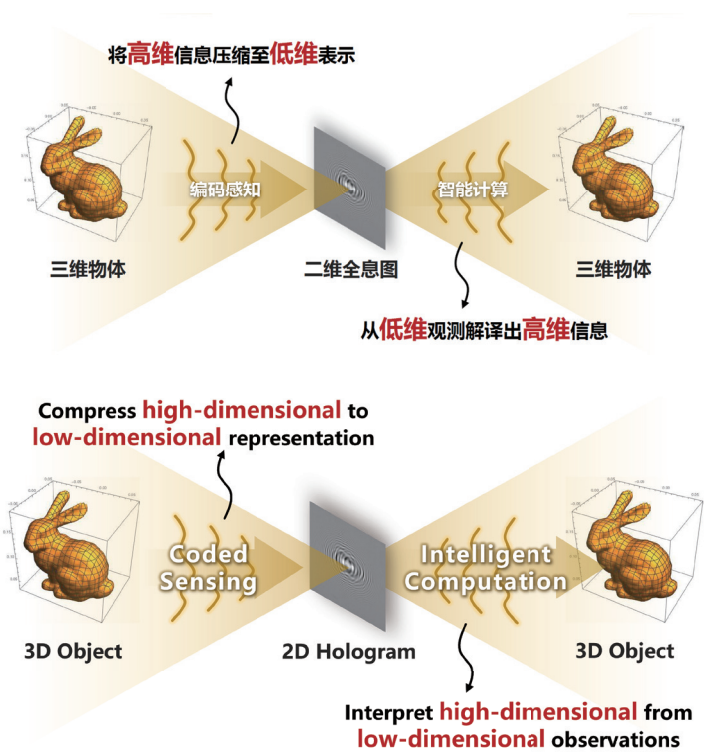
Holography is an important method for acquiring and reconstructing multidimensional light fields. Due to limitations of sensor, high-throughput light field reconstruction and modulation remain challenging. Focusing on high-dimensional light field acquisition and reconstruction, the team has developed a holographic encoding framework that integrates coded sensing with intelligent computation, offering a new approach to intelligent optical information processing.

突破高维信息编码与调控难题，推动全息技术跨越发展
Break Through the Challenges of High-Dimensional Information Encoding and Modulation, Driving a Leap Forward in Holography

本项目提出编码感知与智能计算协同的创新性全息理论体系，将信息科学与光学深度融合，开辟了多维信息重建的新路径。长期以来，全息成像受制于探测器局限、模型失配和算法效率，存在分辨率不足、噪声干扰和无法实时调控的难题。

This project proposes an innovative holographic framework that integrates coded sensing with intelligent computation, deeply combining information science and optics to open a new path for multidimensional information reconstruction. Conventional holographic imaging has long been limited by detector constraints, model mismatch, and low algorithmic efficiency, resulting in insufficient resolution, noise interference, and lack of real-time control.

研究团队在理论上揭示了重建物体与孪生像间衍射传播核函数差异，通过压缩感知消除了全息图中的孪生像伪影，与麻省理工学院联合提出菲涅耳孔径编码无透镜成像技术，助力智能化、小型化和集成化成像器件发展。



编码感知与智能计算协同的全息理论体系
Holographic framework integrating coded sensing and intelligent computation

At the theoretical level, the team revealed differences in the diffraction propagation kernels between the reconstructed object and the twin image, and eliminated twin-image artifacts in holograms using compressive sensing. In collaboration with MIT, they developed Fresnel zone aperture–coded lensless imaging, advancing intelligent, compact, and integrated imaging devices.

在方法上提出时空正则反演框架和特征域相位恢复方法，有效应对复杂实验条件下的误差干扰，使全息成像从“看得清”走向“看得准”。

At the methodological level, the team introduced a spatiotemporal regularized inversion framework and a feature-domain phase retrieval method. The method effectively suppresses error interference under complex experimental conditions, and advances holography from “seeing clearly” to “seeing accurately”.

在应用上，突破了动态高保真成像与实时光场调控的瓶颈，在 4K 分辨率级别的实时全息显示和车载抬头显示领域展现重要应用价值。为推动光学与信息科学的深度交叉和新兴产业发展提供了关键支撑。

At the application level, the team overcame bottlenecks in dynamic high-fidelity imaging and real-time light field control, demonstrating significant potential in real-time 4K holographic displays and automotive head-up displays. The project provides key support for deep cross-disciplinary integration of optics and information science and for emerging industrial development.

阐释全息光场重建和调控机理，构建编码感知与智能计算体系

Elucidating the Mechanisms of Holographic Light Field Reconstruction and Modulation, Establishing a Coded Sensing–Intelligent Computing Framework

本项目围绕全息编码的计算光场重建与调控开展系统研究，首创基于相位核函数稀疏差异的压缩感知重建，实现单帧同轴全息图无孪生像重建，并构建时空稀疏正则反演计算框架，实现动态高保真全息成像，同时通过特征域相位恢复有效解决模型失配问题，拓展计算显微成像理论边界。

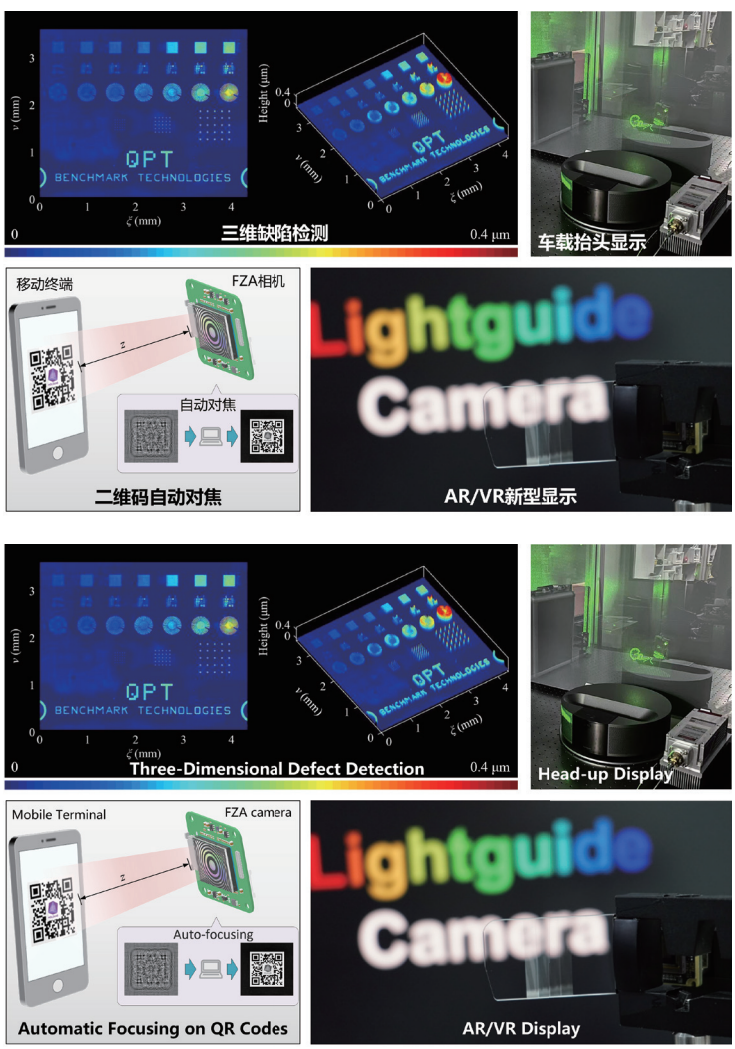
This project conducts a systematic study of computational light field reconstruction and modulation based on holographic encoding. It pioneers a compressive sensing reconstruction method that exploits the sparse difference of phase kernel functions, enabling twin-image-free reconstruction from a single inline hologram. A spatiotemporal sparse regularized inversion framework is established to achieve dynamic high-fidelity holographic imaging, while feature-domain phase retrieval effectively addresses model mismatch and expands the theoretical scope of computational microscopy.

方法上创新结合菲涅耳孔径编码无透镜成像、压缩感知和深度学习，实现自然光下一次曝光高质量成像，并构建衍射模型驱动的全息图生成网络，实现高分辨率全息图生成与实时光场调控。

Methodologically, the project integrates Fresnel zone aperture coded lensless imaging, compressive sensing, and deep learning to enable high-quality single-shot imaging under natural light. It further develops a diffraction model driven hologram generation network, achieving high-resolution hologram synthesis and real-time light field control.

成果在基础理论、算法方法及系统实现方面形成系统性突破，并在三维显微测量、工业缺陷检测、AR/VR 新型显示、车载抬头显示等应用领域展现重要价值，为高端制造、智能光学与新型显示产业注入创新动力，推动相关技术的升级与应用拓展，彰显广阔市场潜力。

The project has achieved systematic breakthroughs in fundamental theory, algorithmic methodology, and system implementation, demonstrating significant value in applications such as 3D microscopic measurement, industrial defect inspection, AR/VR next-generation displays, and automotive head-up displays. It injects innovation into high-end manufacturing, intelligent optics, and emerging display industries, driving technological upgrades and application expansion while showing strong market potential.



本项目成果在缺陷检测、自动对焦、AR/VR 显示、车载抬头显示等应用领域展现重要价值
Applications of the project in defect detection, autofocus, AR/VR display, and automotive head-up display

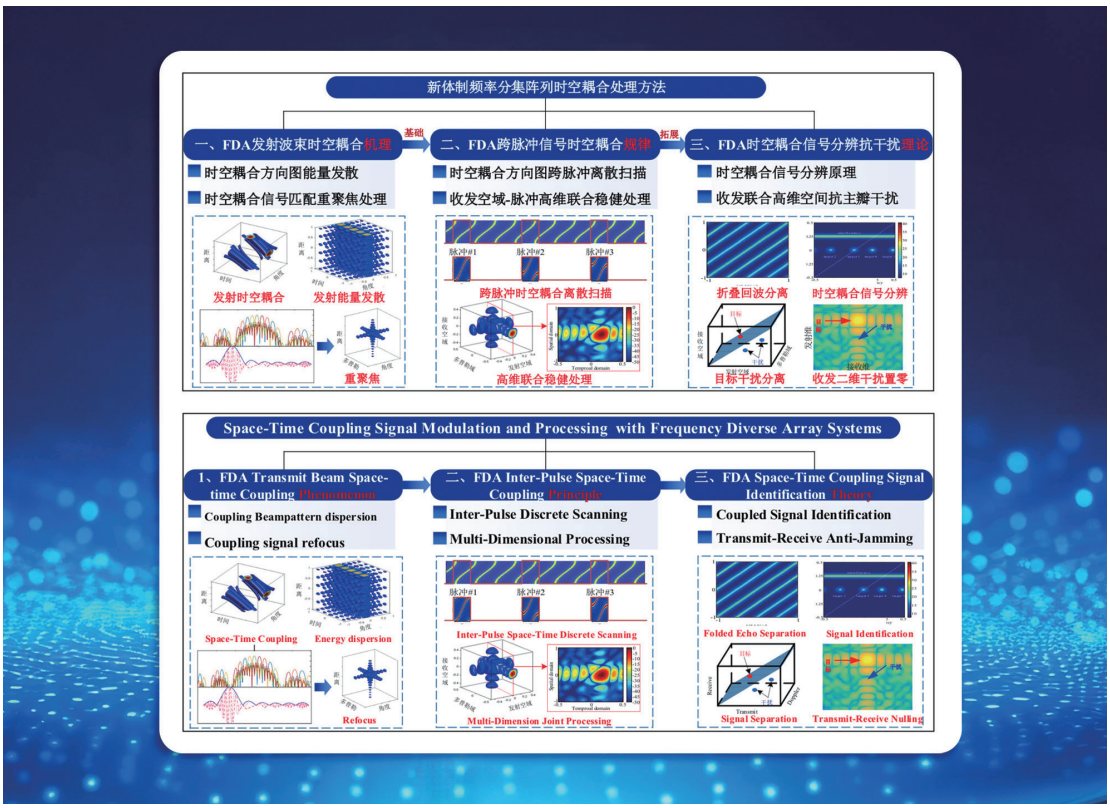
成果获高被引和国际学术界高度认可，彰显全球影响力
The Results Have Received High Citations and Strong International Recognition, Demonstrating Global Impact

本项目共发表论文87篇，SCI他引用共计709次，入选ESI高被引2篇，引用论文来自MIT、Cambridge、UCLA、UC Berkeley等国内外著名院校与科研机构，引用在Nature、Nature Photonics、Nature Communications、Light Science & Applications、Optica等重要学术刊物上。项目开发的算法被德国斯图加特大学、德累斯顿工业大学、英国剑桥大学、清华大学自动化系、北京大学、香港中文大学、上海理工大学等团队采用。项目团队与华为、字节跳动、海信、OPPO等企业就计算成像和全息显示开展合作研究。研究成果荣获2024年第十届中国光学工程学会科学技术奖自然科学奖一等奖、2023年中国产学研合作创新成果奖一等奖、2020年中国仪器仪表学会技术发明奖一等奖、2024年中国光学工程学会计算成像三年成果展优秀成果、2022年纽伦堡国际发明展金奖等荣誉，推动光学系统向“无透镜化”、“智能化”跨越。

This project has produced 87 publications with 709 SCI citations, including two ESI Highly Cited Papers. The work has been cited by researchers from leading institutions such as MIT, Cambridge, UCLA, and UC Berkeley, with citations appearing in top journals including Nature, Nature Photonics, Nature Communications, Light: Science & Applications, and Optica. The algorithms developed in this project have been adopted by research teams at the University of Stuttgart, TU Dresden, University of Cambridge, Tsinghua University (Department of Automation), Peking University, the Chinese University of Hong Kong, and University of Shanghai for Science and Technology. The team has also carried out collaborative research on computational imaging and holographic display with Huawei, ByteDance, Hisense, and OPPO. The project has received multiple honors, including the First Prize of the Natural Science Award from the 10th Chinese Society for Optical Engineering Science and Technology Awards (2024), the First Prize of the China Industry–University–Research Cooperation Innovation Achievement Award (2023), the First Prize of the China Instrument and Control Society Technological Invention Award (2020), Outstanding Achievement in the Computational Imaging Three-Year Achievement Exhibition of the Chinese Society for Optical Engineering (2024), and the Gold Award at the iENA International Exhibition of Inventions in Nuremberg. These achievements have driven holographic optical systems toward lensless and intelligent development.



本项目成果获多项重要奖项
Major awards received by the project



频率分集阵列时空耦合处理研究概要图：在新体制频率分集阵列系统的发射波束时空耦合机理、跨脉冲信号时空耦合规律、时空耦合信号分辨抗干扰理论方面取得重要原始创新成果，为解决脉冲折叠模糊信号分辨、同频同向有源干扰抑制等行业难题提供了新途径，可应用于雷达、通信、导航等电子信息系统

Research Summary of Space-Time Coupled Signal Modulation and Processing with Frequency Diversity Array Systems: This project has achieved groundbreaking innovations in three aspects: the space-time coupling principle of transmit beampattern in frequency diversity array systems, the inter-pulse space-time coupling principle of transmit signal, and space-time coupled signal processing for anti-jamming theory. The studies provide novel solutions to handle the industry challenges such as pulse-folded signals resolution and mainlobe repeated jammer suppression, with potential applications in radar, communication, navigation, and other electronic information systems

新体制频率分集阵列时空耦合处理方法

Space-Time Coupled Signal Modulation and Processing with Frequency Diverse Array Systems

西安电子科技大学
Xidian University

深圳大学
Shenzhen University

香港城市大学
City University of Hong Kong

中国航天科技集团有限公司第五研究院西安分院
China Academy of Space Technology (Xi'an)

引言

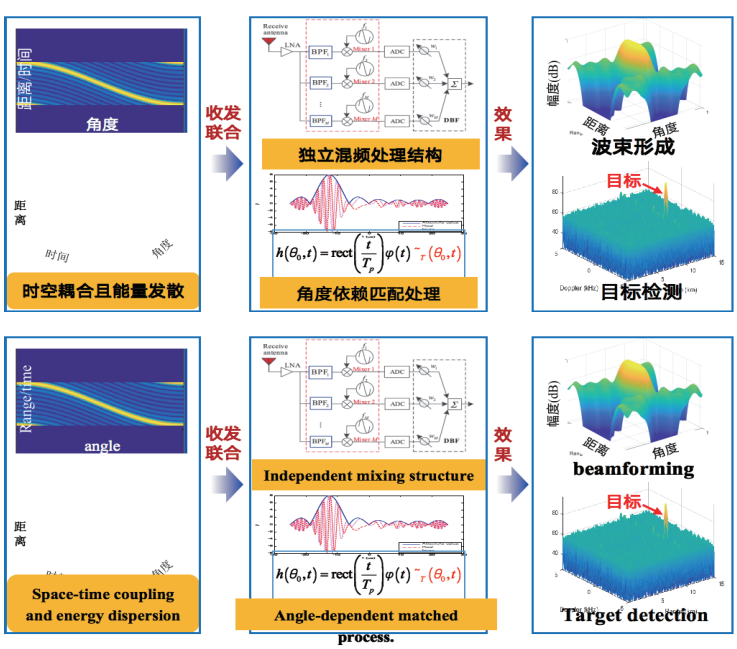
项目在 FDA 系统新现象、新机理、新理论方面取得重要原始创新，开拓了时空耦合信号调控与处理的理论方法，发表了 FDA 领域多篇经典论文，引领了 FDA 系统理论和雷达应用的细分研究领域，受到广泛跟踪研究。

Introduction

The project has achieved significant original innovations in new phenomena, mechanisms, and theories with FDA system, pioneered theoretical methods for space-time coupled signal modulation and processing, published multiple classic papers in the FDA field, led specialized research areas in FDA system theory and radar applications, and attracted extensive follow-up studies.

创新时空耦合信号调控与处理的理论方法
Pioneered Space-Time Coupled Signal Modulation and Processing Theory and Methods

项目组在国际上较早开展了 FDA 基础理论和关键技术研究，在 FDA 变革相控阵的关键基础理论研究上取得重要原始创新。本项目挖掘了 FDA 时空耦合信号调控物理数学原理，最早将发射调控和接收处理两个视角相结合，建立了收发联合广义电磁信号模型，发现了 FDA 发射波束距离 - 时间 - 角度多维耦合及能量发散现象和发射波束跨脉冲周期时空耦合规律，为 FDA 理论方法和应用研究奠定了重要基础。本项目提出接收端通道独立了混频处理方案克服了方向图时变的问题，形成了 FDA 收发联合时空耦合信号分析方法，实现了时空耦合波束形成与时空联合匹配重聚焦处理，解决了信号能量发散问题。本项目提出了 FDA 时空耦合跨脉冲编码概念，将传统相控阵发射波束指向固定变革为跨脉冲时空耦合离散变化，揭示了 FDA 跨脉冲时空耦合信号调控原理。



FDA 收发联合时空耦合匹配处理

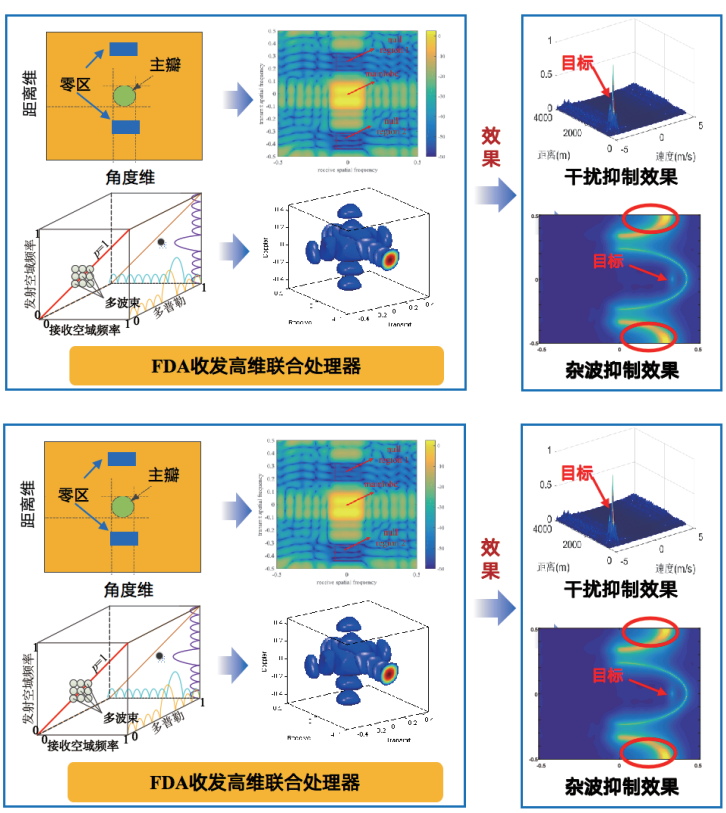
FDA Joint Transmit-Receive Space-Time Coupling Matched Processing

The research team pioneered fundamental theoretical and key technological studies on FDA at an early stage internationally, achieving significant original innovations in the critical foundational theories of FDA. This project uncovered the physical and mathematical principles of FDA's space-time coupling signal modulation by integrating the transmitting and receiving perspectives, and established a generalized electromagnetic signal model for joint transmission and reception. It discovered the multidimensional coupling principle of FDA range-time-angle-dependent beampattern and its energy dispersion phenomenon, as well as the space-time coupling law across pulse periods, laying a crucial foundation for FDA theoretical methods and applied research. The project proposed an independent channel mixing processing scheme at the receiver to overcome the time-varying pattern issue, forming an FDA space-time coupled signal analysis method for joint transmission and reception. This achieved space-time coupled beamforming and space-time matched refocusing processing, resolving the energy dispersion problem. The project introduced the concept of FDA space-time coupled inter-pulse coding, achieving discrete space-time coupled variations of pointing direction across pulses, revealing the principles of FDA inter-pulse space-time coupled signal modulation.

揭示模糊信号分辨和同频同向干扰抑制的原理
Revealed the Principle of Ambiguous Signal Resolution and Mainlobe Jammer Suppression

本项目建立了时空耦合信息转换的主瓣干扰与目标高维空间分辨理论，基于 FDA 时空耦合信号调控原理，将信号脉冲分辨问题转换为发射空域分辨问题，揭示了 FDA 跨脉冲信号分辨和分离的原理，建立了高维空间区分目标与跨脉冲转发干扰的理论基础。本项目挖掘了阵列脉间标识编码新信息，构建了 FDA 收发联合域主瓣转发干扰与脉冲编码之间的数学映射关系，分析了目标与干扰在发射 - 接收 - 脉冲维的分布差异，在国际上首次提出了 FDA 收发联合抗主瓣转发干扰方法，突破了雷达领域主瓣电子干扰抑制的世界难题。本项目成果应用于某机载雷达系统，“与传统相控阵自适应抗干扰技术相比，输出信干噪比性能提升 20dB”，等效压缩敌方有效干扰距离 10 倍。

This project established the theoretical foundation of mainlobe interference and target identification theory in high dimensions based on space-time coupled signal transformation. Based on the FDA space-time coupled signal modulation principle, it transformed the signal pulse resolution problem into a transmit spatial domain resolution problem, revealing the principles for inter-pulse signal resolution and separation, and establishing the theoretical basis for distinguishing targets from mainlobe repeated jamming in high-dimensional space. The project explored additional information in array inter-pulse coding, constructed the mathematical relationship between frequency diversity and inter-pulse coding for distinguishing the mainlobe repeated jamming in FDA, and analyzed the distribution differences between targets and interference in the transmit-receive-pulse dimensions. It pioneered the FDA transceiver joint processing method for mainlobe repeated jamming suppression, breaking through the global challenge in radar systems. The project's achievements were applied to an airborne radar system, demonstrating that "compared with traditional phased array adaptive anti-jamming techniques, the output signal-to-interference-plus-noise ratio performance improved by 20dB," compressing the enemy's effective interference range by a factor of 1/10.



FDA 收发联合高维处理与抗干扰抗杂波效果
FDA Joint Transmit-Receive Multi-Dimensional Processing and Anti-Jamming/Clutter Result

引领了 FDA 系统理论和雷达应用研究领域，受到广泛跟踪研究
Led the field of FDA system theory and radar application research, attracting extensive follow-up studies

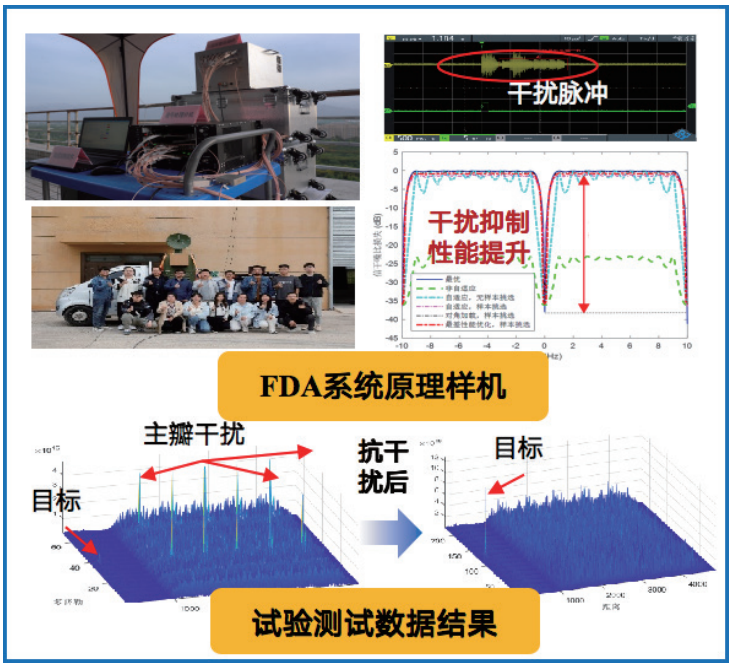
项目成果发表 FDA 参数解模糊和主瓣干扰抑制的国际首篇论文，是 FDA 领域经典论文，连续 8 年 WOS 论文引用量排序国际第一（如图所示）。成果获 IEEE 天线与传播协会 R. W. King Award 提名、IEEE 信号处理协会 Best Paper Award 提名。受到美国科学院院士 David J. Love 教授、英国皇家布朗奖获得者 Yeshaiahu Fainman 教授、以色列科学院院士 Yonina C. Eldar 教授、IEEE 成就奖获得者 Moeness G. Amin 教授、中国科学院黎湘院士、中国科学院王永良院士等 50 余位中科院院士、发达国家院士和 IEEE Fellow 正面评价，受到美国陆军研究实验室 (Anthony F. Martone)、俄罗斯国防研究院 (O. V. Ermolin)、以色列国防研究实验室（David Cohen）等机构的跟踪关注。第一完成人连续入选全球前 2% 顶尖科学家榜单，获中国教育部自然科学一等奖、陕西省自然科学一等奖等。

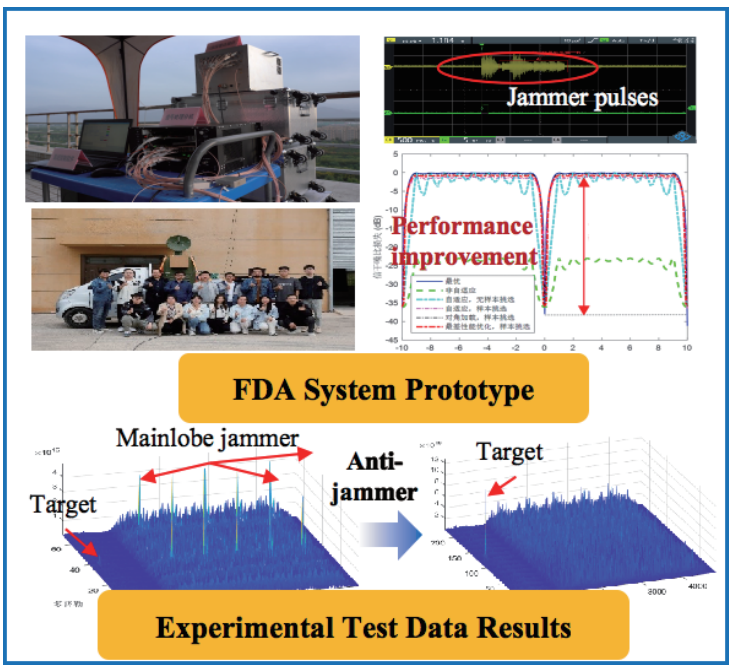
The project has published the first international paper on FDA parameter ambiguity resolution and main lobe interference suppression, which is a classic paper in the FDA field. It has been ranked first in the international WOS paper citation ranking for 8 consecutive years (as shown in the figure). The achievement has been nominated for the R.W. King Award by the IEEE Antenna and Propagation Society and the Best Paper Award by the IEEE Signal Processing Society. More than 50 academicians and IEEE Fellows, including Professor David J. Love (academician of the American Academy of Sciences), Professor Yeshaiahu Fainman (winner of the British Royal Brown Award), Professor YoninaC. Eldar (academician of the Israeli Academy of Sciences), Professor Moeness G. Amin (winner of the IEEE Achievement Award), Professor Li Xiang(academician of the Chinese Academy of Sciences), Professor Wang Yongliang (academician of the Chinese Academy of Sciences), have made positive comments on the papers. The relative papers haveattracted the attention from the United States Army Research Laboratory (Anthony F. Martone), the Russian National Defense Research Institute (O. V. Ermolin), the Israel National Defense Research Laboratory (David Cohen) and other institutions. The first author has been continuously selected as one of the top 2% scientists in the world, and has won the first prize of natural science of the Chinese Ministry of Education.

763 Publications	Sort by Citations: highest...	1 of 16	Citations					Citations					Average per year	Total
			Previous year				Next year	Previous year				Next year		
			2016	2017	2018	2019	2020	2021	2022	2023	2024	2025		
Total			428	567	1,080	1,076	1,471	1,716	2,465	2,107	2,304	1,505	695.73	15,306
1	Joint Range and Angle Estimation Using MIMO Radar With Frequency Diverse Array Xu, JW; Liao, GS; (...); So, HC Jul 1 2015 | IEEE TRANSACTIONS ON SIGNAL PROCESSING 63 (13) , pp.3396-3410		18	24	46	34	53	62	71	51	39	26	38.82	427
2	Frequency Diverse MIMO Techniques for Radar Sammartino, PF; Baker, CJ and Griffiths, HD Jan 2013 | IEEE TRANSACTIONS ON AEROSPACE AND ELECTRONIC SYSTEMS 49 (1) , pp.201-222		41	45	37	25	51	32	50	35	30	22	32	416
3	Transmit Subaperturing for Range and Angle Estimation in Frequency Diverse Array Radar Wang, WQ and So, HC Apr 2014 | IEEE TRANSACTIONS ON SIGNAL PROCESSING 62 (8) , pp.2000-2011		27	30	37	35	38	32	33	20	19	13	25.58	307
4	Frequency Diverse Array Radar With Logarithmically Increasing Frequency Offset Khan, W; Qureshi, IM and Saeed, S 2015 | IEEE ANTENNAS AND WIRELESS PROPAGATION LETTERS 14 , pp.499-502		19	18	35	42	46	40	40	25	24	16	27.82	306

WOS 引用量排序结果
WOS Citation Ranking

突破新体制 FDA 系统关键技术，研制原理样机
Break through the key technologies of the FDA system and develop principle prototypes





原理样机及试验测试数据效果
FDA System Prototype and Experimental Test Data Results

本项目研制了 FDA 雷达原理样机（如图所示），外场试验数据处理结果表明，与相控阵雷达相比，FDA 雷达对单个主瓣转发干扰的抑制性能提升显著。应用于某机载雷达系统，“在三个主瓣干扰源（干噪比为 30dB）的试验条件下，与传统相控阵自适应抗干扰技术相比，输出信干噪比性能提升 20dB，指标达到领先水平”，等效压缩敌方有效干扰距离 10 倍。应用于某天基告警系统，“在典型应用场景下，达到 120°×120° 宽角域波束瞬时覆盖，大大提升雷达广域凝视探测和连续跟踪性能”。

This project developed an FDA system prototype (as shown in the figure). Experimental test data processing results demonstrate that FDA radar exhibits significant performance improvement in suppressing mainlobe repeated jamming, compared with phased array radar. The project's achievements were applied to an airborne radar system, demonstrating that "under test conditions with three mainlobe jammers (JNR=30dB), the output SINR performance improved by 20dB compared to traditional phased array adaptive anti-jamming techniques", equivalently compressing the enemy's effective jamming range by a factor of 1/10. The project's achievements were applied to a space-based warning system, "in typical application scenarios, it achieves 120°×120° wide-angle beam coverage, enhancing the wide-area detection and continuous tracking performance."



世界互联网大会
领先科技奖收录成果

Collection of World Internet Conference
Awards for Pioneering Science and Technology

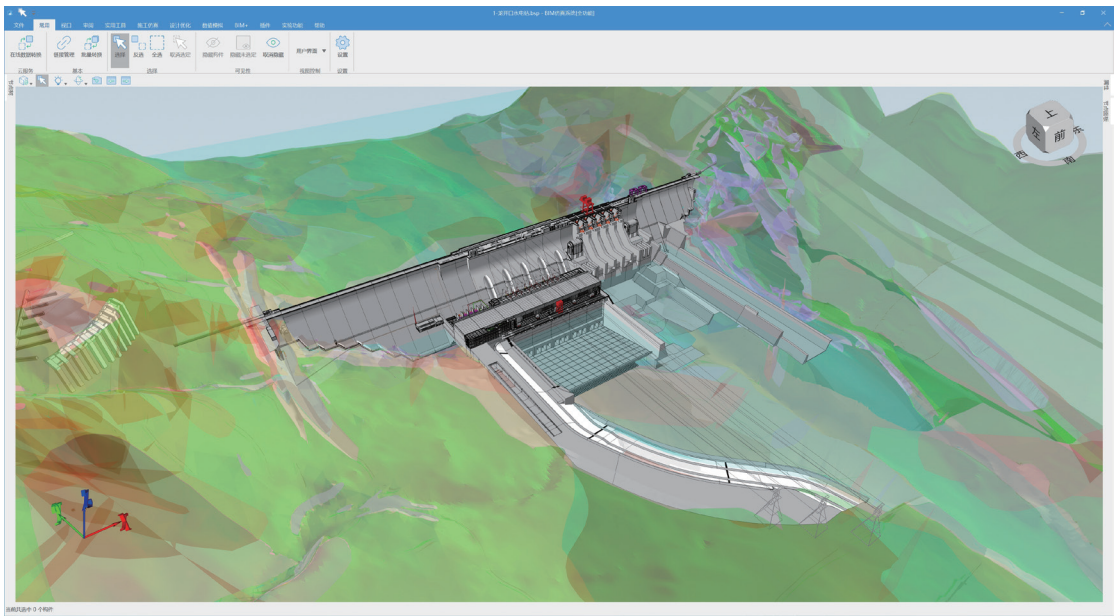


02

世界互联网大会
领先科技奖收录成果

Collection of World Internet Conference
Awards for Pioneering Science and Technology

关键技术组
Key Technology Group



BIM 仿真系统在水电工程三维数字化审查和模型交付中的应用
Application of CyberSim in 3D Digital Review and Model Delivery for Hydropower Projects

BIM 仿真系统
CyberSim

中国电建集团华东勘测设计研究院有限公司
POWERCHINA HUADONG ENGINEERING CORPORATION LIMITED

引言

BIM 仿真系统是中国电建华东院研发的一款面向全球基础设施工程领域的新一代 BIM 基础软件，适用于从单体到城市级项目全过程 BIM 应用。该系统已应用于多个世界级工程。技术出口全球多个国家，推动行业技术升级与产业链创新。

Introduction

CyberSim, developed by POWERCHINA HUADONG ENGINEERING CORPORATION LIMITED (HDEC), is a new-generation BIM software platform designed for global infrastructure engineering projects. It supports comprehensive BIM applications ranging from building-scale to city-scale projects throughout their entire lifecycle. It has been deployed in multiple world-class engineering projects and it has been exported to numerous countries, promoting technological advancement and innovation in the industry.

重构图形引擎基石，实现多维度数据高性能覆盖
Refactoring the Cornerstone of the Graphics Engine, Achieving High-Performance Coverage of Multi-Dimensional Data

系统攻克了大体量复杂模型实时渲染、多源异构模型融合应用、软硬件生态适配等关键技术瓶颈，获得授权发明专利 12 项，软件著作权登记 11 项，发表论文 16 篇，专著 1 部，标准 1 项。经院士专家组鉴定，成果整体达到国际先进水平，其中在 TB 级异构大体量模型实时渲染方面达到国际领先水平，其核心创新主要体现在：

CyberSim has overcome critical technical challenges such as real-time rendering of large-scale models, integration of model of different formats, and compatibility adaptation to multiple software and hardware ecosystems. It has been granted 12 patents, 11 software copyright registrations, and has contributed to 16 academic publications, 1 monograph, and 1 technical standard. An appraisal committee led by academicians has evaluated the achievement as internationally advanced in its overall technical merit, with its real-time rendering capability for terabyte-scale models of multiple formats recognized as leading globally. The core innovations of CyberSim are demonstrated in the following aspects:

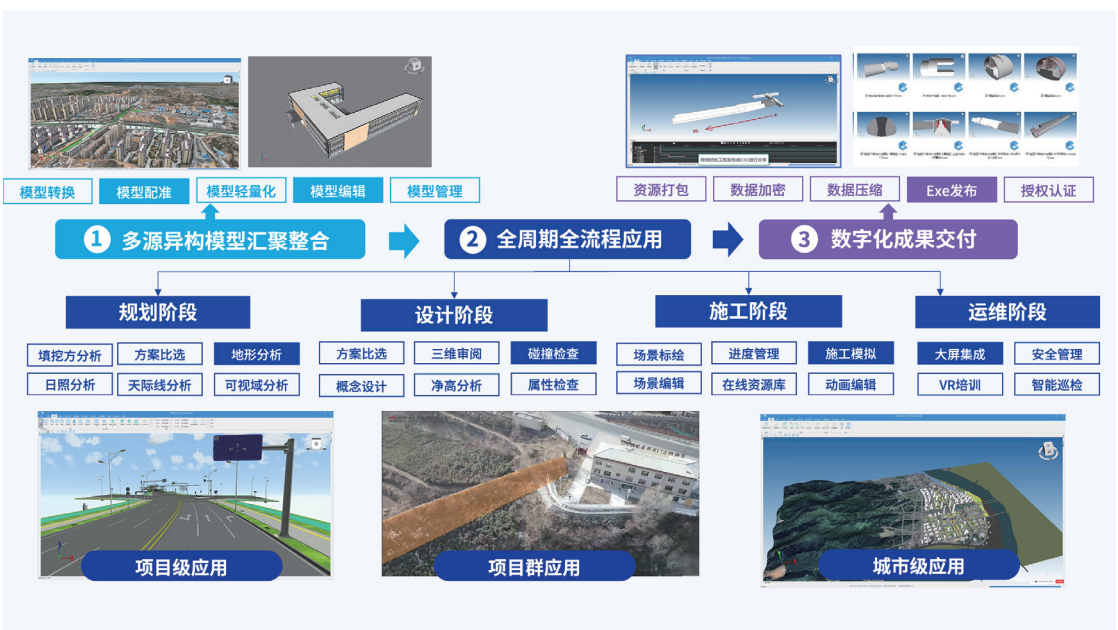
1、跨平台的 BIM 图形引擎：基于 OpenGL 开发了适用于复杂工程异构大体量模型实时渲染的图形引擎；提出了一种基于分页加载机制的多源异构模型数据存储格式并研制了 BIM 仿真基础平台，实现跨平台稳定运行。

1.Cross-Platform BIM Graphics Engine: Developed an OpenGL-based graphics engine capable of real-time rendering of large-scale, complex engineering models. Introduced an innovative multi-source model storage format utilizing a paged level of detail loading mechanism, and developed the CyberSim foundation platform that ensures compatibility and performance across diverse operating systems.

2、BIM 模型多源数据汇聚轻量化整合技术：开发了国际领先的 BIM 模型转换工具，实现了 TB 级数据的解析重构、快速加载、实时渲染与多源整合。

2.Lightweight Integration Technology for Multi-Source BIM Data: Developed an internationally leading BIM model conversion tool capable of parsing, reconstructing, rapidly loading, and real-time rendering of terabyte-scale data. This enables efficient integration of multi-source models while maintaining high performance and visual fidelity.

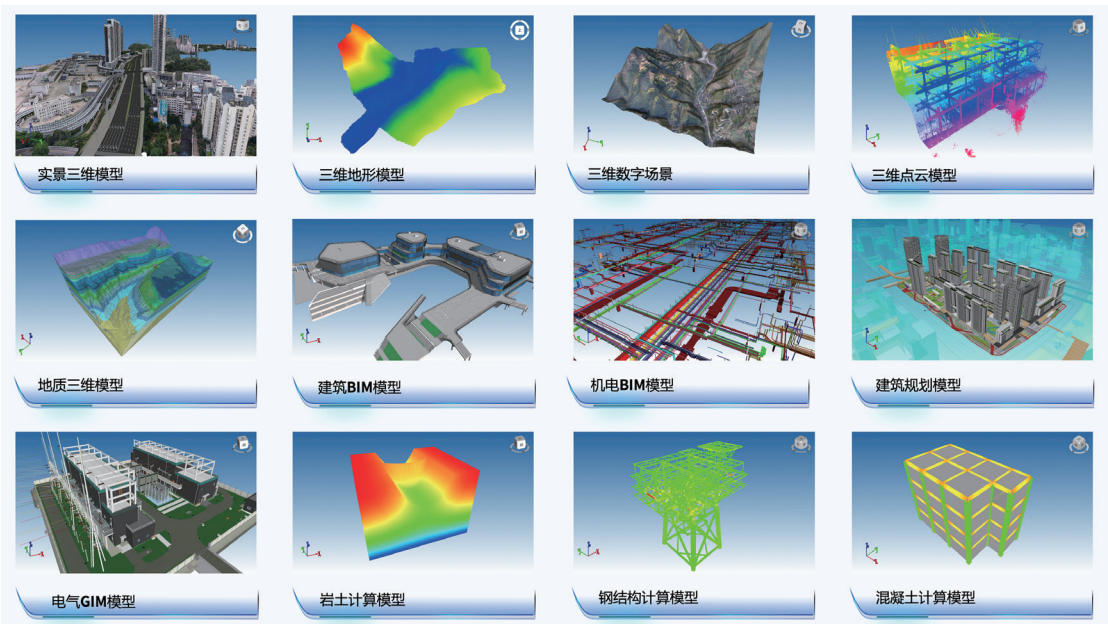
3、一体化 BIM 仿真平台：构建了贯穿规划、设计、施工的工程



BIM 仿真系统应用图谱
CyberSim Applications Diagram

数字化应用体系，大幅提升大型项目应用效率。形成一套完备的工程数字化应用体系，实现城市级、流域级、工程级项目应用效率提升。

3.Integrated BIM Simulation Platform: Established a comprehensive digital engineering application system that spans planning, design, and construction phases, significantly enhancing efficiency in large-scale project execution. The platform provides a complete suite of digital engineering solutions, delivering substantial improvements in operational efficiency for different infrastructure projects.



多源异构模型汇聚整合
Integration of Multi-Source Models and Data

产学研深度融合结硕果，实现经济与社会双向赋能
Deep Industry-Academia-Research Collaboration Drives Tangible Outcomes, Achieving Dual Empowerment of the Economy and Society

BIM 仿真系统已成功应用于沙坪一级水电站、永嘉抽水蓄能项目等一百多个重大基础设施项目。其服务对象包括河北省水利水电勘测设计研究院、中国水电七局、中铁水利水电等多家企业，实现了成果的有效转化和市场化推广。

CyberSim has been successfully implemented in over 100 major infrastructure projects, including the ShaPing Level I Hydropower Station and the YongJia Pumped Storage Power Plant. It serves a wide range of clients such as the Hebei Provincial Water Resources and Hydropower Survey and Design Institute, PowerChina Sinohydro Bureau 7 Co., Ltd., and China Railway Water Conservancy & Hydropower Planning and Design Group, achieving effective transformation and market-oriented promotion of the research outcomes.

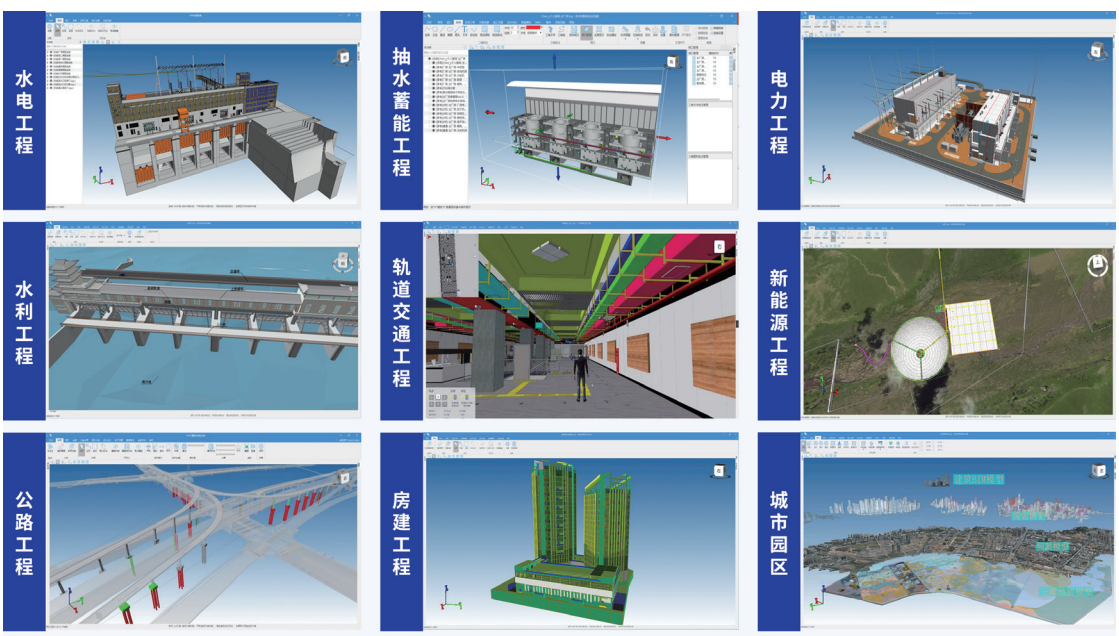
经济效益方面：该系统产生了显著的经济价值。2022 至 2024 年间，其应用直接带动勘察设计施工产业链增值超 7.5 亿元，助力企业数字化业务年增长 20%，并通过节省外部采购与人力成本，近两年累计节约 2500 万元。

Economic Impact: CyberSim has generated substantial economic value, delivering significant benefits across project lifecycles. From 2022 to 2024, its application directly contributed to an added value of over RMB 750 million throughout the survey-design-construction industry chain. It also supported an annual growth rate of 20% in digital business revenue for HDEC. Furthermore, by reducing exter-

nal procurement and labor costs, CyberSim achieved cumulative savings of RMB 25 million during this period.

社会效益方面：该系统成功攻克了三维图形引擎等关键技术，打破了行业技术壁垒，保障了工程数据安全。同时，其为重大工程的 BIM 应用替代提供了可靠方案，极大地推动了基础设施行业的数字化转型进程，并通过校企合作反哺教育，为人才培养做出了贡献。

Broader Societal Impact: CyberSim has successfully conquered key technological challenges, such as the development of an advanced 3D graphics engine, effectively lowering barriers to entry within the industry and enhancing the security of engineering data. It provides a reliable solution for adopting BIM in major infrastructure projects, significantly accelerating the digital transformation of the sector. Furthermore, through partnerships with academic institutions, CyberSim will contribute to education and talent cultivation.



工程项目应用
Application of Engineering Projects

大量工程复杂环境严格验证，推动全球工程数字化技术进步与转型升级
Rigorously Validated in Large-Scale Complex Engineering Environments, Advancing Global Digital Engineering Progress and Transformation

在技术进步上：系统成功攻克了 TB 级异构模型实时渲染、多源数据整合等关键难题，研发成果支撑了 2 项国家重大科研专项，核心技术已成功应用于多个重大复杂工程项目，建立了完善的数据标准体系，促进了工程软件技术的整体提升与创新发展。

Technological Advancements: CyberSim has successfully overcome critical challenges such as real-time rendering of terabyte-scale models and multi-source data integration. These technological breakthroughs have supported two major national research initiatives

and have been deployed in multiple large-scale, complex engineering projects. Furthermore, the platform has established a comprehensive data standard framework, contributing to the overall advancement and innovation of engineering software technology.

在产业结构上：通过开放 SDK、提供插件工具和示范应用，吸引中国电建、中国铁建、广联达等央企和民企共建 BIM 生态。联合浙大、西南交大等高校突破轻量化引擎与多源数据融合关键技术，与浙水院共建数字化人才培养平台，形成“需求 - 技术 - 工程 - 产业”创新链。依托中央企业 BIM 软件创新联合体，整合行业资源，深化底层基础、拓展上层应用，推动共性技术研发与领域拓展。

Industrial Structure: CyberSim has fostered a collaborative BIM ecosystem by opening up SDKs, providing plugin tools and demonstration applications, engaging both state-owned and private enterprises—including PowerChina, China Railway Construction Corporation, and Glodon—in joint development. In partnership with leading academic institutions such as Zhejiang University and Southwest Jiaotong University, it has advanced key technologies in lightweight model engines and multi-source data integration. Collaborative initiatives, like the digital talent development platform established with Zhejiang University of Water Resources and Electric Power, have helped form an innovation chain connecting “market demand – technology development – engineering application – industrial growth”. Furthermore, through the Central Enterprise BIM Software Innovation Consortium, the platform facilitates integration of industry resources, strengthens foundational technologies, expands application scenarios, and promotes the development and adoption of technologies.

标杆案例示范：该成果先后在白鹤滩水电站、平陆运河等重大工程中进行试点应用，赋能大型基础设施的智能化转型。

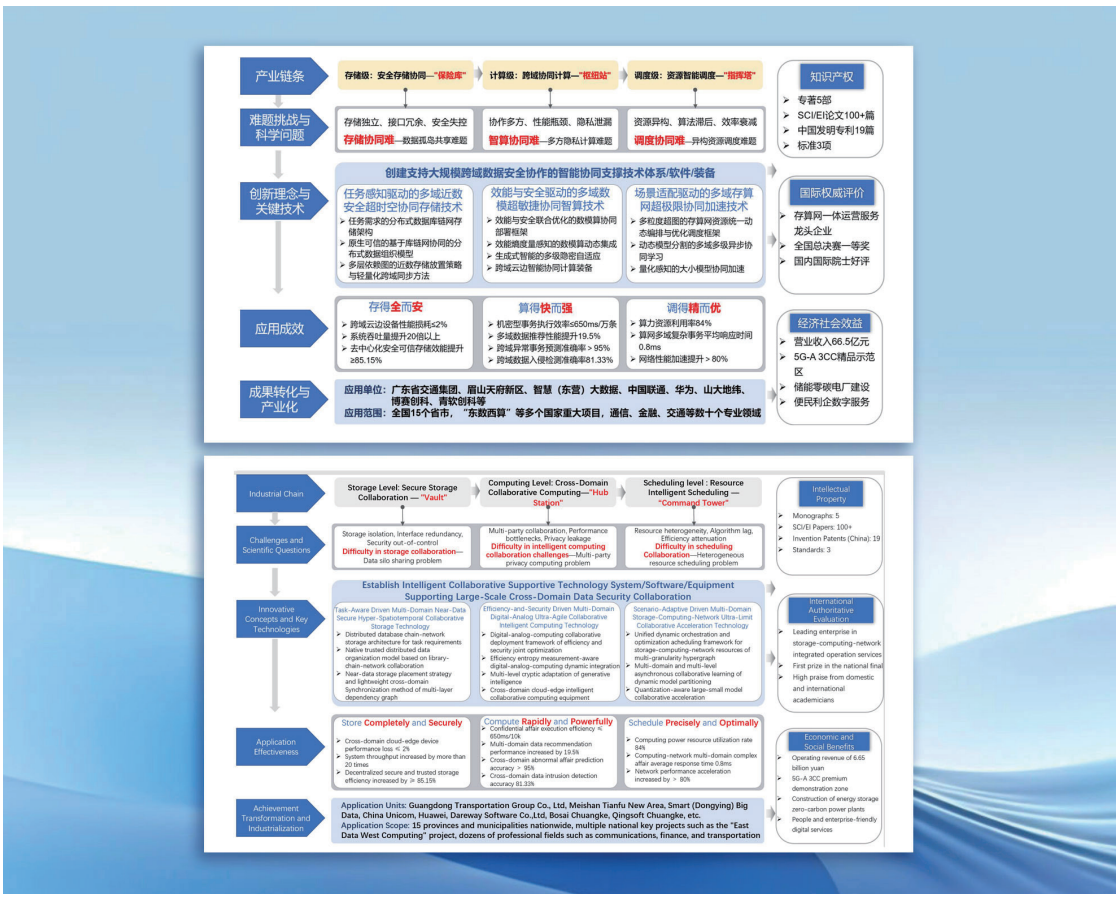
Benchmark Case Applications: The achievements have been piloted and implemented in multiple landmark strategic projects, including the Baihetan Hydropower Station and the Pinglu Canal. These applications demonstrate the platform's capability to enable intelligent transformation of large-scale infrastructure.



数字化解决方案
Cooperation and Promotion



品牌价值
Awards and Achievements



技术整体研究框图
The overall research framework of the technology

多域数据安全的云边存算网智能装备关键技术及应用

Key Technologies and Applications of Cloud-Edge Storage-Computing-Network Intelligent Equipment for Multi-Domain Data Security

山东大学
Shandong University

浪潮通信信息系统有限公司
Inspur Communication Information System Co., Ltd.

浪潮（山东）计算机科技有限公司
Inspur (Shandong) Computer Technology Co., Ltd.

三未信安科技股份有限公司
Sansec Technology Co., Ltd.

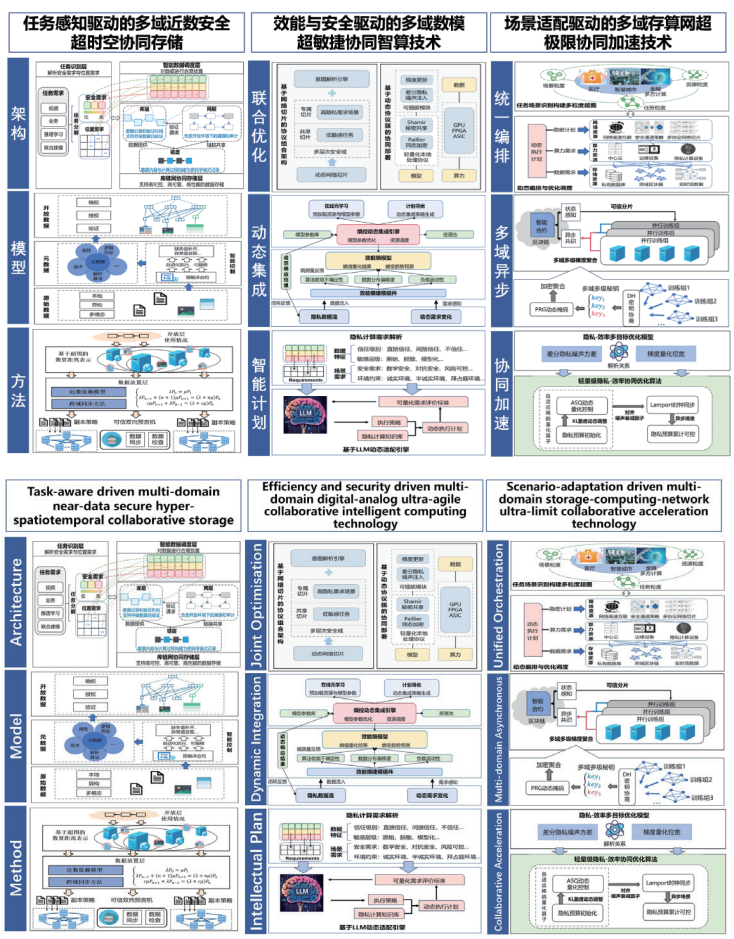
引言

项目面向跨地理 / 管理 / 信任域的数据治理多维安全挑战，构建“存—算—调”三位一体云边智能协同技术体系，研制形成云边存算网一体系列智能装备、服务器和支撑软件系统，在数据安全治理、跨域协同计算领域取得突破。

Introduction

Facing the multi-dimensional security challenges of data governance across geographic, management and trust domains, the project has established a "storage-computing-scheduling" trinity cloud-edge intelligent collaborative technology system, and developed a series of integrated cloud-edge storage-computing-network intelligent devices, servers and supporting software systems, achieving breakthroughs in the fields of data security governance and cross-domain collaborative computing.

“协同存储—协同计算—协同运作”三位一体
Trinity of "Collaborative Storage - Collaborative Computing - Collaborative Operation"



项目主要创新点
Key innovations of the project

跨域数据流通日益广泛，多域数据安全成为战略科技重点。当前的存算网基础设施在保障高效协同与安全可控层面存在显著瓶颈。AI 赋能存算网智能协同急需破解“三难困境”：以任务为中心的多域数据安全存储协同难；平衡效能与安全的多域数据智算协同难；多场景业务敏捷适配的存算网资源调度协同难。项目立足于多域数据安全治理与分析的实际应用需求，设计了任务感知驱动的多域近数安全超时空协同存储架构，提出了效能与安全驱动的多域数模超敏捷协同智算策略，研发了场景适配驱动的多域存算网超极限协同加速方法。创新性成果获山东省科技进步一等奖、中国产学研合作促进会创新成果奖一等奖、教育部高校科学技术奖二等奖等中国多个省部级奖励，获多个国际学术会议最佳论文奖。相关工作得到了包括加拿大工程院院士、欧洲科学院院士、IEEE/ACM/AAAI Fellow 等诸多国际知名学者的高度评价。

Cross-domain data circulation is becoming increasingly widespread, making multi-domain data security a key focus in strategic science and technology. However, current storage-computing-network infrastructure faces significant bottlenecks in ensuring efficient collaboration and secure controllability. AI-enabled storage-comput-

ing-network intelligent coordination urgently needs to overcome the 'three dilemmas': the difficulty of task-centric multi-domain data security storage coordination; the difficulty of balancing efficiency and security of multi-domain data intelligent computing coordination; the difficulty of storage-computing-network resource scheduling coordination for multi-scenario business agile adaptation. Based on the practical application needs of multi-domain data security governance and analysis, the project has designed a task-aware driven multi-domain near-data secure hyper-spatiotemporal collaborative storage architecture, proposed an efficiency and security driven multi-domain digital-analog ultra-agile collaborative intelligent computing strategy, and developed a scenario-adaptation driven multi-domain storage-computing-network ultra-limit collaborative acceleration method. These innovative achievements have been honored with the First Prize of Shandong Provincial Science and Technology Progress Award, the First Prize of Innovation Achievement Award from China Industry-University-Research Institute Collaboration Association, the Second Prize of the Ministry of Education Higher Institution Science and Technology Award, and multiple provincial and ministerial awards in China, as well as many Best Paper Awards at international academic conferences. The related work has been highly praised by many internationally renowned scholars, including Fellows of the Canadian Academy of Engineering, Fellows of the European Academy of Sciences, and IEEE/ACM/AAAI Fellows.



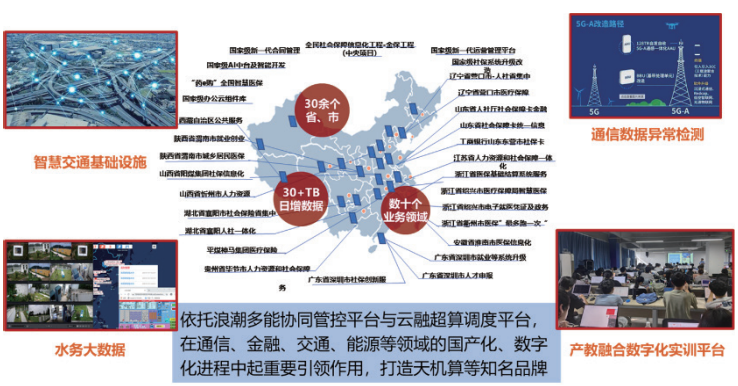
项目创新成果
Innovative achievements of the project

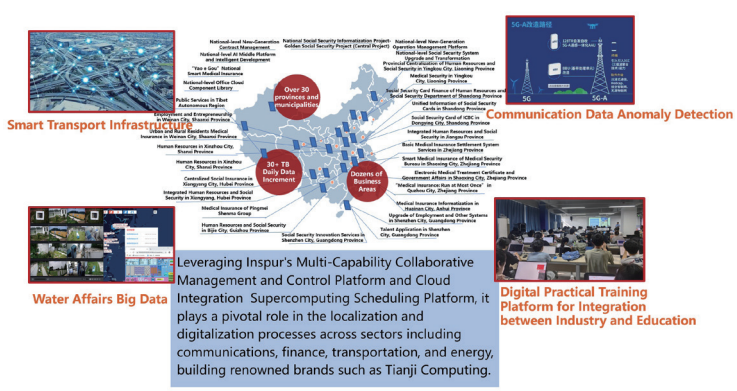
规模化应用助力重大工程与产业化
Scaled application facilitates major projects and industrialization

本成果实现了异构存算网资源的无缝接入与统一调度，构建了多方参与的数据可信协同服务和安全底座，支撑了数模算任务的融合服务，成功完成产业化应用。在广东、四川等 10 余省通信、交通等领域形成规模化落地，部署超 3 万套，提供规建营维全栈解决方案，支撑了“东数西算”、智慧城市云脑等中国重大工程实施，助力浪潮通信打造天机算等知名品牌，通过向客户提供运营支撑服务、算力基础设施规建维优、政企数智化一系列产品与服务，累计直接经济效益超 60 亿元。面向济南联通、济南西站、东营算力中心等各行业领域提供定制化、全站式算力服务，在改善通信、金融、政务等领域的运转效率和质量、提升群众满意度和获得感等方面获得了显著的社会效益。

This achievement has realized the seamless access and unified scheduling of heterogeneous storage-computing-network resources, established data-trusted collaborative services and security foundation with multi-party participation, and supported integrated services for data and model computation tasks, achieving successful industrial application.

It has achieved large-scale implementation in fields including communications and transportation across over 10 provinces such as Guangdong and Sichuan, with the deployment of more than 30,000 sets of equipment. The project provides full-stack solutions spanning planning, construction, operation, and maintenance, and has supported the implementation of China’s major national initiatives including the "East Data West Computing" project and smart city cloud brains. It has also assisted Inspur Communications in building renowned brands such as Tianji Compute. By offering operational support services, planning-construction-maintenance-optimization of computing infrastructure, and a range of digital-intelligent products and services for government and enterprise, the project has generated cumulative direct economic benefits exceeding RMB 6 billion. It provides customized and full-service computing power services to various industries and fields such as Jinan Unicom, Jinan West Railway Station, and Dongying Computing Power Center. It has achieved significant social benefits, including improving the operational efficiency and quality in fields like communications, finance, and government services, as well as enhancing public satisfaction and sense of gain.





项目应用推广情况

Application and promotion of the project



项目支撑规建营维、政企数智化产品服务
The project supports planning-construction-operation-maintenance and digital-intelligent products and services for government and enterprise

推动存算网一体服务新业态与产业升级
Driving new business formats of storage-computing-network integrated services and industrial upgrading



自研技术标准体系
Independent technical standard system

本成果在数据安全治理与跨域协同计算领域实现了推动技术进步的突破性创新：破解跨域数据安全核心难题，填补动态任务适配与可信存储协同的技术空白；重构多域安全的存算网融合架构，将跨域数据处理延迟压缩至毫秒级；研发支持多域数据安全的存算网智能协同装备和支撑软件，建立自主技术标准体系，授权发明专利 19 项，软著 20 项，牵头制定行业标准 3 项，出版教材 3 部、专著 3 部。本成果催生“存算网一体”服务新业态，驱动产业结构优化与升级：带动算力服务产业链升级，支撑成员单位成为全球存算网一体运营服务商前列；为跨区域算力调度提供安全技术保障，赋能“东数西算”等中国重大工程；带动传统行业数字化升级，降低多域数据管理成本 30% 以上；拓展新兴应用场景，支撑工

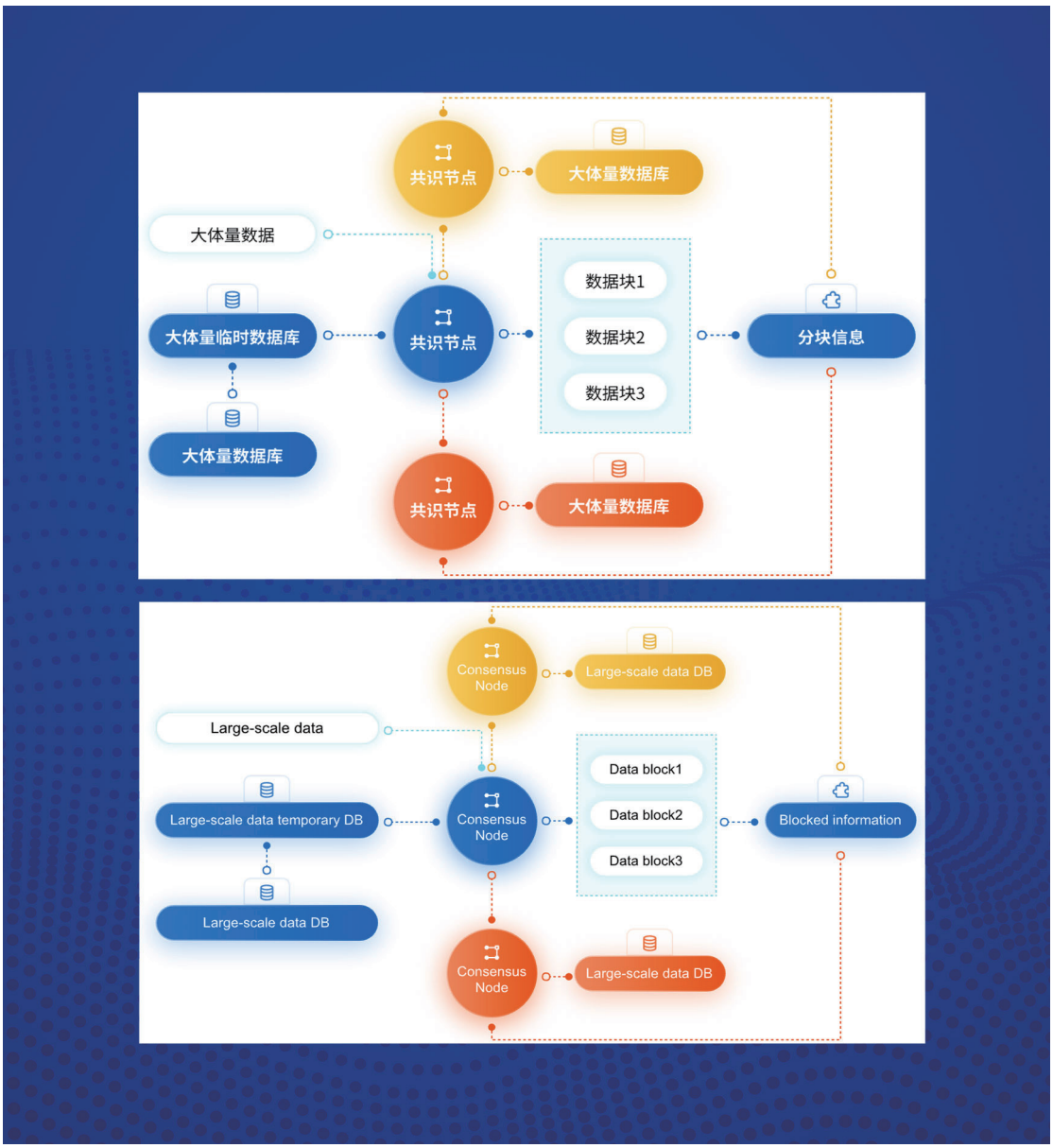
业互联网、自动驾驶等复杂场景落地。

This achievement represents a groundbreaking innovation that advances technological progress in the fields of data security governance and cross-domain collaborative computing. It addresses core challenges in cross-domain data security, filling technical gaps in dynamic task adaptation and trusted storage collaboration. The project reconstructs a multi-domain secure storage-computing-network integrated architecture, reducing cross-domain data processing latency to millisecond levels. It has developed intelligent collaborative equipment and supporting software for multi-domain data security, establishing an independent technical standard system. These efforts have resulted in 19 authorized invention patents, 20 software copyrights, 3 leading industry standards, and the publication of 3 textbooks and 3 monographs. The outcomes have catalyzed new business models in "storage-computing-network integrated" services, driving industrial structure optimization and upgrading. They have facilitated the upgrade of the computing service industry chain, supporting member organizations in becoming leading global operators of integrated storage-computing-network services. The project provides critical security assurance for cross-regional computing power scheduling, enabling the implementation of China's major national projects such as the East-Data-West-Computing Project. It also promotes digital transformation in traditional industries, reducing multi-domain data management costs by over 30%, while expanding emerging application scenarios such as industrial internet and autonomous driving, supporting their deployment in complex environments.



存算网一体服务赋能产业结构升级

Storage-computing-network integrated services enabling industrial structure upgrading



分布式可信数据协同存储技术原理示意图
Schematic Diagram of the Principle of Distributed Trusted Data Collaborative Storage Technology

分布式可信数据协同存储技术
Distributed Trusted Data Collaborative Storage Technology

联通数据智能有限公司
China Unicom Data Intelligence Co., Ltd.

引言

区块链是分布式网络、加密技术等集成的新型数据库软件。中国联通深耕其研发应用，自主研发底层平台，首创分布式可信数据协同存储技术，破解大体量数据上链难题，性能行业领先。

Introduction

Blockchain is a new type of database software integrated with distributed networks, encryption technologies, and other components. China Unicom has deeply engaged in its R&D and application, independently developed an underlying platform, pioneered the Distributed Trusted Data Collaborative Storage Technology, solved the challenge of onboarding large-scale data onto the blockchain, and achieved industry-leading performance.

首创行业领先的分布式可信数据协同存储技术
Pioneered the industry-leading Distributed Trusted Data Collaborative Storage Technology

中国联通行业首创分布式可信数据协同存储技术精准攻克三大核心技术难题：一是大体量数据上链效率低，二是节点存储资源适配难，三是高存储成本制约数据密集型领域推广。技术创新上，其将纠删码与区块链共识技术融合，以极小存储代价实现 100MB 以上文件快速上链，为 Web3.0 可信数据库筑基；原创区块数据调度算法让系统存储消耗降 25%+，适配不同资源节点；存储优化较 Hyperledger Fabric 降耗 90%+，适配大数据、物联网场景，还构建分布式授权与 CA 体系，底链 CTPS 破 10 万次且秒级确认。

China Unicom has pioneered the industry's first Distributed Trusted Data Collaborative Storage Technology, which precisely addresses three core technical challenges: 1) low efficiency in onboarding large-scale data onto the blockchain; 2) difficulty in adapting node storage resources; and 3) high storage costs restricting the promotion of data-intensive fields.
In terms of technological innovation, the technology integrates erasure coding with blockchain consensus technology, enabling fast on-chain upload of files over 100MB at minimal storage cost and laying the foundation for Web3.0 trusted databases. Its original block data scheduling algorithm reduces system storage consumption by more than 25% while adapting to nodes with diverse resources. Compared with Hyperledger Fabric, it achieves over 90% reduction in storage costs, making it suitable for big data and IoT scenarios. Additionally, it builds a distributed authorization and CA (Certificate Authority) system, enabling the underlying blockchain to achieve over 100,000 CTPS (Chain Transactions Per Second) with second-level confirmation.

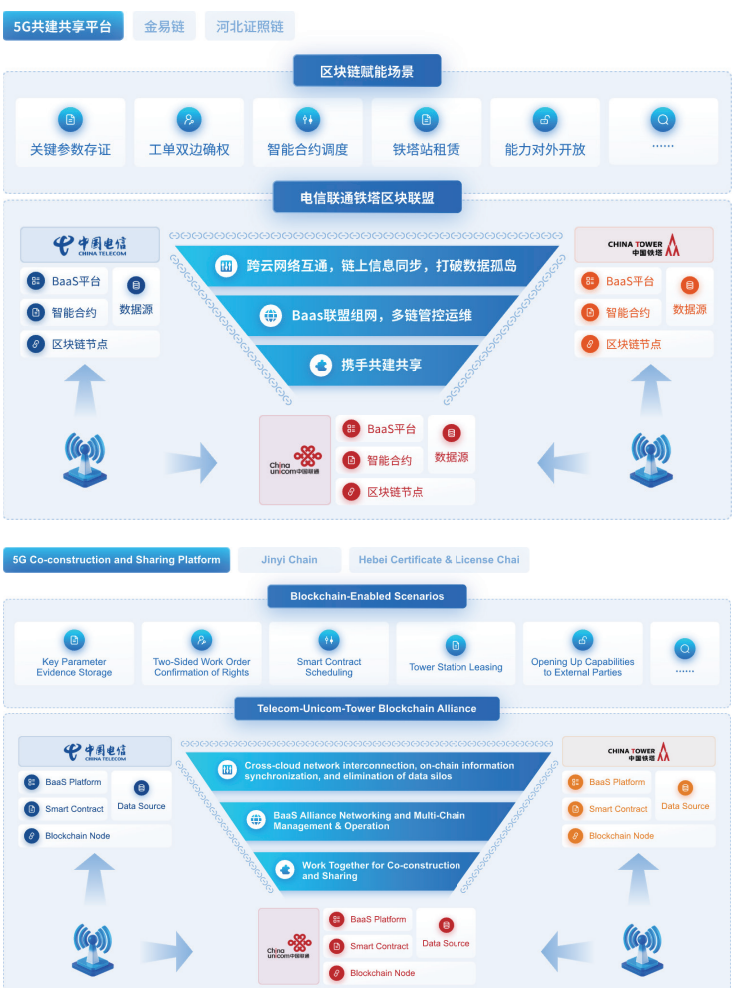


采用多种创新技术破解区块链数据存储难题，提升系统性能
Multiple innovative technologies are adopted to solve the data storage challenges of blockchain and enhance system performance

赋能联通区块链平台，已广泛应用于多个领域
The Distributed Trusted Data Collaborative Storage Technology has been widely applied across multiple fields

联通区块链平台依托分布式可信数据协同存储技术，已落地数字政府、产业金融等领域。经济效益上，2022 年 6 月以来促进大数据收入增长 1.78 亿元，累计市场化收入 2.36 亿元，支撑超万亿行业业务；赋能供应链工单拦截效率升 35%，可信交易破百亿，开标报价 100% 合规。

社会效益方面，承担 2 项中国科技部重点专项，支撑 4 项中国区块链试点验收。标杆案例亮眼：5G 共建共享平台经百万基站上链考验获中国国家级奖项，“金易链” 接入 20 家成员、日查 3000 笔（中国首个“隐私计算 + 区块链 + 数据要素流转” 案例），还实现河北 700 种证照核验、武汉近亿补贴发放等。



分布式可信数据协同存储技术已应用于 5G 共建共享、金易链等领域
The Distributed Trusted Data Collaborative Storage Technology has been applied in fields such as 5G co-construction and sharing, and Jinyi Chain

Relying on the Distributed Trusted Data Collaborative Storage Technology, China Unicom's Blockchain Platform has been implemented in fields such as digital government and industrial finance.

In terms of economic benefits, since June 2022, it has driven an increase of 178 million yuan in big data revenue, with a cumulative market-oriented revenue of 236 million yuan, supporting industrial businesses worth over 1 trillion yuan. It has enhanced the efficiency of supply chain work order interception by 35%, enabled trusted transactions exceeding 10 billion yuan, and achieved 100% compliance in bid opening and quotation.

In terms of social benefits, the platform has undertaken 2 key special projects of China's Ministry of Science and Technology and supported the acceptance of 4 blockchain pilot projects in China. Its benchmark cases are remarkable: the 5G Co-construction and Sharing Platform won a national-level award in China after withstanding the test of onboarding data from millions of base stations; "Jinyi Chain" has connected 20 members and handles 3,000 daily inquiries (as China's first case integrating "privacy computing + blockchain + data element circulation"); in addition, it has realized the verification of 700 types of certificates and licenses in Hebei Province, and the distribution of nearly 100 million yuan in subsidies in Wuhan.

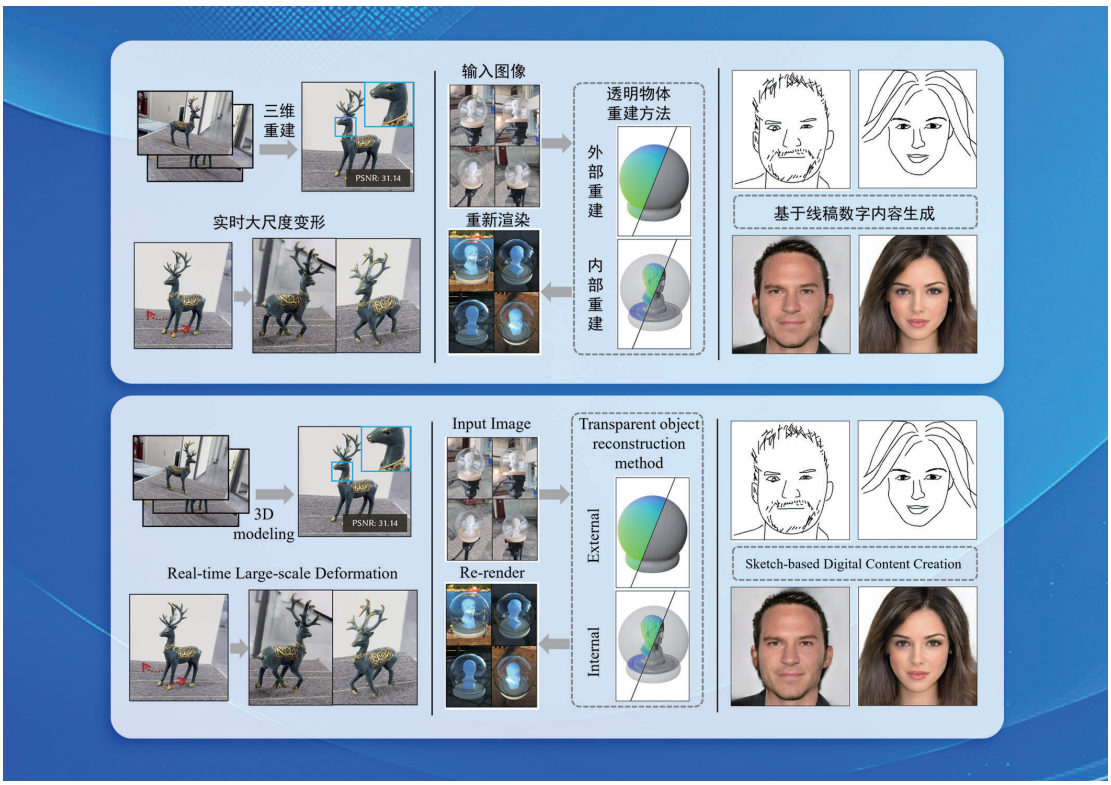
牵头国际标准，推动技术进步与产业升级
Take the lead in international standards to advance technological progress and industrial upgrading

该成果对技术进步与产业结构优化升级影响显著：技术进步上，牵头“ITU-T X.mbaas-cs-sec，多区块链服务平台协作服务的安全需求与框架”国际标准项目及参与 IEEE 可信标准，为行业提供技术规范；首创分布式可信数据协同存储技术，获得开源大赛一等奖，推动技术共享。产业结构上，结合云网打造智链协同云基础设施，支撑跨领域资源联动；5G 共建共享平台获 Gartner 奖成行业标杆，带动通信业高效共建，助力产业向协同化、高安全化升级，推动数字基础设施与实体经济深度融合。

This achievement has exerted a significant impact on technological progress and the optimization and upgrading of industrial structure:
In terms of technological progress, it has taken the lead in the international standard project "ITU-T X.mbaas-cs-sec, Security Requirements and Framework for Collaborative Services of Multi-Blockchain Service Platforms" and participated in IEEE trusted standards, providing technical specifications for the industry. It has pioneered the Distributed Trusted Data Collaborative Storage Technology, won the first prize in an open-source competition, and promoted technology sharing.
In terms of industrial structure, it has built an intelligent chain collaborative cloud infrastructure by integrating cloud and network capabilities, supporting cross-domain resource linkage. Its 5G Co-construction and Sharing Platform has won the Gartner Award and become an industry benchmark, driving efficient co-construction in the communications industry, helping the industry upgrade toward collaboration and high security, and promoting the in-depth integration of digital infrastructure and the real economy.



联通区块链平台依托分布式可信数据协同存储技术已取得的各项成果
Achievements Attained by China Unicom's Blockchain Platform Relying on the Distributed Trusted Data Collaborative Storage Technology



可视媒体合成结果展示
The Results of Controllable Visual Media Synthesis

高可控高效可视媒体合成方法研究与应用

Highly Controllable and Efficient Visual Media Synthesis Method Research and Application

中国科学院计算技术研究所
Institute of Computing Technology, Chinese Academy of Sciences

引言

成果围绕智能化数字内容创作展开并提出多项创新技术，包括大尺度变形及理解的几何建模分析方法、复杂拓扑精细纹理的三维重建方法、低成本高效高可控的高真实感数字内容生成方法，相关成果被广泛应用并受到高度关注。

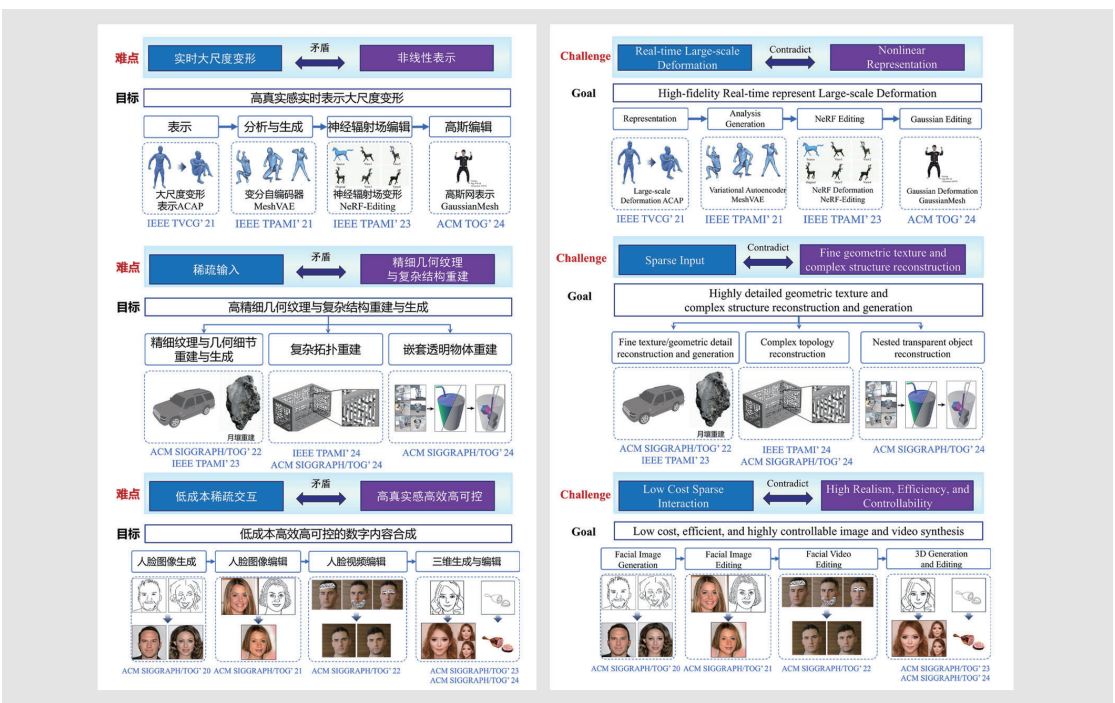
Introduction

The achievements focus on intelligent digital content creation and introduce several innovative technologies, including geometric modeling and analysis methods for large-scale deformation and understanding, 3D reconstruction techniques for complex topologies with fine textures, and low-cost, efficient, and highly controllable approaches for generating high-fidelity digital content. These results have been widely applied and attracted significant attention.

突破三维表示及建模瓶颈，实现高质量可控生成
Breaking Through the Bottlenecks of 3D Representation and Modeling for High-Quality Controllable Generation

本成果解决了三维数字内容生成中大尺度变形建模易扭曲、几何细节与拓扑结构合成质量低、生成过程控制精度不足三大技术难题。创新提出优化空间变形的连续性的 ACAP 大尺度变形表征方法，解决变形梯度歧义性问题，并被拓展应用于高斯泼溅与神经辐射场建模；创新提出 NeUDF 复杂拓扑重建框架与 NU-NeRF 透明物体重建方法，实现复杂拓扑结构的精确表达并将透明物体重建精度提升 10 倍；创新提出基于线稿的生成控制技术，通过流形投影与无监督解耦方法实现像素级精确控制，解决多模态生成中的纹理与时序一致性问题。系列成果连续 6 年发表于 ACM SIGGRAPH，3 次入选大会亮点视频，并被选为 ACM TOG 期刊封面，被国际同行广泛应用于人脸、人体、物体和场景的建模及生成等领域。

This project addresses three core challenges in 3D digital content generation: distortions in large-scale deformation modeling, low-quality synthesis of geometric details and topological structures, and insufficient control accuracy in the generative process. We innovatively propose the ACAP large-scale deformation representation method, which optimizes spatial deformation continuity and resolves the ambiguity of deformation gradients. It is further extended to Gaussian Splatting (3DGS) and Neural Radiance Field (NeRF) modeling. Moreover, we introduce the NeUDF framework for complex topology reconstruction and the NU-NeRF method for transparent object reconstruction, which enables accurate representation of complex topologies and improves reconstruction accuracy of transparent objects by tenfold. Furthermore, we propose a sketch-based generation control technique, which achieves pixel-level precision through manifold projection and unsupervised disentanglement, addressing texture and temporal consistency issues in multimodal generation. This series of works has been continuously published at ACM SIGGRAPH for six consecutive years, selected three times in the SIGGRAPH Video Trailer, and selected as a cover article of ACM TOG. The above works have been widely applied by international peers to face, body, object, and scene modeling and generation.



大尺度变形、精细化重建、高效高可控数字内容合成解决方案
Large-scale Deformation, Detailed Reconstruction, Highly Efficient and Controllable Digital Content Synthesis Approach

可视媒体合成方法的落地应用
Real-World Applications of Controllable Visual Media Synthesis

本成果通过实时变形表征、复杂拓扑重建、线稿精准控制等核心技术，在科学探测、医疗健康及数字人产业进行落地应用。相关工作与中科院地质与地球物理研究所合作，成功应用于中科院月壤颗粒精细建模，获新华社等 250 家媒体报道，浏览量超 300 万次。与阿里巴巴公司开源 3D-FRONT 场景数据集和 3D-FUTURE 几何纹理模型数据集，获得了 CCF CAD&CG 图形开源数据集奖。几何对称分析方法 PRS-NET 在北京大学口腔医院数字化中心应用，用于自动检测颅颌面的对称平面。基于线稿控制技术所开发的在线系统被国际用户广泛使用，并获得了 CCF CAD&CG 优秀图形开源软件奖。开发了高真实感播报数字人和实时交互对话数字人，并在爱尔眼科集团落地应用，合作发布“爱科”视频数字人。

The key technologies, such as real-time deformation representation, complex topology reconstruction, and precise sketch-based control, have been successfully applied across scientific exploration, healthcare, and the digital human industry. In collaboration with the Institute of Geology and Geophysics, Chinese Academy of Sciences, it was applied to fine-grained modeling of lunar soil particles, reported by Xinhua News Agency and over 250 media outlets, with more than 3 million views. Together with Alibaba, we released the 3D-FRONT scene dataset and the 3D-FUTURE geometry-texture dataset, awarded the CCF CAD&CG Graphics Open Data Award. The PRS-NET symmetry analysis method has been deployed at the Digital Center of Peking University School and Hospital of Stomatology for automatic detection of craniofacial symmetry planes. An online sketch-based generation system has been widely adopted by international users and awarded the CCF CAD&CG Outstanding Graphics Open-Source Software Award. Furthermore, we developed photorealistic news anchor digital humans and real-time interactive conversational digital humans, which have been deployed at AIER Eye Hospital Group, including the release of the “AiKe” digital human broadcaster.



可视媒体合成方法的应用于月壤重建和数字人系统，并获得多项奖励
The visual media synthesis methods have been applied in lunar soil reconstruction and digital human systems, and won multiple awards

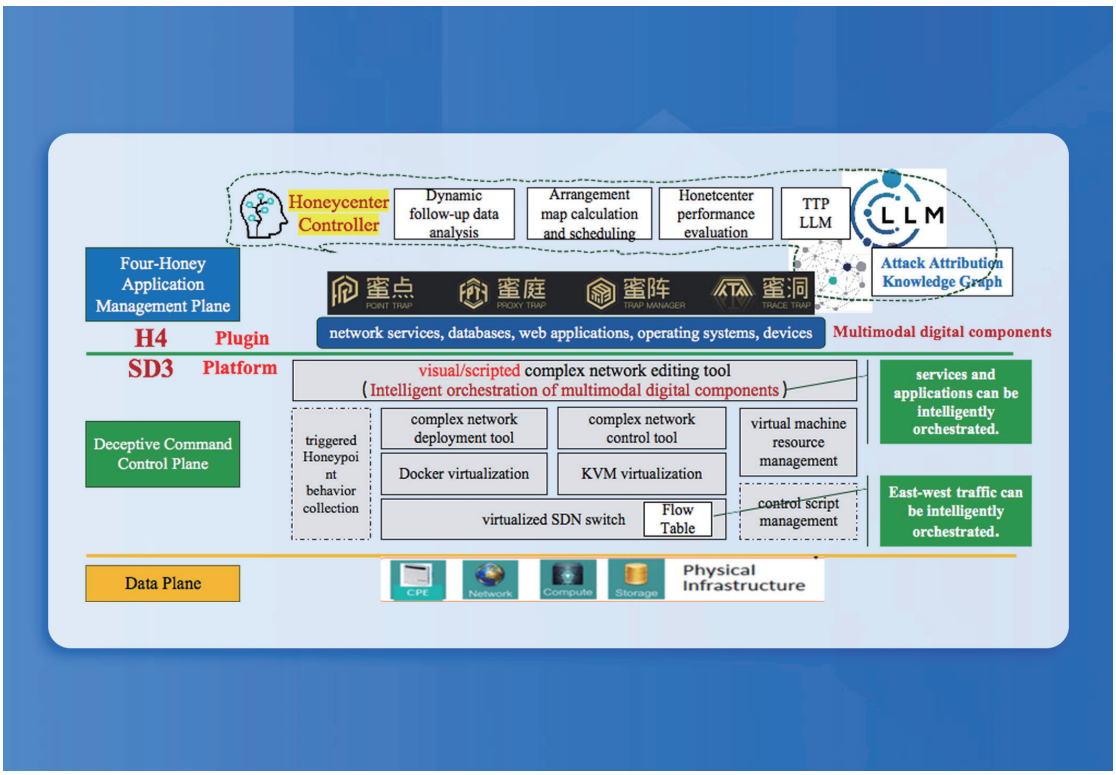
智能媒体生成技术产生广泛影响
Broad Impact of Intelligent Media Generation Technologies

本成果提出多项智能数字内容生成技术，在计算机图形学与人工智能领域产生了广泛影响。在学术影响方面，相关工作被纳入 ESI 高被引论文，入选欧洲图形学年度进展报告，成为加州大学圣迭戈分校等国际知名院校的课程内容，并获得中国计算机学会科学技术奖技术发明一等奖。在产业影响方面，开源数据集 3D-FRONT 被斯坦福大学、苹果等全球 250 余家机构采用，有效降低了行业三维内容制作门槛；几何生成技术在腾讯、阿里巴巴实现产业化应用，推动数字内容生产从手工制作向智能生成转型；数字人技术落地爱尔眼科集团，开创了数字医疗服务的全新模式；月壤三维重建工作获新华社等全球媒体 300 万次浏览，被新华社等 250 余家媒体报道。人脸绘制系统覆盖全球 186 个国家，累计生成 700 万张图像，使高精度数字内容创作从专业领域走向大众化。



技术论文入选 ACM TOG 期刊封面并获得多项荣誉，在线系统被广泛使用
Technical papers have been selected as the cover of ACM TOG journals and have received numerous honors. The online systems have been widely used

The proposed multiple innovative technologies for intelligent digital content generation have significant impact in both computer graphics and artificial intelligence. In the academic field, the related works have been listed as ESI Highly Cited Papers, included in the Eurographics State of the Art Report, incorporated into courses at leading universities such as the University of California, San Diego, and awarded the First Prize of CCF Science and Technology Award for Technical Invention. In the industrial field, the 3D-FRONT dataset has been adopted by more than 250 institutions worldwide, including Stanford University and Apple, substantially lowering the barriers to 3D content creation. Geometric generation techniques have been industrialized at Tencent and Alibaba, accelerating the progress from manual content production to intelligent generation. Digital human technologies have been deployed at Aier Eye Hospital Group, pioneering new modes of digital healthcare services. The lunar soil 3D reconstruction project attracted over 3 million views globally and was reported by 250+ media outlets. A facial drawing system has been rolled out in 186 countries, generating over 7 million images, bringing high-precision digital content creation from a professional tool into the hands of the public.



软件定义欺骗防御的四蜜体系架构
Four-Honey Framework based on Software Defined Deception Defense

H4SD3：基于软件定义欺骗防御的四蜜体系及关键技术

H4SD3: Four-Honey Framework and Key Technologies based on Software Defined Deception Defense (SD3)

广州大学
Guangzhou University

国网江西省电力公司
State Grid Jiangxi Electric Power Co., Ltd.

软极网络技术（北京）有限公司
Rangesoft Network Technology (Beijing) Co., Ltd.

引言

高级持续性威胁（Advanced Persistent Threat，APT）对全球以电网为代表的关键基础设施网络安全造成了严峻威胁。为有效应对 APT 攻击，本项目突破设陷探查、威胁观测、协同变换和狩猎诱骗等关键技术，提出了一套基于软件定义欺骗防御的四蜜技术体系，在电网、银行、政府等关键行业应用，取得显著社会和经济效益。

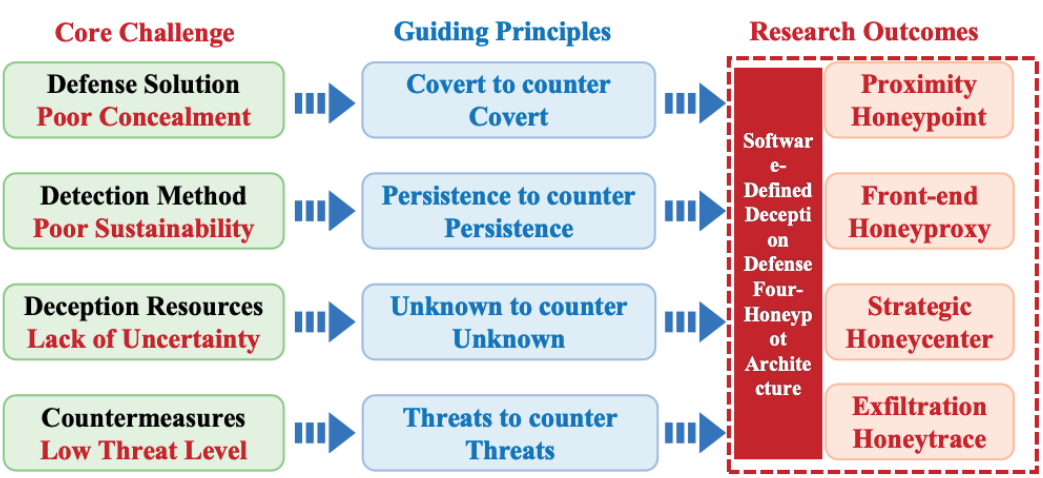
Introduction

Advanced Persistent Threats (APTs) pose severe threats to global critical infrastructures which are represented by electric power grid. To effectively counter APTs, we have achieved key technological breakthroughs including trap-based probing, preemptive threat observation, collaborative transformation, and hunting deception, and proposed Four-Honey framework based on software defined deception defense (H4SD3). Deployments and applications in key industries such as power grids, banks and governments have demonstrated the remarkable social and economic benefits of H4SD3.

从被动保护转向主动护卫，开启“护卫模式”安全防御新范式
The shifting from reactive protection to active guarding initiates a new security defense paradigm of "safeguard mode"

随着全球基础设施数字化、网络化、智能化进程不断加快，以APT为代表的网络攻击呈现高隐蔽性、长持续性、强未知性、高威胁性四个特征。传统边界防护、异常检测等技术，以保护防护目标为核心，难以有效检测和阻断。项目团队提出“以隐蔽应对隐蔽、以持续应对持续、以未知应对未知、以威胁应对威胁”的软件定义欺骗防御的四蜜体系，以发现攻击者为核心，实现对APT等高隐蔽威胁的主动护卫，并在中国国家级重要活动网络安全保障任务和关键信息基础设施网络部署验证，防御效果良好。攻关的技术创新包括：基于软件定义欺骗防御的智能编排、面向威胁先期感知的近身蜜点、基于持续观测与欺骗诱导的前置蜜庭、基于攻击技战术预测的中枢蜜阵、面向溯源反制的场景定制化外溢蜜洞等关键技术。

With the continuous acceleration of digitalization, networking, and intelligence of global infrastructure, cyberattacks, particularly those represented by APTs, present four characteristics: high concealment, long-term persistence, strong uncertainty, and high threat. Traditional defense technologies such as boundary protection and anomaly detection, which focus on protecting the target system from intrusions, are difficult to effectively detect and block these advanced cyberattacks. We propose the Four-Honey based on Software Defined Deception Defense (H4SD3) framework, and its guiding principles are "countering concealment with the concealment, responding to persistence with the persistence, responding to unknown with the unknown, and responding to threats with the threats". The core of H4SD3 is to discover cyber attackers, achieving active guardianship against highly concealed threats such as APTs. H4SD3 has been deployed and validated in the cybersecurity protection tasks of important national-level events in China and safeguarding critical information infrastructure networks, demonstrating its defensive effectiveness. The technological innovations of H4SD3 include: intelligent orchestration based on software-defined deception defense, close-range HoneyPoint for early threat perception, preemptive HoneyProxy based on persistent observation and deception induction, strategic HoneyCenter based on attack tactics and techniques prediction, and scenario-customized overflow HoneyTrace for traceability and countermeasures.



基于软件定义欺骗防御的四蜜技术创新思路
The Innovations of the Four-Honey technologies based on software defined deception defense

项目成果显著提升多行业 / 领域关键信息基础设施主动防御能力
The project outcomes have significantly enhanced the active defense capabilities of critical information infrastructures in multiple industries and fields

项目团队通过探索适配 APT 的护卫模式防护体系，突破了多样性攻击检测技术和对抗性防御应对技术，首次提出基于软件定义欺骗防御四蜜体系（H4SD3），研制了蜜点、蜜庭、蜜阵、蜜网等具有国际领先水平的装置。

The project team pioneered the exploration of a Four-Honey Safeguard Mode protection system specifically adapted for APTs. It achieved breakthroughs in diverse attack detection technologies and adversarial defense response techniques, and for the first time, proposed the Four-Honey framework based on Software Defined Deception Defense (H4SD3), leading to the development of internationally leading apparatuses, including HoneyPoints, HoneyProxy, HoneyCenter, and HoneyTrace.

四蜜装置已应用覆盖多行业、多场景应用场景。项目成果部署于 27 个省级电网（覆盖 80% 电力网络），服务超 11 亿人口。以江西公司为例，2024 年抵御 480 万余次网络攻击、修复 765 个漏洞、溯源 58 名黑客并获取 112 台傀儡机权限，实现攻击链全闭环处置；项目成果被 50 余家核心机构采用（公安、银行、金融、政府等领域）；项目成果在包括冬奥会、亚运会、大运会、亚冬会、广交会等重大国际赛事活动中应用（连续 10 年保障广交会并实现网络安全零事故记录），累计识别 2481 万余起高风险威胁；项目提交 67 项零日漏洞（CVE/CNVD 双认证）；近 3 年创收超 57 亿元（约 7.8 亿美元）。

Four-Honey has achieved a mature application system covering multiple industries and scenarios. The project outcomes have been deployed across 27 provincial power grids (covering 80% of the national electric power network of China), serving a population exceeding 1.1 billion. Taking Jiangxi Power Company as an example, in 2024, Four-Honey system has repelled over 4.8 million cyber-attacks, patched 765 vulnerabilities, attributed attacks to 58 hackers and obtained control permissions for 112 botnet nodes, achieved the full closed-loop handling of the attack chain. The project outcomes have been adopted by over 50 core institutions across sectors including public security, banking, finance, and government. This framework has been successfully deployed for critical events including the Winter Olympics, Asian Games, Universiade, Asian Winter Games, and the Canton Fair (maintained a zero-incident record for over 10 consecutive years for the Canton Fair), and cumulatively identified over 24.81 million high-risk threats. So far 67 zero-day vulnerabilities have been submitted and certified by both CVE and CNVD. Over the past three years, the technology framework has generated cumulative direct economic benefits reaching 5.7 billion RMB (approximately $780 million USD).

HoneyPoint

Device Model	Applicable scenarios
Honeypoint device basic version AD-PTT-Base	Small businesses or branches
Honeypoint device standard version AD-PTT-Standard	Medium-sized enterprises or branches
Honeypoint device performance version AD-PTT-Performance	Headquarters of large enterprises
Honeypoint Front-end Equipment AD-PTT-Mini	Small branch proxy devices, in conjunction with the main device.
Honeypoint probe AD-PTT-Probe	Installation of host and terminal

HoneyProxy

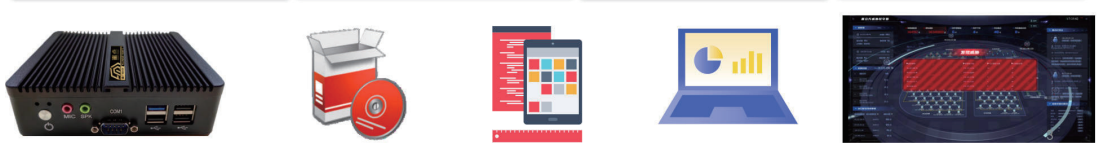
Device Model	Applicable scenarios
Honeyproxy basic version AD-PRT-1G	Small and medium-sized enterprises or branches
Honeyproxy Performance version AD-PRT-10G	Large enterprises have many devices and high performance requirements.

HoneyCenter

Device Model	Applicable scenarios
Honeycenter basic version AD-TMG-Base	Have multiple honeypoint and honeyproxy facilities that need to be managed collaboratively.

HoneyTrace

Device Model	Applicable scenarios
Honeytrace AD-TRT-License	When it is necessary to trace and collect evidence against the attackers.



研制的四蜜装置
The Developped Four-Honey Devices and Equipments

推动网络安全标准体系升级，构建安全产业新生态

Promoting the upgrading of the cybersecurity standard system and building a new ecosystem for the security industry

项目首创基于软件定义欺骗防御的四蜜体系，从根本上突破了传统被动防御的技术局限。在标准化建设方面，技术团队深度参与网络安全标准体系建设，制定标准 19 项，其中中国国家标准 1 项、行业标准 18 项，作为牵头单位，制定行业标准 5 项，其中包括四蜜相关 3 项：《四蜜平台总体技术框架》、《四蜜平台数据应用规范》、《四蜜平台功能接口规范》。获 316 位国际权威专家认可（含 158 位 IEEE Fellow 及 62 位中国两院院士）。项目所研发的新型防御装置（蜜点、蜜庭、蜜阵、蜜网等）已在电力、公安、银行、金融、政府等关键行业部署应用，有效赋能各行业网络安全防御体系新升级。作为发起单位，于 2024 年 8 月成立组建盾立方产业联盟，联盟单位包括国家能源集团、南方电网、国家电网、深圳政数局等 30 余企事业单位。

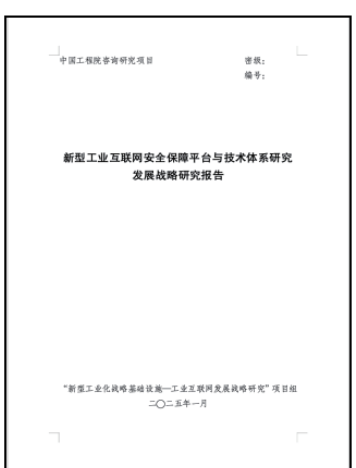
The project has pioneered the H4SD3 concepts, and has fundamentally broken through the technical limitations of traditional reactive defense. In terms of standardization construction, the project team has been deeply involved in the construction of the cybersecurity standard system, formulating 19 standards, including 1 national standard in China and 18 industry standards. As the leading unit, we have formulated 5 industry standards, among which 3 are related to the Four-Honey system : Overall Technical Framework of Four-Honey Platform, Data Application Specification of Four-Honey Platform, Functional Interface Specification of Four-Honey Platform. The system has gained recognition from 316 internationally renowned experts, including 158 IEEE Fellows and 62 Academicians from the CAS and CAE. The new apparatuses (HoneyPoint, HoneyProxy, HoneyCenter, HoneyTrace, etc.) developed by the project have been deployed and applied in key industries such as power, public security, banking, finance, and government, effectively empowering the new upgrade of the network security defense system in various industries. As the initiating unit, we established the Shield Cube Industry Alliance in August 2024, which includes over 30 enterprises and institutions such as the China National Energy Group, China Southern Power Grid, and State Grid.



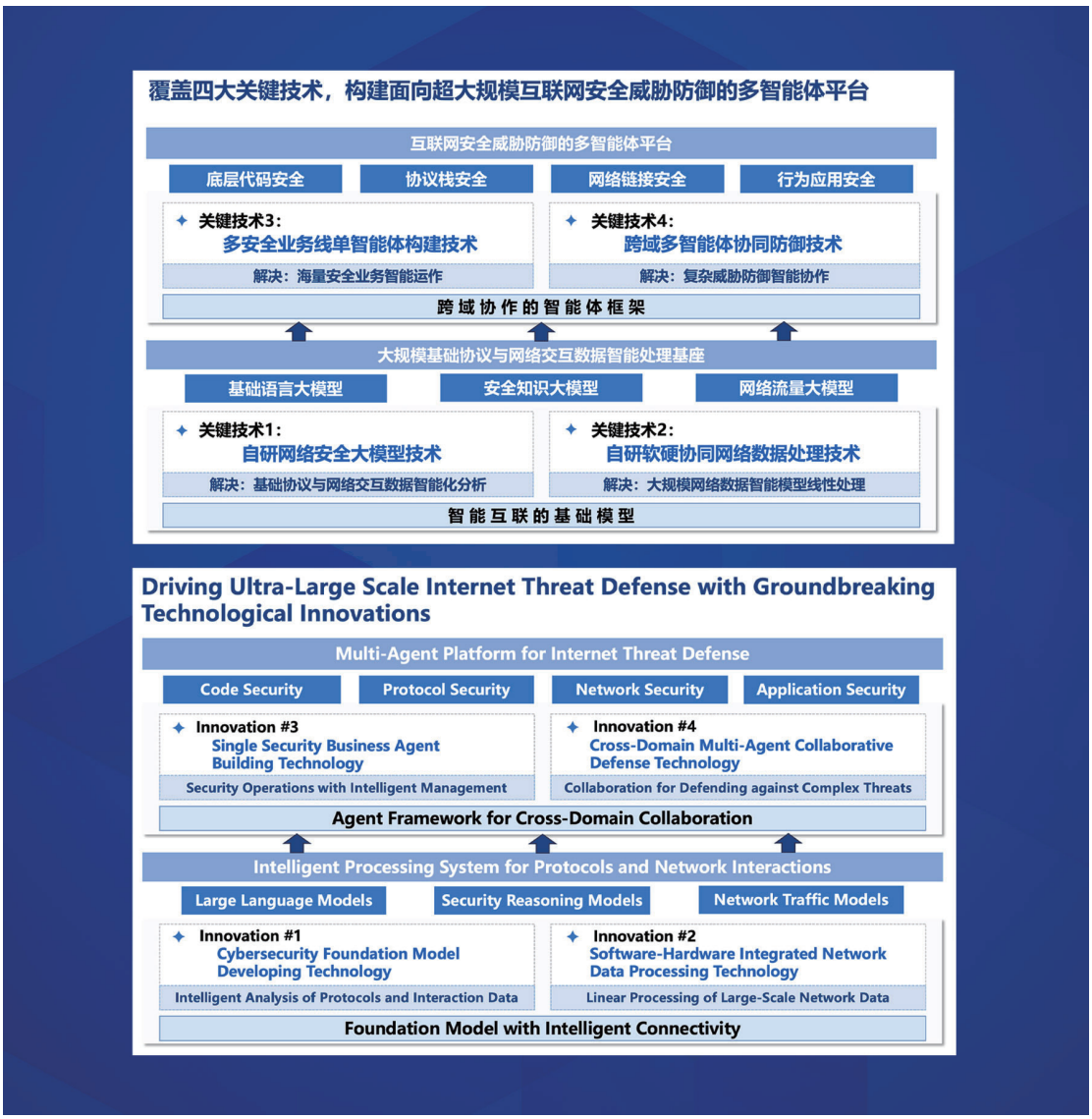
Three Four-Honey Industry Standards Adopted



The Shield Cube Alliance was officially established in August 2024.



Industry Development Report



面向大规模互联网安全威胁防御的多智能体平台架构
Multi-Agent Platform Architecture for Large-Scale Internet Threat Defense

互联网异构安全威胁防御的多智能体系统
Multi-Agent System for Internet Heterogeneous Threat Defense

清华大学
Tsinghua University

天翼安全科技有限公司
Tianyi Security Technology Company Limited

引言

项目基于跨域协同的互联网安全多智能体框架，构建面向互联网异构安全威胁防御的多智能体系统，突破智能化网络安全运营范式，打通跨场景多源威胁的网络安全认知壁垒，有力支撑云、边、端复杂场景下关键基础设施防护。

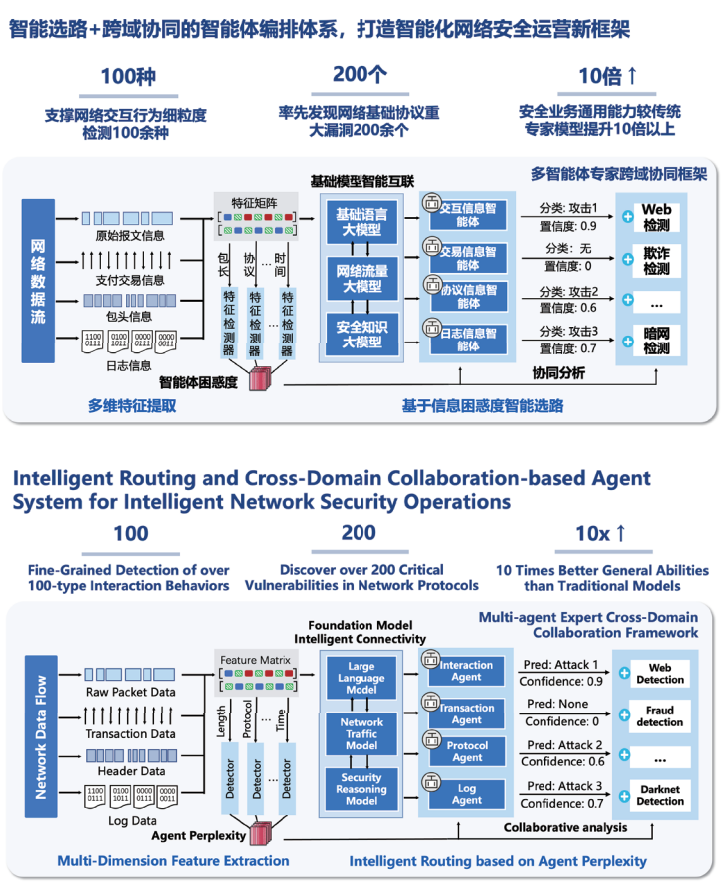
Introduction

The project is based on a cross-domain collaborative Internet security multi-agent framework, aimed at building a multi-agent system for defending against heterogeneous internet security threats. It breaks through the paradigm of intelligent network security operations, bridges the cognitive barriers of multi-source threats across different scenarios, and strongly supports the protection of critical infrastructures in complex cloud, edge, and end environments.

平台攻克超大规模基础协议、网络交互的智能分析处理难题

Platform Overcomes the Challenges of Intelligent Analysis and Processing of Large-Scale Network Protocols and Interactions

平台针对全球互联网行为产生的超大规模基础协议、网络交互数据智能分析处理难的挑战，自主研发面向互联网安全的跨域协同多智能体框架。框架形成大模型层 + 小模型层 + 工具层的智能体编排体系，基于 TB 级安全业务指令和网络行为数据，构建集合通用基础语言大模型、安全知识大模型、网络流量大模型于一体的智能知识体系，打造覆盖代码安全、协议栈安全、网络链接安全、应用行为安全等多安全业务线的多智能体系统。平台支撑 DDoS、Web 攻击、恶意软件、暗网行为、路由劫持等 100 余种行为细粒度检测。率先发现了工业以太网、5G、Wi-Fi、IPv4/IPv6、ICMP、UDP、TCP 等网络基础协议重大漏洞 200 余个。安全业务通用能力较传统专家模型提升 10 倍以上，威胁识别平均准确率达 99.5%，显著超越业界水平。



超大规模网络异构数据智能协同处理的多智能体框架

Multi-Agent Framework for Intelligent Collaborative Processing of Large-Scale Heterogeneous Network Data

The platform addresses the challenge of intelligent analysis on large-scale foundational protocols and network interaction data generated by global Internet behaviors. It develops a cross-domain collaborative multi-agent framework for Internet security. The framework forms three layers in the system, including foundation models, small models, and tools. Based on TB-level security service instructions and network data, it builds an intelligent knowledge system integrating large language models, security reasoning models, and network traffic models. The multi-agent system encompasses various security business lines, including code security, protocol security, network security, and application security. It supports fine-grained detection of over 100 behaviors, including DDoS, web attacks, malware, dark web activities, and route hijacking. It has identified over 200 major vulnerabilities in Ethernet, 5G, Wi-Fi, IPv4/IPv6, ICMP, UDP, and TCP network protocols. The platform's performance improves by more than 10 times compared to traditional expert models in diverse security businesses, with a threat detection accuracy rate of 99.5%, significantly surpassing industry standards.

推动产业转化应用，为网络安全生态发展做出重要贡献
Promoting the Application of Technologies and Contributing to the Development of the Cybersecurity Ecosystem

项目研究成果有效提高了互联网系统的威胁检测能力，被蚂蚁集团、腾讯、华为、中国电信等多个知名组织和厂商部署应用，支撑 TB 级流量智能化监管能力，覆盖百余项威胁识别与漏洞分析业务，极大降低人工专家投入成本并提升网络安全运营效率。攻克支付宝交易账号、腾讯黑灰产账号检测难题，实际场景召回率提升 10% 以上；平台发现的 IP 协议、TCP 协议跨层交互语义漏洞帮助 Linux、FreeBSD、OpenWrt 等开源社区改进了多个内核版本安全性，为开源社区的安全生态构建做出了重要贡献。帮助 Linux 社区自内核 5.16 开始，有效缓解了互联网上超过 20% 的服务器面临的远程攻击，有效保障了现实世界中大量下游路由设备（包括 NETGEAR、Linksys、TP-Link、H3C、Ruijie、Xiaomi、Google、360 等厂商的路由设备产品）的安全性，得到多次致谢。

The project's findings have effectively enhanced the threat detection capabilities of Internet systems. It has been deployed by several well-known organizations and vendors, including Ant Group, Tencent, Huawei, and China Telecom, supporting intelligent monitoring of TB-scale traffic and covering over a hundred threat identification and vulnerability analysis tasks. This has greatly reduced the cost of human expert resources and improved network security operational efficiency. The platform has overcome challenges in detecting Alipay transaction accounts and Tencent black market accounts, achieving a more than 10% improvement in recall rate in real-world scenarios. Vulnerabilities in IP and TCP protocol cross-layer interactions identified by the platform helped improve the security of multiple kernel versions in open-source communities such as Linux, FreeBSD, and OpenWrt, making a significant contribution to the security ecosystem. Since Linux kernel version 5.16, the project has effectively mitigated remote attacks against over 20% of Internet servers, ensuring the security of downstream router devices, including NETGEAR, Linksys, TP-Link, H3C, Ruijie, Xiaomi, Google, and 360. It has received numerous acknowledgements for its contributions.



项目研究成果被多个知名组织和厂商部署应用
Findings of the Project have been Deployed by Several Well-Known Organizations and Vendors

成果具备重要产业与学术价值，在国际上产生广泛影响力

The Findings Achieve Significant Industrial and Academic Value with A Broad International Impact

项目在引领技术创新和推动产业进步方面成效显著。研究成果发表安全领域“四大”顶级会议及安全顶刊论文 40 余篇，相关专利授权 20 余项。平台获得了首届“国际基础科学大会前沿科学奖”（安全领域亚太地区唯一入选者）、SIGSAG Doctoral Disseration Award Runner-Up（亚太地区历史唯一入选者）、以及多篇顶会最佳论文，得到了 Wi-Fi 联盟、Linux 社区、OpenWrt 社区、高通、华为、中国电信、中国联通、阿里巴巴、360、小米、锐捷、新华三、腾达等的公开致谢。平台相关技术在中国大模型竞赛 ATEC 2023 中作为赛题内容推广给 200 家参赛单位使用，58% 以上参赛团队基于平台技术收获了 90% 以上准确率的威胁分析结果，成效显著。研究成果被中国国家自然科学基金委员会、The Register、APNIC、Cyber Security News、GitHub 等知组织媒体多次报道，引发社会的广泛关注。

The project has achieved impressive success in driving technological innovation and promoting technology and industry growth. It has published over 40 papers in top security conferences and secured more than 20 patents. The platform received the first Frontiers of Science Award (being the only Asia-Pacific recipient in the security field), the SIGSAC Doctoral Dissertation Award Runner-Up (the only Asia-Pacific recipient in history), and several best paper awards at leading conferences. It has also gained public recognition from organizations such as the Wi-Fi Alliance, the Linux Foundation, OpenWRT, Qualcomm, Huawei, China Telecom, China Unicom, Alibaba, 360, Xiaomi, Ruijie Networks, H3C, and TP-Link. The platform's technology was used in the ATEC 2023 Large Language Model Competition with over 200 participating teams. Over 58% of these teams achieved an accuracy of above 90% using the platform's technology, demonstrating its strong effectiveness. It has been highlighted by prestigious organizations and media outlets, including the National Natural Science Foundation of China, The Register, APNIC, Cyber Security News, and GitHub, attracting widespread public attention.



目前收获多项学术、产业重要成果，引领安全领域技术创新

Achievements Recognized Internationally, Leading to Technological Innovation in the Field of Security

研究成果受到国际行业专家和权威机构的广泛认可
Project Achievements Recognized by Industry Experts and Authoritative Institutions

研究成果获得了中国电子学会科技进步一等奖，国际网络安全领域知名专家Adrian Perrig、Ravi Sandhu等教授对研究成果也进行了高度评价。成果也被德国达姆施塔特研究中心、以色列耶路撒冷希伯来大学、美国加州大学河滨分校等多个国际知名安全团队参考引用。支持发布了中国国家网络安全技术标准1项，国际标准2项，行业白皮书2项，为产业应用提供标准化支撑。

The project won the First Prize Award for Scientific and Technological Progress from the Chinese Institute of Electronics (CIE). Renowned international cybersecurity experts, including Professors Adrian Perrig and Ravi Sandhu, also highly praised the research. The findings have been referenced by several internationally renowned security research groups, including the Darmstadt Research Center in Germany, the Hebrew University of Jerusalem in Israel, and the University of California, Riverside in the United States. The research has also contributed to the publication of one Chinese national standard, two international standards, and two industry white papers, providing standardized support for industry applications.

项目荣誉与资质

✦ 项目获多项电子学会科技进步一等奖，成果获行业专家和权威机构广泛认可

项目成果《高效协作的互联网动态行为安全可信关键技术与应用》、《无连接网络中安全可信的端到端传送关键技术及应用》获得中国电子学会科技进步一等奖



中国电子学会科技进步1等奖2项

项目支持发布了中国国家标准1项，国际标准2项，行业白皮书2项，为产业应用提供标准化支撑，受到权威机构广泛认可



行业白皮书　　行业白皮书

成果获行业专家和权威机构广泛认可，推动产业创新
Project Achievement Widely Recognized by Industry Experts and Authoritative Institutions





基于 RISC-V 架构的芯片、硬件、操作系统和云桌面技术体系
A technology stack built on the RISC-V architecture, hardware, operating systems, and cloud desktops

基于 RISC-V 开放指令集的原生操作系统和云桌面关键技术创新及应用

Innovation and Application of Key Technologies for the Native Operating System and Cloud Desktops, based on the RISC-V Open Instruction Set

中国科学院软件研究所
The Institute of Software, Chinese Academy of Sciences

中国电信研究院
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引言

团队基于 RISC-V 开放指令集的玄铁 CPU IP 的曳影处理器，研发了原生操作系统、“如意 BOOK”笔记本电脑及云桌面应用，率先打通了从芯片到应用的 RISC-V 关键链路技术，实现了软硬一体化的应用终端，推动了全球 RISC-V 生态产业发展。

Introduction

The team has developed a native operating system, the “Ruyi BOOK” laptop, and a suite of cloud desktop applications. These innovations are based on the Yeying SoC and XuanTie CPU IP, which are built on the open standard instruction set architecture (ISA) - RISC-V. This achievement marks a pivotal breakthrough, establishing a complete and critical technology chain from chip-level design to application in the RISC-V domain. By creating a fully integrated hardware-software application terminal, we have not only delivered a cohesive solution but have also propelled the advancement of the global RISC-V industrial ecosystem.

打通“软硬芯”全链路，构建 RISC-V 原生操作系统与云桌面技术体系
Establishing a Full-Stack Technology Ecosystem for RISC-V: From Silicon to a Native OS and Cloud Desktop

RISC-V 的原生操作系统：基于开源鸿蒙（OpenHarmony）和开源欧拉（openEuler），研发了具备原生安全、智慧互联能力的系统能力，实现了端云一体的系统架构使得用户交互和应用体验无缝衔接，自由流转。

基于 RISC-V 的云桌面技术：完成业界关键开源软件 Electron（19 版本）的 RISC-V 适配与优化，完成 Opus、GStreamer 等关键基础库的 RISC-V 的适配，实现跨平台的桌面应用开发工具在 RISC-V 平台上的稳定运行和性能提升。优化启动、登录的响应时间低至秒级，进一步提升了用户体验。

打通 RISC-V“软硬芯”全链路的如意 BOOK 笔记本电脑：基于玄铁 C910 IP 核处理器的软硬件协同优化，实现全栈低功耗能力。通过多阈值电压、多电源域、CPU 调频调压等，确保长续航和高效节能，在“如意 BOOK”上实现了小于 10mW 的待机功耗和长达 20 天的续航。如意 BOOK 打通了芯片到原生操作系统、云桌面软硬一体全链路，为全球 RISC-V 技术和产业生态提供了新的遐想空间。

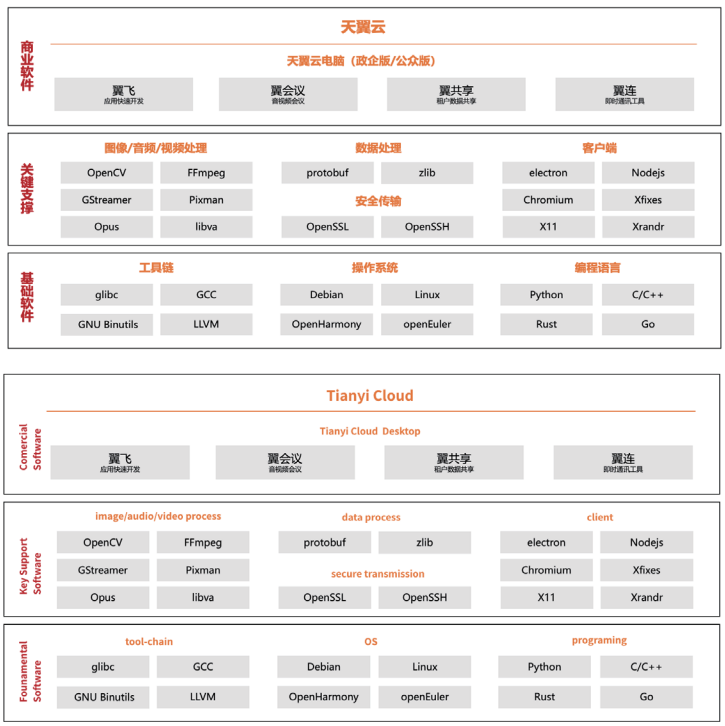


RISC-V 原生操作系统 - 如意 OS
A Native Operating System for RISC-V - Ruyi OS

A Native Operating System for RISC-V: Built upon the OpenHarmony and openEuler open-source projects, the team has developed a native RISC-V operating system with inherent security and intelligent interconnection capabilities. Its integrated device-cloud architecture facilitates a fluid user experience and application transitioning across different environments.

Cloud Desktop Technology on RISC-V: The team has successfully adapted and optimized the key open-source framework Electron (v19) for the RISC-V architecture. This initiative included porting essential foundational libraries such as Opus and GStreamer, which enables cross-platform desktop development tools to run with enhanced stability and performance on RISC-V. System startup and login response times have been reduced to the order of seconds, delivering a substantial improvement in user experience.

The Ruyi BOOK Laptop, Pioneering Full-Stack RISC-V Integration from Silicon to Software: The Ruyi BOOK laptop exemplifies the power of deep hardware-software co-optimization based on the XuanTie C910 CPU, achieving full-stack power efficiency. Through advanced power management solution — including multi-threshold voltages, multiple power domains, and dynamic voltage and frequency scaling (DVFS)—the device boasts a standby power consumption of less than 10mW and can remain on standby for up to 20 days. The Ruyi BOOK pioneers a complete, end-to-end technology integration from the RISC-V chips to the a native operating system and cloud desktop applications, realizing a fully unified software-hardware chain. This groundbreaking achievement opens new horizons for the global RISC-V technology and industrial ecosystem, creating strong momentum for future development.



云桌面技术架构
Cloud Desktop Technology on RISC-V



具备原生操作系统和云桌面的如意 BOOK 笔记本
Ruyi BOOK laptop with Native Operating System and Cloud Desktop

为 RISC-V 通用计算领域应用提供重要的技术创新和商业价值
Driving Technological Innovation and Commercial Value in the RISC-V General-Purpose Computing Sector

该成果的落地为 RISC-V 架构在通用计算领域软件生态欠缺、性能优化不足、硬件支持配套性差等痛点，提供了重要的技术创新和商业价值。

团队借助 RISC-V 的开放性核心优势，以软件需求反馈驱动迭代，展示一体化优势，通过关键成果促进全球技术生态协同进化，并推动形成国际和中国的标准制定，促进了技术民主化和跨文化协作。

RISC-V 云桌面具备高性能、低延时、可定制、灵活性高等特点，在教育教学、政企办公、金融研发等多种场景已具备较高成熟度。与传统 PC 相比，RISC-V 云桌面部署周期短以及芯片功耗低，可节约运维成本 40% 以上，节约电力消耗 64% 以上，有效推动了社会数字经济的普惠与低碳发展。在市场方面，云桌面行业每年市场规模超 500 万台，市场潜力大。

This achievement represents a crucial breakthrough, delivering technological innovations and commercial value. It directly addresses the key limitations within the RISC-V high performance computing domain. These challenges include its nascent software ecosystem, insufficient performance optimization, and lack of comprehensive hardware support.

By harnessing the fundamental advantage of RISC-V's openness, the team has created a development model where iterations are driven by software requirements feedback, demonstrating the profound benefits of vertical integration. The key accomplishments catalyze the synergistic evolution of the global technology ecosystem, contribute to the development of new international and Chinese standards, and champion the democratization of technology through cross-cultural collaboration.

The RISC-V cloud desktop solution offers high performance, low latency, extensive customizability, and superior flexibility. It has already reached a high level of maturity for deployment in diverse sectors, including education, government, corporate offices, and financial R&D. In contrast to traditional PCs, RISC-V cloud desktops feature significantly shorter deployment cycles and lower chip-level power consumption. These advantages translate into a reduction of over 40% in operational and maintenance (O&M) costs and a decrease in power consumption of more than 64%. This effectively fosters a more inclusive and sustainable digital economy. The cloud desktop market is substantial, with annual sales exceeding five million units, signaling a vast potential for growth.



部分应用场景介绍
Deployment in diverse sectors

有力推动行业示范，促进了生态发展，加速 RISC-V 技术在更多领域普及
Effectively driving industry adoption, fostering ecosystem growth, and accelerating the proliferation of RISC-V technology across new sectors

成果创新性地将 RISC-V 指令集架构与操作系统深度融合，通过重构系统内核架构、优化指令执行机制，开发出适配 RISC-V 的云桌面应用，构建了从指令集、IP、操作系统、应用到硬件终端的完整技术链条，支持 RISC-V 技术在桌面系统领域的规模化应用，具有开创性和代表性意义，为 RISC-V 技术发展提供了关键支撑。未来，项目成果有望进一步拓展应用边界，推动 RISC-V 技术在更多领域的普及。

成果的创新技术将为新兴产业发展注入新动力，加速产业升级，低成本、可扩展的 RISC-V 解决方案，将助力形成新的生产模式和商业模式，并加速产业升级与新质生产力形成。同时，项目组通过开源生态建设、软件生态贡献、标杆成果创新，在全球 RISC-V 生态中发挥了重要作用。

The project culminates in the innovative, deep integration of the RISC-V instruction set architecture (ISA) with the operating system. By re-architecting the system kernel and optimizing instruction execution mechanisms, cloud desktop applications specifically adapted for RISC-V have been created. This establishes a complete technology stack—from the instruction set, IP, and operating system to applications and hardware devices. This comprehensive approach enables the large-scale deployment of RISC-V technology in the desktop computing sector, marking a pioneering and representative achievement that provides critical support for the advancement of the RISC-V platform. In the future, these accomplishments are expected to push the boundaries of application, driving the proliferation of RISC-V technology into even more domains.

The innovative technology developed through this project is set to inject fresh momentum into emerging industries and accelerate industrial upgrading. The low-cost, scalable RISC-V solutions will help forge new production and business models, expediting both industrial transformation and the formation of new quality productive forces. Simultaneously, through its commitment to building an open-source ecosystem, contributing to software development, and delivering benchmark innovations, the project team has played a pivotal role within the global RISC-V community.



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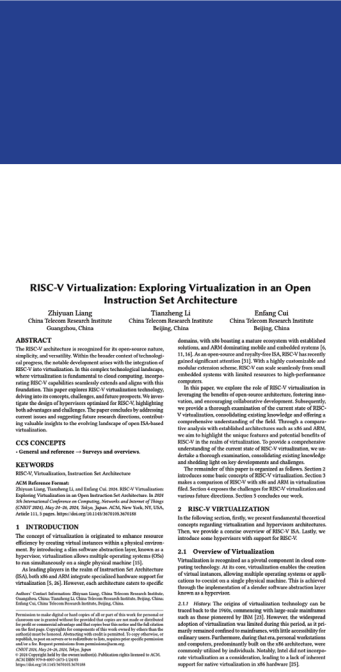
玄铁C910获得(RISC-V首次) GP安全认证

玄铁 C910 GP 安全认证
Xuantie C910 GP Security Certification



RISC-V Virtualization: Exploring Virtualization in an Open Instruction Set Architecture

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ABSTRACT

The RISC-V architecture is recognized for its open-source nature, simplicity, and versatility. Within the broader context of technological progress, the notable development arises with the integration of RISC-V into virtualization. In this complex technological landscape, where virtualization is fundamental to cloud computing, incorporating RISC-V capabilities seamlessly extends and aligns with this foundation. This paper explores RISC-V virtualization technology, delving into its concepts, challenges, and future prospects. We investigate the design of hypervisors optimized for RISC-V, highlighting both advantages and challenges. The paper concludes by addressing current issues and suggesting future research directions, contributing valuable insights to the evolving landscape of open ISA-based virtualization.

CCS CONCEPTS

· General and reference → Surveys and overviews.

KEYWORDS

RISC-V, Virtualization, Instruction Set Architecture

ACM Reference Format:

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1 INTRODUCTION

The concept of virtualization is originated to enhance resource efficiency by creating virtual instances within a physical environment. By introducing a data software abstraction layer, known as a hyper-visor, virtualization allows multiple operating systems (OSs) to run simultaneously on a single physical machine [33].

An leading players in the realm of Instruction Set Architecture (ISA), both x86 and ARM integrate specialized hardware support for virtualization [5, 36]. However, each architecture caters to specific domains, with x86 boasting a mature ecosystem with established solutions, and ARM dominating mobile and embedded systems [6, 11, 16]. As an open-source and royalty-free ISA, RISC-V has recently gained significant attention [31]. With a highly customizable and modular extension scheme, RISC-V can scale seamlessly from small embedded systems with limited resources to high-performance computers.

In this paper, we explore the role of RISC-V virtualization in leveraging the benefits of open-source architecture, fostering innovation, and encouraging collaborative development. Subsequently, we provide a thorough examination of the current state of RISC-V virtualization, consolidating existing knowledge and offering a comprehensive understanding of the field. Through a comparative analysis with established architectures such as x86 and ARM, we aim to highlight the unique features and potential benefits of RISC-V in the realm of virtualization. To provide a comprehensive understanding of the current state of RISC-V virtualization, we undertake a thorough examination, consolidating existing knowledge and shedding light on key developments and challenges.

The subsequent sections of this paper are organized as follows. Section 2 introduces some core concepts of RISC-V virtualization. Section 3 makes a comparison of RISC-V with x86 and ARM in virtualization filed. Section 4 exposes the challenges for RISC-V virtualization and various future directions. Section 5 concludes our work.

2 RISC-V VIRTUALIZATION

In the following section, firstly, we present fundamental theoretical concepts regarding virtualization and hypervisors architectures. Then, we provide a concise overview of RISC-V ISA. Lastly, we introduce some hypervisors with support for RISC-V.

2.1 Overview of Virtualization

Virtualization is recognized as a pivotal component in cloud computing technology. At its core, virtualization enables the creation of virtual instances, allowing multiple operating systems or applications to coexist on a single physical machine. This is achieved through the implementation of a slender software abstraction layer known as a hypervisor.

2.1.1 History. The origins of virtualization technology can be traced back to the 1960s, commencing with large-scale mainframes such as those pioneered by IBM [28]. However, the widespread adoption of virtualization was limited during this period, as it primarily remained confined to mainframes, with little accessibility for ordinary users. Furthermore, during that era, personal workstations and computers, predominantly built on the x86 architecture, were commonly utilized by individuals. Notably, Intel did not incorporate virtualization as a consideration, leading to a lack of inherent support for native virtualization in x86 hardware [21].

2024 ACM/IEEE 47th Annual International Symposium on Computer Architecture (ISCA)

Xuantie-910: A Commercial Multi-Core 12-Stage Pipeline Out-of-Order 64-bit High Performance RISC-V Processor with Vector Extension

Industrial Product

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***Abstract*—The open source RISC-V ISA has been quickly gaining momentum. This paper presents *Xuantie-910*, an industry leading 64-bit high performance embedded RISC-V processor from Alibaba T-Head division. It is fully based on the RV64GCV instruction set, and has been optimized with 12-stage deep pipeline operation, 16 outstanding load and store, TLB and cache operations. It also implements the 0.7.1 stable release of RISC-V vector extension specification for high efficiency vector processing. *Xuantie-910* supports multi-core multi-cluster SMP with built-in L2 cache subsystem and coherency unit. It is capable of booting the Linux operating system. Each single core utilizes the state-of-the-art 12-stage deep pipeline, out-of-order, multi-issue superscalar architecture, achieving a maximum clock frequency of 2.5 GHz in the typical process, voltage and temperature condition in a TSMC 12nm FinFET process technology. Each single core with vector extension unit scores 7.1 CoreMark/MHz and 2.2 coremark per core MHz in scalar enhancement. Additionally to support the vector extension and custom extensions. Through hardware and toolchain co-optimization, to date *Xuantie-910* delivers the highest performance (in terms of IPC, speed, and power efficiency) for a number of industrial control flow and data processing benchmarks. Leveraging the RISC-V ecosystem and the RISC-V family, *Xuantie-910* FPGA implementation has been deployed in the data centers of Alibaba Cloud, for application-specific acceleration (e.g., blockchain transaction). The ASIC deployment at low-cost SoC applications, such as IoT endpoints and edge computing, is planned to facilitate Alibaba's end-to-end and cloud-to-edge computing infrastructure.

***Index Terms*—RISC-V, processor, cache, memory architecture, out of order, vector, extension.**

I. INTRODUCTION

Cloud computing and IoT applications are fueling the wave of semiconductor growth and development. The demand for low-power and cost-effective CPUs is ever increasing. The RISC-V is very attractive at this point in time, because: i) as an alternative to closed and costly ISAs, the open and free ISA of RISC-V accelerates processor innovation through open standard collaboration; ii) its scalability, extensibility, and modularity enable processor customization and optimization for domain-specific workload (e.g., machine learning accelerators, network processing, security enclave, storage controllers and supercomputing), thereby boosting processing efficiency and reducing design cost; iii) RISC-V is becoming a mainline platform in Unix/Linux OS. The toolchains like GNU/LCC/LLVM and LLVM are getting mature, further improving software *experience and driving down software development cost.*

Admittedly, compared with the X86, ARM, MIPS [16]–[18], PowerPC, SPARC [11], [20], [21], [23], [30], openRISC [14], [24], [26] and other ISAs under the hood of popular GPUs and DSPs, RISC-V is still in its infancy. We see many RISC-V efforts have been making inroads, some of which are highlighted below:

- Academic work - The UC Berkeley released the in-order *Rocket* core, the out-of-order core *BOOM* and the open-source design generator tool [9], [10]. *Rocket* and *BOOM* are capable of booting Linux. ETH Zurich and Università di Bologna offered three flavors of RISC-V cores in the *PULP* platform [4] - *RISCY* (32-bit, 4-stage pipeline), *Zero-riscy* (32-bit, 2-stage pipeline) and *Ariane* (64-bit, 6-stage pipeline) [32]. Also, IIT-Madras has been working on a series of *Shakti* RISC-V processors, from a 3-stage pipeline in-order core to an out-of-order multiple threading core at a target operating frequency of 1.5-2.5 GHz [5], [13].
- Industrial work - For many years nVIDIA has been using RISC-V as the *Falcon* controllers in the GPUs [8]. Besides, chip vendors such as SiFive, Microsemi, Alibaba T-Head, Andes, Codasip offer a range of silicon-proven 32-bit and 64-bit embedded RISC-V IPs. Recently, Western Digital open-sourced the SweRV*EH2 Core* [25], which is an industry-quality 32-bit, 2-way superscalar, 9-stage pipeline core. This power-efficient design reaches over 1.0 GHz operating frequency in a TSMC 28nm CMOS process technology. With a performance of up to 5.0 CoreMarks/MHz (based on internal simulations) have gradually expanded from edge scenarios to cloud data centers. Some traditional virtual machines and containers, such as QEMU and Docker, already support RISC-V architecture, but currently lack lightweight virtual machines that support the RISC-V architecture.

The RISC-V instruction set is modular and includes a set of basic instructions and optional instruction extensions. RISC-V instruction set provides hardware virtualization support in the privileged architecture, i.e. hypervisor extension (H-extension). Compared to the hardware virtualization technology of x86 architecture, RISC-V's extension is optional, as a reduced instruction set, RISC-V requires fewer instructions and registers to implement virtualization. For CPU virtualization, similar to the root and non-root modes provided by the x86 architecture, RISC-V's hypervisor extension has also added new privileged mode, which switches between privileged modes when executing related instructions. For memory virtualization, x86 architecture uses memory management technologies such as EPT, which typically involve managing multi-level page tables, while the page table structure of the RISC-V architecture is simpler.

In this work, we propose a lightweight virtual machine TeleVM for the RISC-V architecture. TeleVM is written using the memory security language Rust and supports KVM and the H-extension of RISC-V hardware to achieve strong isolation and security. It only contains a small number of necessary functions and components, which can effectively reduce costs and enable rapid deployment. TeleVM can be used for serverless computing and security containers, improving the cloud computing software ecosystem of RISC-V architecture. The contributions of this paper are as follows:

- We propose and open source a lightweight virtual machine TeleVM for RISC-V architecture. [3]
- We port kvm-bindings [4] and kvm-ioctls [5] libraries for RISC-V architecture.
- We simulate interrupt controller of RISC-V in user space through Rust code for interrupt virtualization.
- We test the optimization of TeleVM compared to QEMU+KVM in terms of boot time and memory overhead through experiments.

II. RELATED WORK

Firecracker [1] is a lightweight virtual machine for serverless and container applications. Firecracker has a minimalist design that retains a small number of management functions and device models. Cloud Hypervisor [6] is a virtual machine open-sourced by Intel. It shares some code with Firecracker, but the difference is that it has more features and device models, aiming to be a general purpose VMM for cloud workloads. Stratos-rt [2] is an open-source lightweight virtual machine in the OpenEuler

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TeleVM: A Lightweight Virtual Machine for RISC-V Architecture

Tianzheng Li, Enfang Cui, Yuting Wu, Qian Wei, and Yue Guo

***Abstract*—Serverless computing has become an important paradigm in cloud computing due to its convenient and fast large-scale deployment and pay-as-you-go charging model. Due to shared infrastructure and multi-tenant environments, serverless applications have high security requirements. Traditional virtual machines and containers cannot fully meet the requirements of serverless applications. Therefore, lightweight virtual machine technology has emerged, which can reduce overhead and boot time while ensuring security. In this letter, we propose TeleVM, a lightweight virtual machine for RISC-V architecture. TeleVM can achieve strong isolation through hardware support from the RISC-V. Compared with traditional virtual machines, TeleVM only implements a small number of I/O devices and functions, which can effectively reduce memory overhead and boot time. We compared TeleVM and QEMU+KVM through experiments. Compared to QEMU+KVM, the boot time and memory overhead of TeleVM have decreased by 74% and 90% respectively. This work further improves the cloud computing software ecosystem of RISC-V architecture and promotes the use of RISC-V architecture in cloud computing scenarios.**

***Index Terms*—Hypervisor, RISC-V, serverless, virtualization.**

I. INTRODUCTION

SERVERLESS has become a popular technology in cloud computing. Serverless applications must be able to handle different requests through rapid scaling to adapt to constantly changing workloads. And strong isolation should be implemented between workloads of multiple customers. Virtual machines can provide isolation and security through hardware assisted virtualization, but traditional virtual machines have drawbacks such as slow startup and high resource overhead. Containers have low overhead, but multiple containers share the operating system kernel, which poses a security risk. Therefore, the industry and academia have proposed lightweight virtual machines, which have the security of virtual machines while achieving low overhead and fast startup, and have become an ideal solution for serverless computing.

Currently, there are some lightweight virtual machine projects such as Firecracker [1] and Stratovirt [2], but these projects only support x86 and ARM architecture. RISC-V is an open source instruction set architecture, first released by the University of California, Berkeley, in 2010. In recent years, RISC-V architecture has been rapidly developing, and its application scenarios

II. RELATED WORK

Firecracker [1] is a lightweight virtual machine for serverless and container applications. Firecracker has a minimalist design that retains a small number of management functions and device models. Cloud Hypervisor [6] is a virtual machine open-sourced by Intel. It shares some code with Firecracker, but the difference is that it has more features and device models, aiming to be a general purpose VMM for cloud workloads. Stratos-rt [2] is an open-source lightweight virtual machine in the OpenEuler

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Enhancing RISC-V Vector Extension for Efficient Application of Post-quantum Cryptography

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***Abstract*—We present a cryptography extension built on RISC-V Vector Extension for efficient application of lattice-based post-quantum cryptography, offering custom instructions that can perform vectorized operations on polynomials of variable length and data width. We use micro-operation architecture to simplify the instruction design. Additionally, we implement a configurable fruitarable modular arithmetic unit to support operations on variable coefficient width. On this basis, a vector unit is designed, achieving significant speed-up compared to the state-of-the-art counterparts for number-theoretic-transform-based polynomial multiplication. We integrate our design into a RISC-V processor and run the good simulator to evaluate CRYSTALS-Kyber and CRYSTALS-Dilithium; results outperform the state-of-the-art implementation with more than 2.31× improvement in cycle count.**

***Index Terms*—Post-quantum cryptography, RISC-V, Vector Architecture, ISA Extension**

I. INTRODUCTION

Modern information society relies on Public-key Cryptography (PKC) as a reliable security infrastructure. However, the emergence of the quantum computer, combined with Shor's algorithm [1], enables attackers to quickly crack traditional PKC algorithms. Therefore, it is necessary to develop quantum-resistant PKC algorithms as the next generation of cryptosystems.

In this regard, the National Institute of Standards and Technology (NIST) launched the Post-Quantum Cryptography (PQC) Standardization process. In July 2022, NIST announced four candidate algorithms for standardization, with Kyber key encapsulation mechanism [2] and Dilithium digital signature scheme [3] selected as the PQC algorithms. selected as two primary algorithms to be used broadly because of their strong security and excellent performance [4].

As the standard PQC algorithms have been selected, the cryptographic implementations on processors call for faster migration to the post-quantum cryptosystem. However, empowering general-purpose processors with quantum resistance is challenged by complex polynomial operations over finite fields with variable data width. Under such circumstances, the instruction set extension (ISE) strategy can play an instrumental role in deploying PQC on processors due to its fine balance between achieving performance advantages and

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基于 LLVM 的 RISC-V 自定义扩展指令支持方法①

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摘 要: RISC-V 指令集架构具有模块化、可扩展等特性. 基于 RISC-V 架构的处理器, 可以在整数指令集的基础之上, 根据具体处理器的设计需求和应用场景的不同, 以及总指令数、对于每个指令的操作位宽之扩展指令集. 用户都需要自己在编译工具链中实现相应支持. 通过分析 LLVM 编译框架, 研究 RISC-V 自定义扩展指令支持的通用方法, 并以支持 CV10 自定义指令集为例进行实现和验证. 为基于 LLVM 基础架构的 RISC-V 自定义指令集扩展研究与实现提供借鉴.

关键词: LLVM; RISC-V; 自定义扩展; CV10

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Method of LLVM-Based RISC-V Custom Extended Instructions Support

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Abstract: The RISC-V instruction set architecture features modularization and scalability. On the basis of the integer instruction set, the RISC-V architecture based processors can optionally support the official standard and non-standard custom instruction set extensions. This also means that, or each new custom extended instruction set, users need to implement corresponding support in the compiler toolchain. After analyzing the LLVM compilation framework and researching the general methods supporting RISC-V custom extended instructions, we conduct the implementation and verification with the XuanTie C910 custom instruction set as an example. The results can provide references for the research and implementation of RISC-V custom instruction set extension based on LLVM infrastructure.

Key words: LLVM; RISC-V; XuanTie C910

由于 RISC-V 指令集架构具有开源、模块化、可扩展等特性, 后年来在非多领域迅速兴起. 国内外也出现了一些基于 RISC-V 进行指令集扩展的研究和实现. 例如, 神经网络指令集扩展研究[7–9], 如密指令集扩展研究[10], 千头等公司发布的玄铁 C910 处理器[11]等. 对于标准指令集扩展, RISC-V 社区会提供完整的工具链

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本文在"RISC-V 技术与生态"专题的编辑组成员审核意见、评审组长以及匿名评选意见基础上提升而成.
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基于 LLVM 的 RISC-V 向量扩展栈帧布局优化①

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[2]浙江工业大学 计算机科学与技术学院, 杭州 310012)
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摘 要: 为了能够生成正确、优化的机器指令代码, 需要在编译器后端代码的生成阶段, 设计和使用合适的程序栈帧布局. 由于 RISC-V 向量扩展架构具有可伸缩特, 其向量寄存器的长度在编译时不可知, 传统的栈帧布局无法适用. 之前 LLVM 中针对向量扩展实现的栈帧布局虽然能够生成正确的机器指令, 但仍依旧存在许多优, 栈帧空间较大, 以及预留寄存器较多等问题. 我们对所有实现所存在的问题进行分析, 在此基础上提出了新的布局方式以及向量对象地址计算方式, 并通过巴塞罗那超算中心开发的测试集进行验证. 实验表明新的栈帧布局能够有效减少语言指令数和栈空间大小.

关键词: LLVM; RISC-V; 向量扩展; 栈帧布局

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Optimization of RISC-V Vector Extension Stack Frame Layout Based on LLVM

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Abstract: For correct and optimized machine instructions, it is necessary to design and use a suitable program stack frame layout during the code generation stage of the compiler back-end. Due to the scalability of the RISC-V vector extension architecture and the unknown length of its vector register at compile time, the traditional stack frame layout cannot be applied. Although the previous stack frame layout implemented for vector extension in LLVM can generate correct machine instructions, it has problems such as many load/store instructions and reserved registers as well as large stack frame sizes. We analyze the problems existing in the previous implementation and propose a new layout and vector object calculation method on this basis. Then we verify it through the test set developed by the Barcelona Supercomputing Center. Experiments show that the new stack frame layout can greatly reduce the number of load/store instructions and stack space.

Key words: LLVM; RISC-V; vector extension; stack frame layout

1 引言

LLVM[12,13]是一种开源的编译基础设施, 采用模块化的方式进行设计, 具有前端的架构层次和评指的文档资料, 并且提供了丰富的工具集, 因此基于 LLVM 来开发支持特定体系结构的编译器, 可以即短开发时间, 并生成高效的代码.

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Foundation item: CAS Strategic Priority Program (Category C)(XDC05040200)
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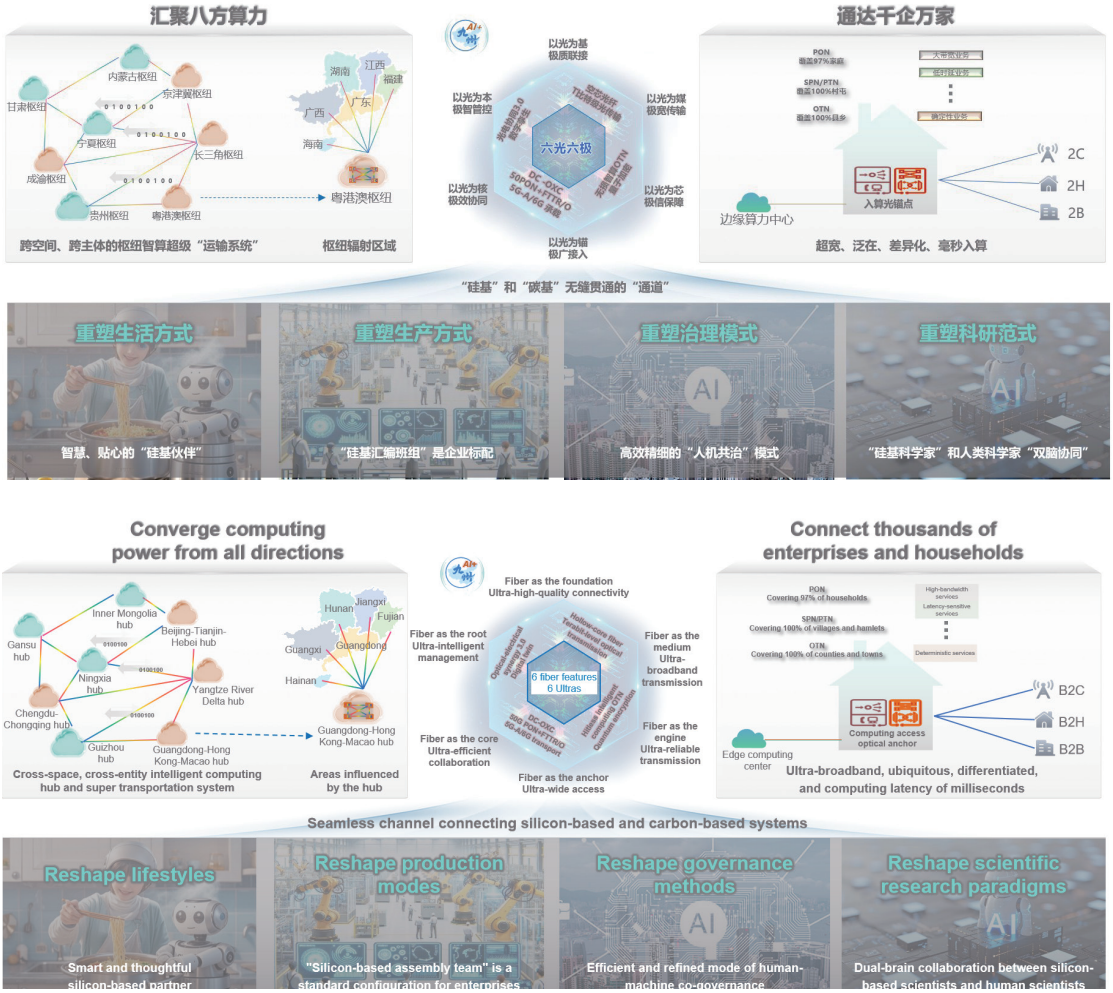


“九州”算力光网总体架构及远景
Overall architecture and vision of the "Jiuzhou" computing optical network

“九州”算力光网
"Jiuzhou" Computing Optical Network

中国移动通信集团有限公司
China Mobile Communications Group Co., Ltd.

华为技术有限公司
Huawei Technologies Co., Ltd.

中兴通讯股份有限公司
ZTE Corporation

烽火通信科技股份有限公司
FiberHome Telecommunication Technologies Co., Ltd.

引言

“九州”算力光网以“光电贯东西，触点达厅堂”的网络能力，实现数据要素跨区域、跨主体的高效互联，促进 AI 具身智能体发展，推动社会迈向“硅碳融合”新范式。

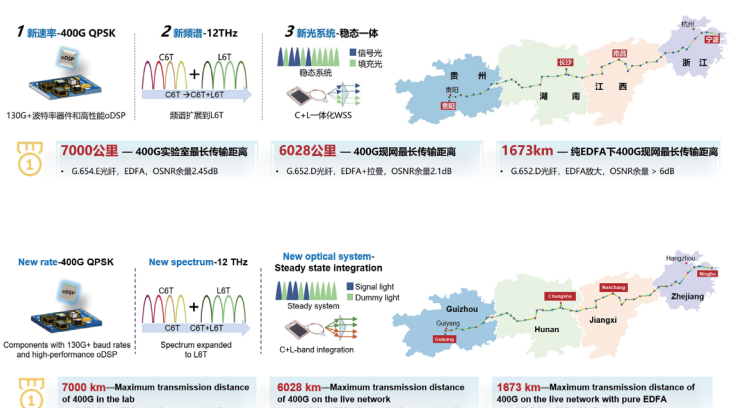
Introduction

Leveraging its network capabilities of spanning the east and west with optoelectronic integration and reaching every space with intelligence, the "Jiuzhou" computing optical network efficiently interconnects data elements across regions and entities, fosters the development of embodied AI agents, and propels society toward a new paradigm of silicon-carbon integration.

原创“九州”算力光网，引领宽带互联与普惠入算新格局

Original "Jiuzhou" Computing Optical Network Is Pioneering a New Paradigm of Broadband Interconnection and Inclusive Computing Access

本成果面向 AI 算力时代算间跨区域大规模互联和末端多业务高并发入算的核心挑战，提出新型“九州”算力光网并实现系统性创新突破。在算间互联方面，原创构建基于 QPSK 码型、130GBd 超高速器件和 C6T+L6T 宽谱架构的 400G 全光网，实现传输距离提升 50%、波段扩展 200%，并首次揭示宽谱受激拉曼散射机理，提出 SRS 功率均衡等原创方案，全面突破宽谱传输理论瓶颈，刷新 6028km 现网、7000km 实验室与 1673km 商用场景三大世界纪录，开启 400G 商用元年。在普惠入算方面，原创提出 SPN 小颗粒切片技术，统一 TDM 与分组交换，实现单节点时延优于 3μs、同步精度优于 5ns 和 <1ms 保护倒换，并形成国际标准化进程；同时主导 50G PON 与 FTTR 国际标准制定，攻克 32dB 功率预算瓶颈，提出 oDSP 动态均衡和光层 OAM 原生管控，解决千兆体验与灵活组网难题。

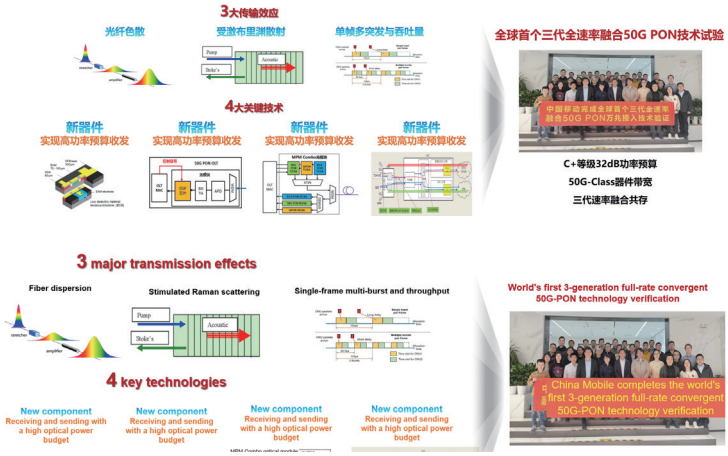


400G 全光骨干网关键技术及长距传输记录
Key technologies of 400G all-optical backbone networks and long-haul transmission records

成果已在中国实现规模部署并向全球推广，算间承载能力超 30PB、泛在覆盖超 6 亿用户。

This achievement addresses the core challenges of large-scale cross-regional interconnection between computing centers and multi-service high-concurrency computing access on end nodes in the AI computing era, by proposing a novel "Jiuzhou" computing optical network and achieving systematic innovation breakthroughs. In terms of interconnection between computing centers, China Mobile has pioneered a 400G all-optical network based on the QPSK modulation format, 130 GBd ultra-high-speed components, and a C6T+L6T wide-spectrum architecture. This innovation boosts the transmission distance by 50% and expands the band range by 200%. For the first time, it reveals the mechanism of wide-spectrum stimulated Raman scattering (SRS) and introduces original solutions such as SRS power equalization. These breakthroughs overcome theoretical bottlenecks in wide-spectrum transmission and set three new world records: 6028 km in live networks, 7000 km in laboratory tests, and 1673 km in commercial deployment—ushering in the inaugural year of 400G commercialization. In the domain of inclusive computing access, China Mobile has pioneered SPN small-granularity slicing technology to unify TDM and packet switching, achieving single-node latency below 3 μs, synchronization accuracy better than 5 ns, and protection switching time shorter than 1 ms—while initiating the process of international standardization. In addition, China Mobile has led the formulation of

international standards for 50G PON and FTTR, overcome the 32 dB power budget bottleneck, and proposed oDSP dynamic equalization and native OAM management and control at the optical layer, to solve the problems of gigabit experience and flexible networking. The solution has been deployed on a large scale in China and promoted globally, delivering over 30 PB of inter-computing capacity and ubiquitous coverage for more than 600 million users.



三代五模 50G PON 关键技术与全球首验证
Key technologies of third-generation five-mode 50G PON and their first global verification

“九州”算力光网：降门槛、促降碳、拉动万亿产业
"Jiuzhou" Computing Optical Network Lowers Barriers, Drives Carbon Reduction, and Powers Trillion-Yuan Industries

“九州”算力光网整合 OTN、SPN、PON 技术优势激活经济效益新增长，为千行百业用网提供极大的便捷，将促进各种场景应用的不断丰富和发展，带动超过 1000 亿的 GDP 经济产出，形成万亿级以上的产业规模。

“九州”算力光网是构建广域一体化算力网的基础，极大的降低了整个社会调动利用算力的门槛，将算力、存储、带宽等资源疏导至千行百业，利用普惠的算力和 AI 能力，支撑起互联网短视频、直播等业务并实现云游戏、裸眼 3D、大数据、物联网等技术创新与产业化应用，助力全社会数智化转型升级的一大步，持续促进新一轮经济增长。

“九州”算力光网功耗降低每年可节电 8.7 亿度，相当于减少 CO_2 排放 50.4 万吨，等效于累计种



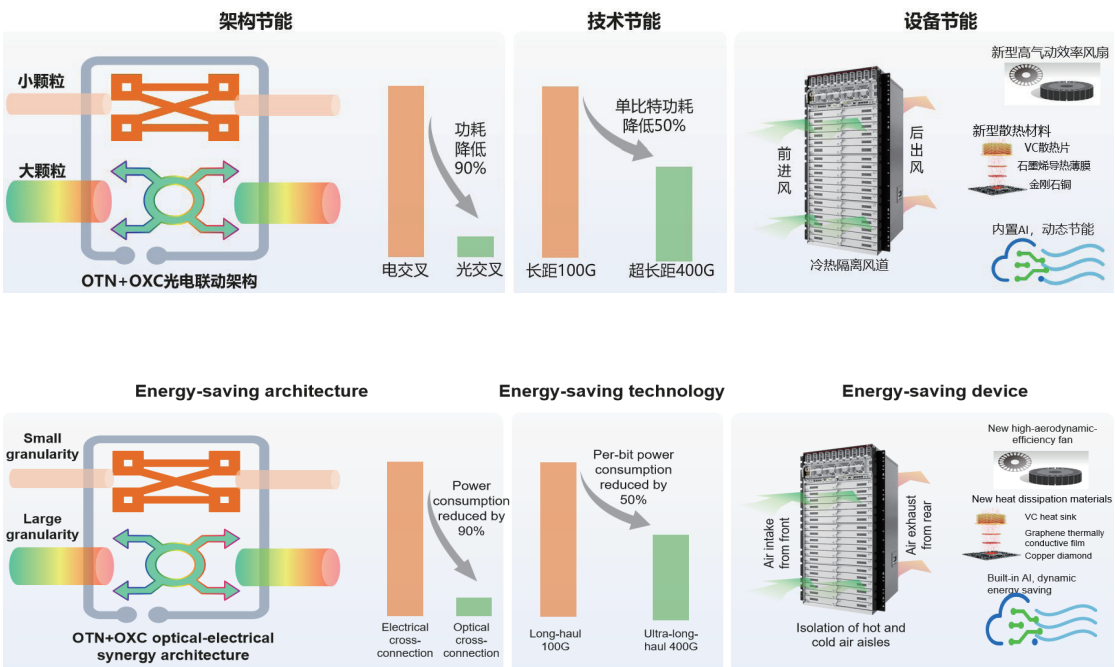
“九州”算力光网业务场景示意图
Service scenarios of the "Jiuzhou" computing optical network

树约 2800 万棵，为实现碳达峰的目标作出巨大贡献。

The "Jiuzhou" computing optical network integrates the strengths of OTN, SPN, and PON technologies to unlock new economic growth, offering significant convenience for network usage across diverse industries. It will accelerate the expansion and enrichment of application scenarios, drive over CNY100 billion in GDP output, and foster an industrial ecosystem exceeding CNY1 trillion in scale.

The "Jiuzhou" computing optical network serves as the foundation for building a wide-area integrated computing network, significantly lowering the barriers for the society to access and utilize computing power. It channels resources such as compute, storage, and bandwidth into a wide range of industries, leveraging inclusive computing and AI capabilities to support services like short video and livestreaming, while enabling technological innovation and industrial applications in cloud gaming, naked-eye 3D, big data, and the Internet of Things. This marks a major step toward the digital and intelligent transformation of society, continuously driving a new wave of economic growth.

The "Jiuzhou" computing optical network can save 870 million kWh of electricity every year, reducing CO_2 emissions by 504,000 tons, which is equivalent to planting 28 million trees, making a great contribution to achieving the carbon peak target.



“九州”算力光网节能降碳示意图

Energy saving and carbon reduction of the "Jiuzhou" computing optical network

400G 全光传输等核心技术突破引领光通信产业链结构升级

Breakthroughs in Core Technologies such as 400G All-Optical Transmission Are Driving Upgrade of the Optical Communication Industry Chain

本项目对推动技术进步和产业结构调整、优化与升级具有深远影响。

技术引领方面：本项目实现了全光 400G 传输、50GPON 等多项原创突破；通过新型铟磷材料和新型掺杂技术、星座图整形算法技术突破 140G+ 高波特率材料和工艺限制，实现高性能 400G 的量产部署；突破 50G APD 关键技术，在现网实现万兆应用中达成 50G PON 对称 Class C+ 目标；荣获中国国家 / 省部奖 13 项，行业奖 20 项，累积申请专利 350 项，主导标准制定 100 余项。

产业结构优化升级：本项目在推动光通信迈入宽谱和超高速时代的同时，还带动了光电器件、算法、标准等全产业链代际跃升，催熟 400G 现网规模部署，在实现产业链的升级的同时，带动中国三大运营商均完成规模集采部署，国际 30+ 主流运营商部署，实现全球产业链的升级。

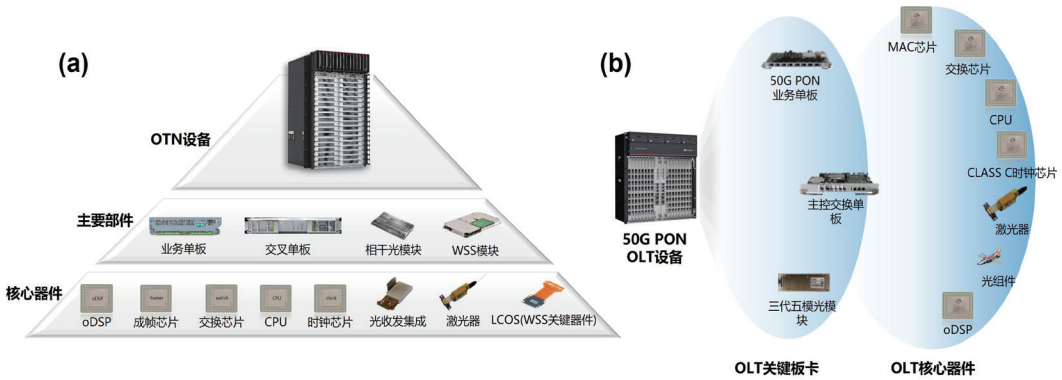
This project has far-reaching impact on the advancement of technologies and the restructuring, optimization, and upgrade of the industrial structure.

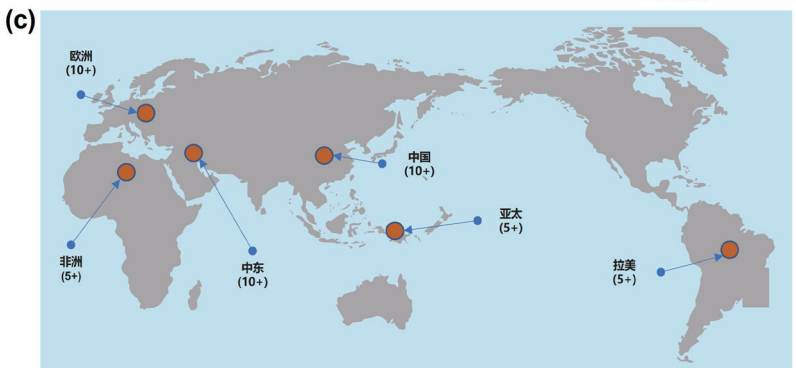
Technology leadership: This project has achieved multiple original breakthroughs, including all-optical 400G transmission and 50G PON. By leveraging new indium phosphide materials, new doping techniques, and probabilistic constellation shaping (PCS) algorithms, it has overcome the limitations of 140G+ high baud rate materials and processes, enabling mass deployment of high-performance 400G. It has also broken through key 50G APD technologies, reaching the symmetrical Class C+ target for 50G PON in live 10G applications. The project has won 13 national/provincial awards in China and 20 industry awards, applied for 350 patents, and led the formulation of more than 100 standards.

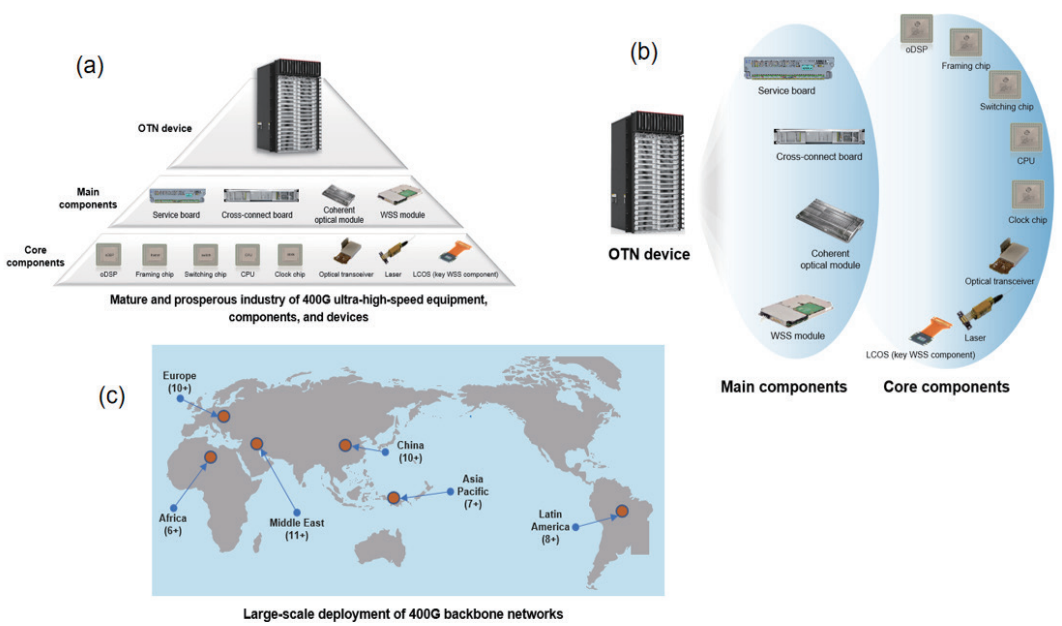
Industrial structure optimization and upgrade: While propelling optical communications into the era of wide-spectrum and ultra-high-speed transmission, this project has also driven generational leaps across the entire industry chain, including optoelectronic components, algorithms, and standards. It has accelerated large-scale deployment of 400G on live networks, enabling an industry-wide upgrade. As a result, all three major Chinese operators have completed large-scale centralized procurement, and over 30 leading international operators have adopted the technology, advancing the global industry chain.



在技术进步方面的影响力示意图
Impact on technological progress



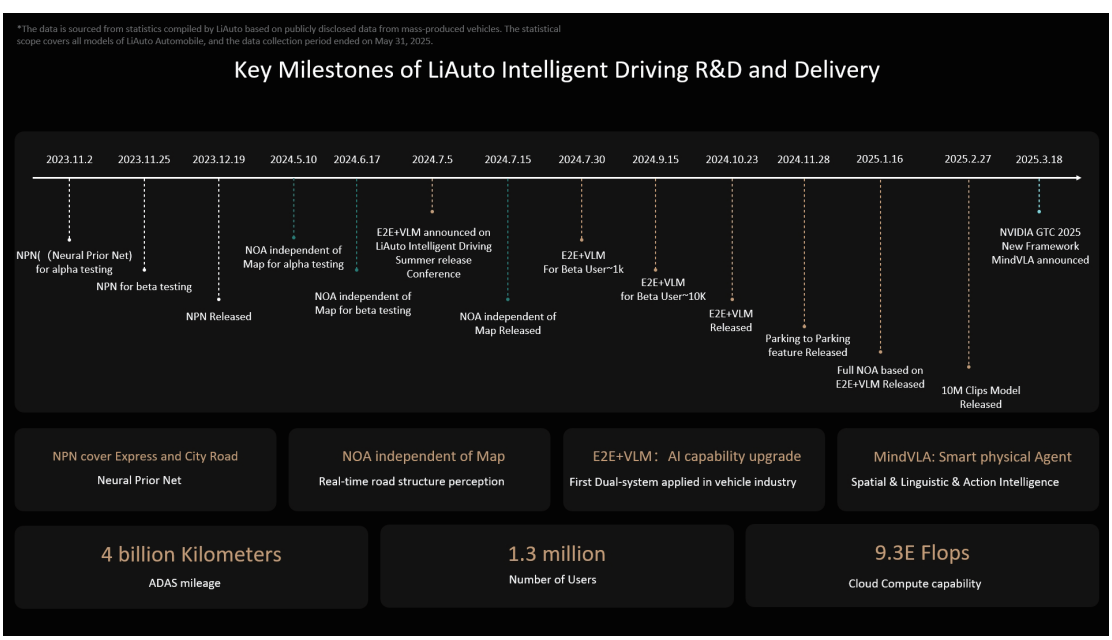




(a) 400G OTN 产业链带动分解；(b) 50G PON 产业链带动分解；(c) 带动全球 400G 全光骨干网规模部署情况

(a) Breakdown of the 400G OTN industry chain; (b) Breakdown of the 50G PON industry chain; (c) Global large-scale deployment of 400G all-optical backbone networks





理想汽车辅助驾驶研发交付关键里程碑
Key Milestones in Li Auto's Assisted Driving R&D and Delivery

理想汽车辅助驾驶技术创新及应用

Li Auto's Technological Innovations and Applications in Assisted Driving

北京理想汽车有限公司
Beijing Li Auto Co., Ltd.

理想

引言

理想汽车深耕辅助驾驶技术。截至 2025 年 5 月 31 日，获辅助驾驶专利 123 项、软件著作权 13 项、在人工智能顶级学术会议与期刊发表论文 34 篇、参与 15 项国家标准起草；在国际竞赛屡获佳绩，且是首个交付破百万辆的中国新势力车企，累计交付超 130 万辆，辅助驾驶功能使用率高达 99%。

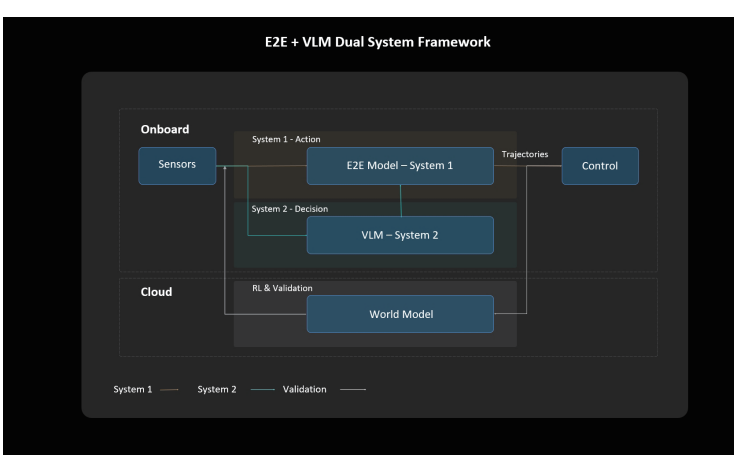
Introduction

Li Auto has been deeply engaged in assisted driving technology. As of May 31, 2025, it has accumulated 123 patents, 13 software copyrights in the field of assisted driving, published 34 papers in top AI academic conferences and journals, and participated in drafting 15 national standards. Li Auto has also achieved outstanding results in international competitions and is the first Chinese new energy vehicle manufacturer to exceed one million deliveries, with cumulative deliveries exceeding 1.3 million units. The usage rate of its assisted driving features has reached as high as 99%.

端到端 +VLM 架构，破解辅助驾驶难题，首家完成车端部署

End-to-End + VLM architecture: Tackling Assisted Driving Challenges, First to Achieve On-Vehicle Deployment





端到端 +VLM 系统架构
End-to-End + VLM Architecture

通过仿人类快慢系统理论，端到端 “快系统” 高效处理 95% 常规场景，VLM “慢系统” 应对 5% 复杂场景；利用多传感器输入，经 CNN、Transformer 处理，多任务输出，无中间规则，优势显著。模型拥有 22 亿参数量，统一 Transformer 架构，可识别环境、理解规则、修正导航；结合世界模型的重建与生成路径，构建虚拟环境，助力系统迭代。

端到端模型提升道路理解，VLM 识别复杂标识规则，显著提升复杂场景的应对能力；基于人类数据训练，提升舒适性与通行效率，实现拟人驾驶；通过虚拟环境结合云端算力，快速优化模型，提升迭代效率。作为首个在车端部署的双系统架构，开创技术新方向，具备覆盖广、性能优，体验领先的场景与性能。在识别中文信息和理解中文语义方面具有独特优势。

Based on the human fast-slow system theory, the End-to-End model, as the "fast system," efficiently handles 95% of routine driving scenarios, while the VLM (Vision-Language Model), as the "slow system," manages the remaining 5% of complex situations. Multi-sensor inputs are processed through CNNs and transformer models to produce multi-task out-

puts without intermediate rules, offering significant advantages. The model contains 2.2 billion parameters within a unified Transformer framework, capable of environmental perception, traffic rule understanding, and navigation correction. By integrating reconstruction and generation pathways of the world model, a virtual environment is created to support efficient system iteration.

The End-to-End model enhances road understanding, while the VLM identifies complex traffic signs and rules, significantly improving performance in complex scenarios. Trained on human driver data, the system enhances ride comfort and traffic efficiency, achieving human-like driving behavior. Leveraging virtual environments and cloud computing, the model can be rapidly optimized to accelerate iteration. As the first dual-system architecture deployed on vehicle terminals, it pioneers a new technical direction, offering broad coverage, high performance, and a leading user experience. It also possesses unique advantages in recognizing Chinese text and understanding Chinese semantics.

端到端 + VLM 架构，经济效益、社会效益和生态效益显著
End-to-End + VLM Architecture Delivers Significant Economic, Social, and Ecological Benefits



2024 年理想汽车交付量超 50 万台
Li Auto delivered over 500,000 vehicles in 2024

端到端 +VLM 架构的应用，推动理想汽车 2024 年交付量超 50 万台；简化系统复杂度、提升模型迭代效率以降低研发成本，还为行业树立技术标杆，促进行业技术进步。该技术累计避险超 700 万次以提升出行安全，实现 “车位到车位” 一键智驾增强便利性，优化拥堵路况决策以提高交通效率，结合理想星环 OS 操作系统有望为智能交通发展提供支持。理想作为率先落地该架构的车企，端到端 +VLM 架构为辅助驾驶技术提供新方向，带动高性能芯片等产业链发展，同时增强消费者对电动车信心，助力交通领域绿色低碳发展。

The application of the End-to-End + VLM architecture drives Li Auto's 2024 deliveries to exceed 500,000 units. By simplifying the complexity of traditional assisted driving systems and facilitating model iteration, it helps reduce R&D costs while setting a technological benchmark for the industry and promoting technological advancement. This technology has cumulatively prevented over 7 million potential risks, enhancing travel safety, enabled the “parking space to parking space” one-click assisted driving to improve convenience, and optimized decision-making on congested roads to increase transportation efficiency. Combined with the Li Auto Halo OS vehicle operating system, it is expected to support the development of intelligent transportation. As the first automaker to implement this architecture, Li Auto’s End-to-End + VLM approach provides a new direction for assisted driving technology, drives the development of high-performance chips and related industries, strengthens consumer confidence in EVs, and contributes to green and low-carbon development in the transportation sector.

端到端 + VLM 架构，推动了技术进步和产业结构升级
End-to-End + VLM Architecture Has Driven Technological Advancements and Upgraded the Industry Structure

端到端 + VLM 架构的应用，为全球汽车行业提供新路径，推动人工智能多模态融合算法优化，加速智驾模型迭代，同时带动高性能传感器研发，促进感知技术进步。该架构提升了理想汽车产品附加值，推动汽车产业向软硬件并重转型；促进汽车与 AI、大数据等产业融合，带动传感器、芯片等上下游发展，如助力禾赛发展成为全球第一大激光雷达企业，助力地平线在辅助驾驶芯片上的市占率达到中国第一。分别与清华大学、中科院自动化所开展辅助驾驶技术研究，推动了相关科研成果转化和人才培养，推动完善了产业生态。

The application of the End-to-End + VLM architecture has opened a new path for the global automotive industry. It advances the optimization of multimodal AI fusion algorithms, accelerates the iteration of assisted driving models, and drives the development of high-performance sensors, thereby promoting progress in perception technology. This architecture enhances the added value of Li Auto's products and accelerates the automotive industry's transformation toward an integrated hardware-software paradigm. It also fosters integration between the automotive sector and industries such as AI and big data, while stimulating upstream and downstream industry development in sensors and chips—for example, supporting Hesai Technology in becoming the world's largest lidar enterprise and helping Horizon Robotics achieve the largest market share in assisted driving chips in China. Li Auto has also carried out joint research on assisted driving technologies with Tsinghua University and the Institute of Automation of the Chinese Academy of Sciences, promoting relevant scientific research achievement transformation and talent cultivation and contributing to the improvement of the industrial ecosystem.



学术成果与国际奖项
Research Accomplishments and International Recognition

基于端到端 +VLM 的实践，上线 VLA 司机大模型
Launching the VLA Driver Large Model Based on End-to-End + VLM Practices

2025 年 2 月，理想汽车完成 1000 万 Clips 模型的全量推送，达成了真正的高阶辅助驾驶里程碑。理想汽车辅助驾驶技术在领先的地位上从未停止探索，基于端到端 +VLM 双系统架构的最佳实践，及对前沿技术的敏锐洞察，理想汽车发布了自研 VLA 模型——MindVLA。VLA 是机器人大模型的新范式，其赋予辅助驾驶强大的 3D 空间理解能力、逻辑推理能力和行为生成能力，让辅助驾驶能够感知、思考和适应环境。2025 年 9 月 10 日，理想汽车开启 VLA 司机大模型全量推送。



辅助驾驶 MindVLA 架构
Assisted Driving Architecture: MindVLA

In February 2025, Li Auto completed the full customer release of the new model, trained on 10 million videos clips, marking a significant milestone in advanced assisted driving. Li Auto has never ceased its exploration in maintaining its leading position in assisted driving technology. Building on the best practices of the End-to-End + VLM dual-system architecture and keen insights into cutting-edge technologies, Li Auto released its self-developed VLA model — MindVLA. VLA (Vision-Language-Action) represents a new paradigm in large-scale robotics models, endowing assisted driving with powerful 3D spatial understanding, logical reasoning, and behavior generation capabilities, enabling vehicles to perceive, think, and adapt to their environment. On September 10, 2025, Li Auto launched the full release of its VLA Driver large model.





面向云系统的数据安全防护关键技术与应用概况
Overview of Key Technologies for Data Security Protection in Cloud Systems and Their Application

面向云系统的数据安全防护关键技术与应用

Key Technologies for Data Security Protection in Cloud Systems and Their Application

奇安信科技集团股份有限公司
Qi An Xin Technology Group Inc.

无锡芯光互连技术研究院有限公司
WUXI Institute of Interconnect Technology

中国科学院计算技术研究所
Institute of Computing Technology, Chinese Academy of Sciences

引言

云系统数据安全防护关键技术与应用，旨在应对数字化转型加速所带来的日益严峻的云上数据安全风险。相关成果已在国际上得到广泛应用，并赢得了客户的高度赞誉与行业权威奖项的认可。

Introduction

Key technologies for data security protection in cloud systems and their application aim to deal with the increasingly severe risks related to data security in the cloud as a result of the accelerated digital transformation. Some achievements have been widely applied internationally and are highly recognized by customers. They have won many awards ratified in the industry.

攻克三大难题，提升云系统数据安全防护能力
Addressing three major challenges to enhance data security protection capabilities in cloud systems

云系统数据安全面临三个亟待解决的关键问题：可信机密计算效率差、单一维度流量检测精度低、高安全密文计算速度慢。本成果通过以下技术创新解决了上述技术问题。

Data security in cloud systems is challenged by: poor efficiency of trusted confidential computing, low accuracy of single-dimensional traffic detection, and slow computing speed of high-security ciphertext. They have been solved by the following technical innovations:

一是提出自主可信机密计算优化技术，突破了传统可信计算和机密计算的效率瓶颈，在实现云平台信任链高效扩展的同时保障了加密设备间的高效互联互通，在硬件密钥稳定性和安全 I/O 执行效率上超越国际主流成果。

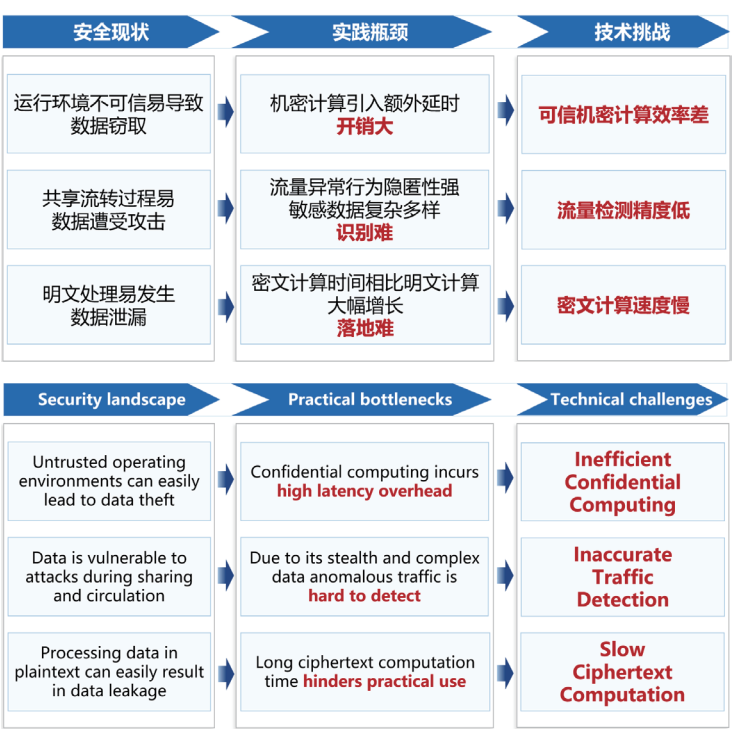
Firstly, the proposed optimized technology for autonomous and trusted confidential computing has broken bottlenecks in efficiency of traditional trusted computing and confidential computing, enabling the efficient extension of trust chains to cloud platforms while guaranteeing interconnectivity between encryption equipment. It has surpassed its peers in terms of hardware key stability and secure I/O execution efficiency.

二是提出多维流量深度检测防范技术，实现了云数据服务层复杂异常流量的有效检测和敏感信息泄露的高精度识别，为提升“一带一路”沿线国家流量检测能力提供了有力的技术支撑。

Secondly, the multi-dimensional traffic deep detection and prevention technology has enabled effective detection of complex anomaly traffic and achieved high-precision detection of sensitive information leakage at the cloud data service layer. As such, it has contributed to traffic detection capabilities of countries along the “Belt and Road”.

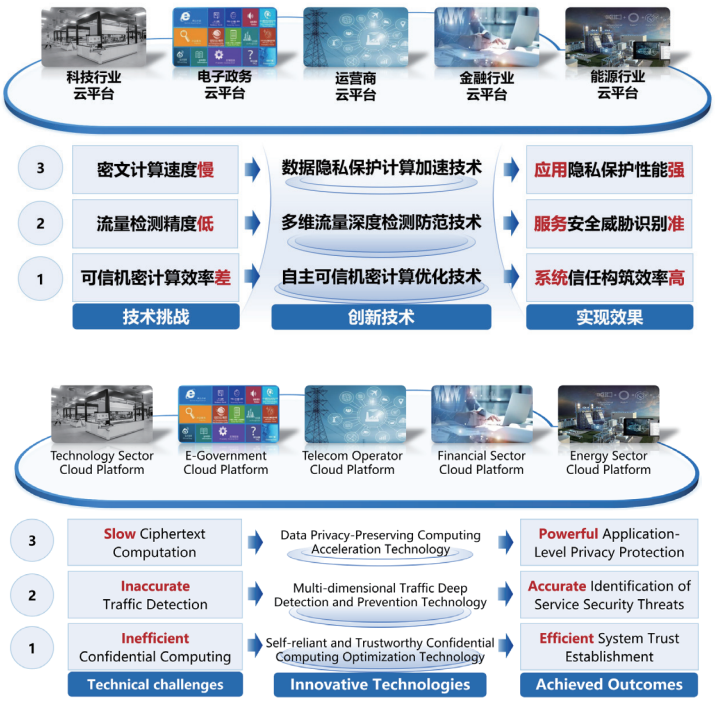
三是提出数据隐私保护计算加速技术，突破了核心算子与整体算法的效率瓶颈，首次实现了支持安全多方计算的加速卡、支持隐私保护应用的加速芯片，大幅提升安全多方计算和全同态加密应用的计算速度。

Thirdly, the data privacy protection computing acceleration technology has over-



面向云系统的数据安全防护三个技术难题
Three Technical Bottlenecks Facing Data Security Protection in Cloud Systems

come low efficiency in core operators and overall algorithms. Also, the acceleration card supporting secure multi-party computation and the acceleration chips supporting privacy protection applications have been introduced for the first time. This has substantially elevated the computing speed of secure multi-party computation and the fully homomorphic encryption.



面向云系统的数据安全防护三个技术难题
Three Technical Bottlenecks Facing Data Security Protection in Cloud Systems

完成规模化应用，护航数字化转型
Achieving large-scale deployment to safeguard digital transformation

成果提升了重要行业的云数据安全防护能力，广泛应用于金融、电子政务、公检法、通信、能源、交通、教育等多个涉及国计民生的重要行业。累计在 1000 余家大型政企机构的云平台上进行了部署，占行业单位总数的 65%，为提升相关重要单位云平台数据安全防护能力，保障大型行业机构业务上云，推动数字化转型发挥了关键支撑作用。成果尤其支撑了中国主要运营商构建安全可靠的云平台，保障了运营商大数据、管理信息、运营平台等主要 IT 系统关键业务的开展运行，切实强化了云数据安全防护能力，扩展了数据应用的场景。主要应用单位包括上海证券交易所、华夏银行、贵州政务云、福建政务云等。

The technology has promoted cloud-based data security protection capabilities in major industries. It has been implemented in sectors including finance, E-government, public security organs, communications, energy, transport and education. As of today, it has been deployed on the cloud platforms of more than 1,000 large institutions, accounting for 65% of the total number of organizations in the industry. Accordingly, the data security protection capabilities of cloud platforms in major entities have been strengthened, so that they are more active to apply cloud. In this way, the digital transformation has been boosted. In particular, our technical achievements have supported major operators in China to build secure and reliable cloud platforms, escorting smooth operation of major IT systems like the big data, management information and operation platforms. They have truly reinforced the operators' cloud data security protection capabilities and expanded application scenarios of data. It is in service in Shanghai Stock Exchange, Hua Xia Bank, Guizhou Government Cloud, and Fujian Government Cloud.

历经实战检验，获得社会广泛认可
Earning widespread societal recognition with proven effectiveness through extensive real-world applications

成果有力支撑了各类中国国家级重大会议活动期间相关重要单位的云系统数据安全防护，为保障各类国家级重大会议活动的网络安全提供了有力技术支撑，荣获 2022 年度云原生安全技术创新案例、网络安全技术应用试点示范项目、2021-2022 年度新一代信息技术创新产品等荣誉奖项。

Our achievements have provided data security protection for cloud systems in major entities during the national-level conferences and events and vigorously supported cybersecurity. They have won awards such as the 2022 Cloud Intrinsic Security Technology Innovation Case, Network Security Technology Application Demonstration Project and 2021-2022 New-generation IT Innovation Product.



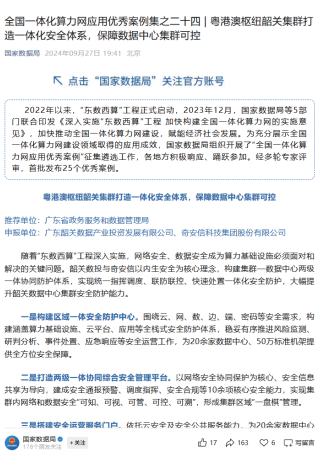
荣获 2022 年度云原生安全技术创新案例
2022 Cloud Intrinsic Security Technology Innovation Case



荣获 2023 年央国企上云用云典型案例遴选优秀案例
Outstanding Cases for Cloud Application in Central Enterprises and SOEs in 2023

项目成果还成功应用于粤港澳枢纽韶关集群等国家“东数西算”战略重要算力枢纽，有效提升了中国重要行业云数据安全防护能力。2024 年，项目成果帮助粤港澳枢纽韶关集群算力节点成功入选中国国家数据局首批“全国一体化算力网应用优秀案例”。

They have been applied to important computing hubs in the national “Channel Computing Resources from the East to the West” strategy, such as the Guangdong-Hong Kong-Macao Greater Bay Hub Shaoguan Cluster, effectively enhancing China's cloud data security protection capabilities in important industries. In 2024, the Guangdong-Hong Kong-Macao Greater Bay Hub Shaoguan Cluster was selected to be the “Outstanding Application Case of National Integrated Computing Power Network”, among the first batch of National Data Administration.


全国一体化算力网应用优秀案例集之二十四 | 粤港澳枢纽韶关集群打造一体化安全体系，保障数据中心集群可控

国家数据局 2024年09月27日 19:41 北京

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2022年以来，“东数西算”工程正式启动，2023年12月，国家数据局等5部门联合印发《深入实施“东数西算”工程 加快构建全国一体化算力网的实施意见》，加快推动全国一体化算力网建设，赋能经济社会发展。为充分展示全国一体化算力网建设领域取得的应用成效，国家数据局组织开展了“全国一体化算力网应用优秀案例”征集遴选工作，各地方积极响应、踊跃参加。经多轮专家评审，首批发布25个优秀案例。

粤港澳枢纽韶关集群打造一体化安全体系，保障数据中心集群可控

推荐单位：广东省政务服务和数据管理局
申报单位：广东韶关数据产业投资发展有限公司、奇安信科技集团股份有限公司

随着“东数西算”工程深入实施，网络安全、数据安全成为算力基础设施必须面对和解决的关键问题。韶关数投与奇安信以内生安全为核心理念，构建集群一数据中心两级一体协同防护体系，实现统一指挥调度、联防联控、快速处置一体化安全防护，大幅提升韶关数据中心集群安全防护能力。

一是构建区域一体安全防护中心。围绕云、网、数、边、端、密码等安全需求，构建涵盖算力基础设施、云平台、应用等全栈式安全防护体系，稳妥有序推进风险监测、研判分析、事件处置、应急响应等安全运营工作，为20余家数据中心、50万标准机架提供全方位安全保障。

二是打造两级一体协同综合安全管理平台。以网络安全协同保护为核心、安全信息共享为导向，建成安全通报预警、调度指挥、安全合规等10余项核心安全能力，实现集群内网络和数据安全“可知、可视、可管、可控、可溯”，形成集群区域“一盘棋”管理。

三是探建安全运营服务门户。依托云安全及安全公共服务能力，为20余家数据中心

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17 163 6 写留言

入选中国国家数据局首批“全国一体化算力网应用优秀案例”
“Outstanding Application Case of National Integrated Computing Power Network”, among the first batch of National Data Administration



面向未来新型信息通信网络演进需求，开展架构范式、技术范式、资源范式、产业范式多维度创新，在算网多维资源要素及多制约因素等复杂条件下，提出“智算网一体”自研技术体系

To meet the evolving demands of next-generation information and communication networks, we are pursuing multi-dimensional innovation across architectural paradigms, technological paradigms, resource paradigms, and industrial paradigms. Under complex conditions involving multi-dimensional computing and networking resources and multiple constraints, we propose an “integrated AI, computing and network” technology system

面向智算网一体的算力网络关键技术创新与规模应用

Innovation and Large-Scale Application of Key Technologies for Computility Network Integrated with AI, Computing and Network

中国移动通信有限公司
China Mobile Communications Group Co.,Ltd.

华为技术有限公司
Huawei Technologies Co., Ltd.

中兴通讯股份有限公司
ZTE Corporation

新华三技术有限公司
H3C Technology Co., Ltd.

引言

中国移动全球首创“智算网一体”自主架构技术体系，构建最大规模智算设施集群（覆盖中国“东数西算”工程枢纽、超 1500 边缘节点）。成果获 WSIS 最高奖等权威认可，授权专利超 300 项、国际标准 169 项，支撑超 13 亿用户，带动千亿级产业规模，引领全球算力网络发展。

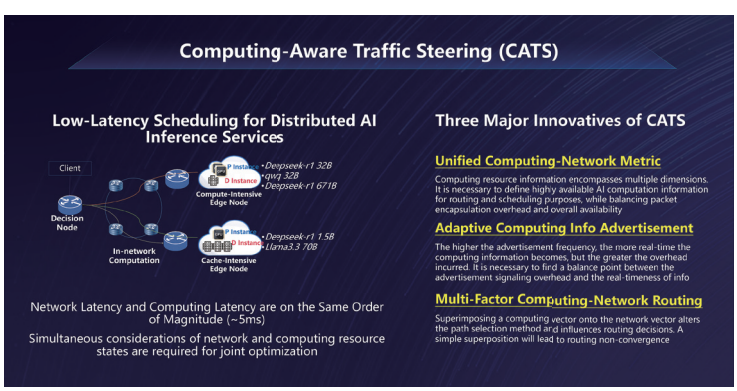
Introduction

China Mobile has pioneered the world's first integrated AI, Computing and Networking architecture, establishing the largest intelligent computing infrastructure cluster to date, which spans hubs of China's "east data, west computing" project and over 1,500 edge nodes. It is recognized with the WSIS Champion Prize and other top honors, the breakthrough has secured more than 300 patents and more than 100 international standards. Currently supporting more than 1.3billion users, the technology drives over 100 billion in industrial value while leading global computility network development.

全球首创“智算网一体”全栈技术体系实现核心性能数量级跃升

The world's first integrated AI, computing and network full-stack technology system achieves a performance leap by orders of magnitude





提出算力路由（CATS）技术，在网络中引入算力因子实现算网联合路由，攻克可扩展归一化有效算力表征、低开销自适应算力通告机制、有限决策域路由选路机制等多项难题

The Computing-Aware Traffic Steering (CATS) technology is proposed, which introduces a computing factor into the network to achieve joint computing and network routing. It addresses multiple challenges, including scalable and normalized effective computing representation, a low-overhead adaptive computing notification mechanism, and a finite decision domain-based routing path selection mechanism

本成果攻克了智算网一体化架构设计、超大规模集群通信、异构算力调度及广域高效互联四大世界级难题，主导制定国际标准 169 项，推动全球智能计算网络领域的创新与领导力。

架构首创：原创提出“智算网一体”融合架构，打破分层设计桎梏，实现设备 - 协议 - 服务全栈协同，奠定规模化应用基础；

性能跃升：卡间互联（OISA 技术）：首创全向对等架构，支持 1024 卡互联（规模提升 128 倍），带宽达 800GB/s（提升 14 倍），时延降低 90%；机间互联（GSE 技术）：创新全调度以太网，组网规模达传统方案 4 倍，时延降低 30%；

异构统管：首创任务非均匀切分框架，千卡异构训练效率达理论极限 95%，推理并发度提升 1.7 倍；

广域革新：算力路由（CATS）：主导成立 IETF 近 20 年唯二由中国引领的工作组，研制全球首台算力路由器，资源利用率提升 40%；广域抗损（uRDMA）：在 70ms 高时延、0.1% 丢包下实现 173Gbps 吞吐（传统方案 2.5 倍），破解长距传输瓶颈。

This achievement has overcome four world-class challenges: integrated archi-

tecture design for AI, computing and networks, communication in hyperscale clusters, heterogeneous computing scheduling, and efficient wide-area interconnection. It has spearheaded the development of 169 international standards, driving innovation in the global intelligent computing network field.





提出广域抗损高吞吐技术，首创基于协议栈全卸载的超远程直接内存访问（uRDMA）协议及智能抗损机制，攻克长距网络下丢包敏感难题

Proposing wide-area loss-resistant high-throughput technology, it pioneers the ultra-Remote Direct Memory Access (uRDMA) protocol based on full offload of the protocol stack and an intelligent loss resilience mechanism, overcoming the challenge of packet loss sensitivity in long-distance networks

Architectural Innovation: Pioneered the "integrated AI, computing and network" architecture, breaking free from the constraints of layered design. This enables full-stack coordination across devices, protocols, and services, laying the foundation for large-scale application.

Performance Leap: Card-to-Card Interconnect (OISA Technology) Pioneered omnidirectional peer-to-peer architecture supporting 1024-card interconnections (128x scale increase), achieving 800GB/s bandwidth (14x improvement) with 90% latency reduction. Machine-to-Machine Interconnect (GSE Technology): Innovated fully-scheduled Ethernet, scaling to 4x larger networks than traditional solutions with 30% latency reduction.

Heterogeneous Unified Management: Pioneering non-uniform task partitioning framework achieves 95% theoretical limit in multi-card heterogeneous training efficiency, with 1.7x improvement in inference concurrency.

Wide-area innovation: Computing-Aware Traffic Steering (CATS): Led the establishment of one of only two IETF working groups spearheaded by China in nearly 20 years, developing the world's first CATS router with 40% improved resource utilization; Wide-area loss resilience (uRDMA): Achieved 173Gbps throughput (2.5 times traditional solutions) under 70ms high latency and 0.1% packet loss, overcoming long-distance transmission bottlenecks.

"智算网一体"技术体系实现全域规模化部署与产业赋能

The "integrated AI, computing and network" Technology System Enables Large-Scale Deployment Across Regions and Empowers Industries

算力基建落地：建成全球运营商最大单体智算中心（1.8 万卡集群）及 13 大智算中心，覆盖中国"东数西算"工程八大枢纽，承载超 13 亿用户算力需求，直接拉动基础设施投资 300 亿元，总产值超千亿；

技术赋能产业：广域抗损技术支撑百 TB 级数据跨省传输时间从 13 天压缩至 0.92 天，年节约物流成本超千万；算力路由（CATS）动态调度 10 万路 AI 视频流，时延敏感业务响应效率提升 50%；异构混训技术推动 15 个大模型落地，行业智能化成本降低 60%；

生态与可持续：联动 40 余家机构构建产业生态，算网资源利用率提升 37.5%，年节电超 500 万度；

跨境辐射：核心技术输出 20 余个"一带一路"国家，云南建成面向南亚、东南亚的跨境数据通道，获 WSIS 最高奖；

科研提效：基因测序 / 天文观测数据传输效率提升 5 倍，日均节省存储 73.8TB，科研效率跃升 90%。

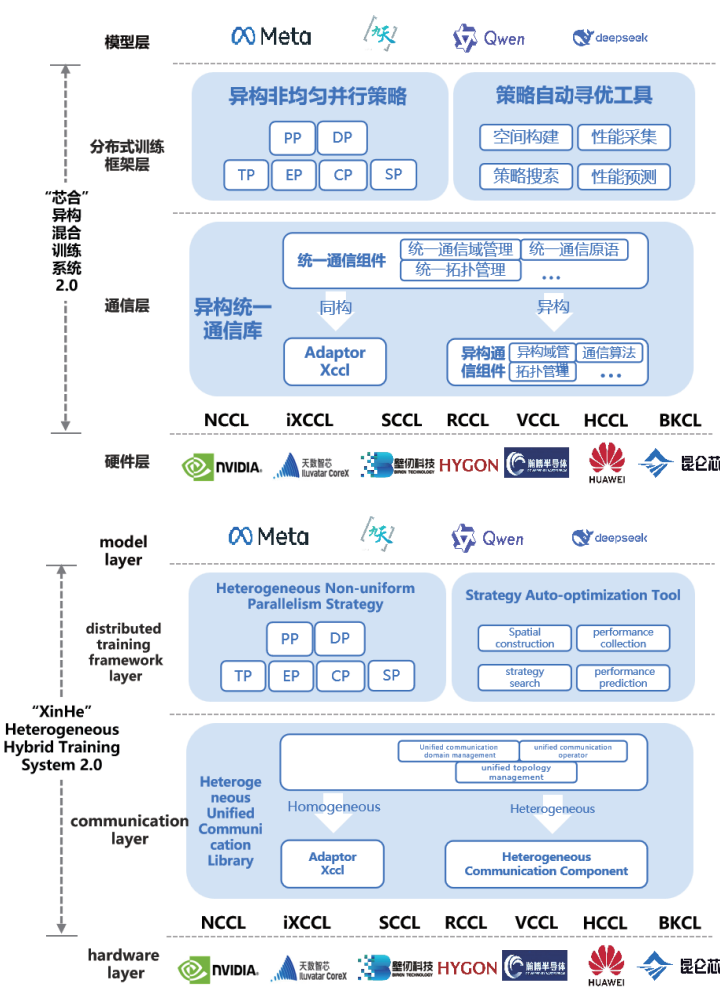
Computing Infrastructure Implementation: Established the world's largest single-site intelligent computing center (18,000-card cluster) operated by a telecom provider, along with 13 major intelligent computing centers. These facilities cover the eight major hubs of China's "east data, west computing" project, supporting computing demands for over 1.3 billion users. This directly stimulated 30 billion in infrastructure investment, generating a total output value exceeding 100 billion.

Technology Empowering Industry: Wide-area loss-tolerant technology reduced cross-province transmission time for terabyte-scale data from 13 days to 0.92 days, saving over 10 million annually in logistics costs; Computing-Aware Traffic Steering (CATS) dynamically schedules 100,000 AI video streams, boosting latency-sensitive service response efficiency by 50%; Heterogeneous mixed training technology enabled deployment of 15 large models, cutting industry AI implementation costs by 60%.

Ecosystem & Sustainability: Collaborated with over 40 institutions to build an industrial ecosystem, boosting computing and network resource utilization by 37.5% and saving over 5 million kWh of electricity annually.

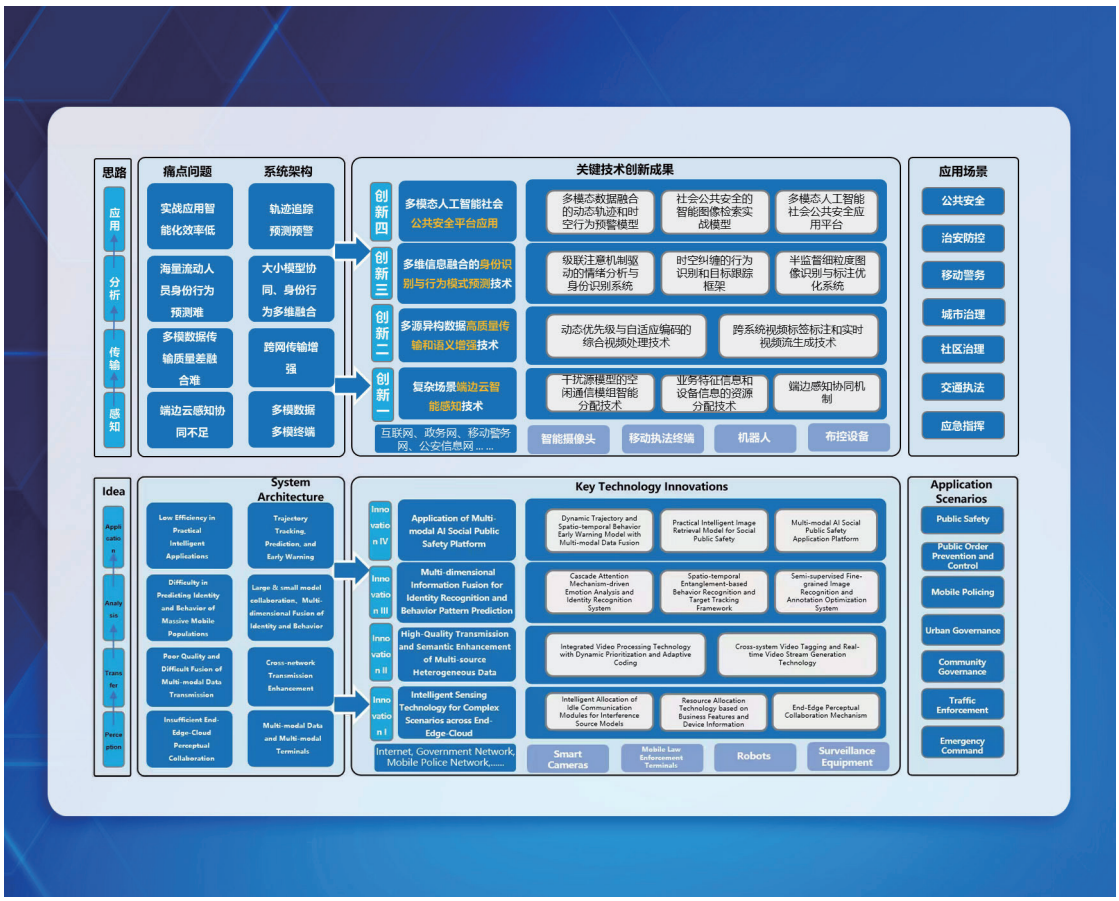
Cross-Border Impact: Core technologies deployed in over 20 Belt and Road countries; Yunnan province established cross-border data channels to South and Southeast Asia, winning the WSIS Grand Prize.

Research Efficiency: 5x improvement in gene sequencing and astronomical observation data transmission efficiency, daily storage savings of 73.8TB, and 90% leap in research productivity.



提出异构混训技术，首创任务非均匀切分框架与动态调度机制，解决显存浪费与算力不均衡问题，训练加速比达 94.5%

Proposing heterogeneous hybrid training technology, it pioneers a non-uniform task segmentation framework and dynamic scheduling mechanism, effectively addressing issues of video memory waste and computing power imbalance, achieving a training acceleration ratio of 94.5%



社会公共安全治理多模态智能分析技术与应用体系框架
Framework for Multimodal Intelligent Analysis Technology and Application Systems in Social Public Security Governance

社会公共安全治理多模态智能分析技术与应用

Multimodal Intelligent Analysis Technology and Applications for Social Public Security Governance

中移（雄安）产业研究院
China Mobile Xiong'an Information and Communication Technology Co., Ltd.

中国科学院自动化研究所
Institute of Automation, Chinese Academy of Sciences

中国移动通信集团河北有限公司
China Mobile Hebei Co., Ltd.

成都鼎桥通信技术有限公司
Chengdu Dingqiao Communications Technology Co., Ltd.

引言

本成果围绕公共安全智能化需求，构建了新一代治理服务体系，突破端边智能协同感知、5G 专网切片、多模态 AI 等关键技术，实现重点人员识别时延降低 90%、身份识别率达 99%，并自主研发多模态大模型，轨迹预警误差小于 0.6 米，为社会公共安全治理注入了强大动能。

Introduction

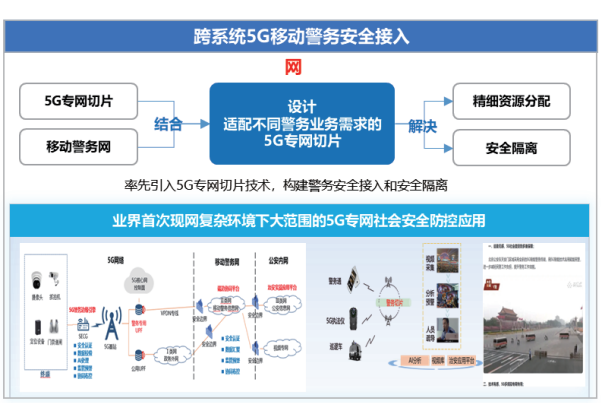
This achievement addresses the intelligentization needs of public security by establishing a new-generation governance service system. It has made breakthroughs in key technologies such as end-edge intelligent collaborative sensing, 5G private network slicing, and multimodal AI, reducing the delay in identifying key personnel by 90% and achieving an identification accuracy rate of 99%. Additionally, a self-developed multimodal large model has been introduced, with trajectory prediction errors of less than 0.6 meters, injecting strong momentum into social public security governance.

首创 5G 智能安防体系：从感知提速到治理升级
Pioneering 5G Intelligent Security System: From Enhanced Perception to Governance Upgrade

本成果攻克了公共安全领域四大技术难题：一是首创跨系统 5G 应用，提出干扰源智能分配框架与专网切片技术，破解了复杂环境下数据传输延迟高的问题，将重点人员识别时延从 30 秒压缩至 2.8 秒，效率提升 10 倍；二是突破多模态数据实时同步与语义增强技术，通过动态优先级与自适应编码，实现高并发数据的高质量传输与标注，为 AI 分析提供精准输入；三是基于级联注意机制与时空纠缠框架，首次实现复杂场景下身份识别率 99%、行为跟踪率 97.5%，精度较传统方法提升 7%；四是自主研发多模态大模型协同技术，将轨迹预警误差控制在 0.6 米内，实战中案件发生率下降 30%，识别准确率超 90%。这些突破填补了技术空白，技术指标全面领先，为全球公共安全智能化提供了跨越式创新方案。

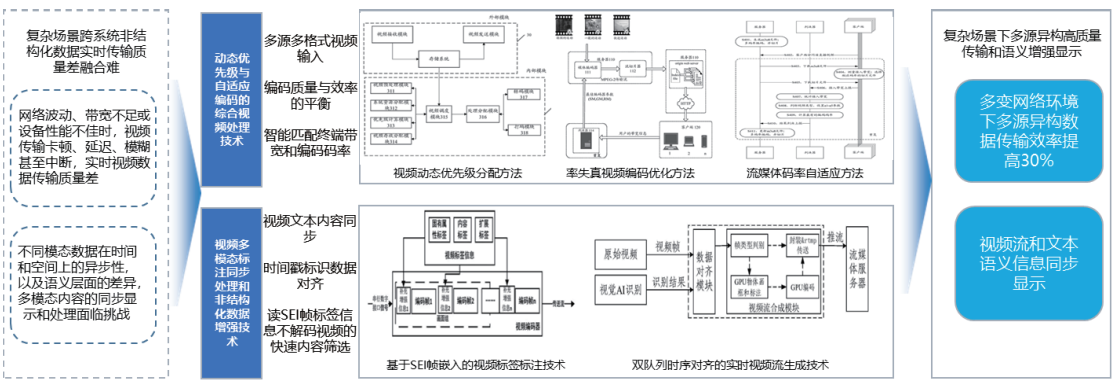
This achievement overcomes four major technical challenges in public security:
1.Pioneering Cross-System 5G Applications: We propose an intelligent interference source allocation framework and private network slicing technology, resolving high data transmission latency in complex environments. This has compressed key personnel identification latency from 30 seconds to 2.8 seconds, a tenfold increase in efficiency.
2.Breakthroughs in Multi-Modal Data Real-time Synchronization and Semantic Enhancement: Utilizing dynamic prioritization and adaptive coding, we achieve high-quality transmission and annotation of high-concurrency data, providing precise input for AI analysis.





面向公共安全治理的端边智能感知技术
Edge-Device Intelligent Sensing Technology for Public Safety Governance

3.First-time Realization of High Identification and Tracking Accuracy in Complex Scenarios: Based on a cascaded attention mechanism and spatio-temporal entanglement framework, we achieve an identity recognition rate of 99% and a behavior tracking rate of 97.5% in complex scenes. This represents a 7% improvement in accuracy compared to traditional methods.
4.Autonomous Development of Multi-Modal Large Model Collaborative Technology: We have controlled trajectory prediction errors within 0.6 meters. In practical applications, this has led to a 30% reduction in incident occurrence and an accuracy rate exceeding 90% for identification.
These breakthroughs fill technology gaps, with technical indicators leading across the board, offering a leapfrog innovative solution for global public safety intelligence.



复杂场景多源异构数据高质量传输和语义增强显示技术
High-Quality Transmission and Semantically Enhanced Display Technology for Multi-Source Heterogeneous Data in Complex Scenarios

创效 30 亿，护航重大安保
Generating 3 billion in value, safeguarding major security

本成果基于人工智能与 5G 技术，构建了覆盖警务、交通、应急等场景的公共安全智能化系统，在河北、北京、江苏等 20 余省市规模化应用。经济效益显著，累计销售额超 30 亿元（2021-2024 年新增 37.27 亿元），利润 6.47 亿元。社会效益突出：支撑庆祝中国共产党成立 100 周年、冬奥会等重大活动安保，助力石家庄获＂全国社会治安防控示范城市＂称号；获中国产学研合作创新奖、工业和信息化部 5G 绽放杯一等奖等 20 余项中国省部级奖项；通过跨层级数据融合与智能预警，提升社会治理效能，获中国中央电视台、中国警察网等权威媒体报道。产学研合作推动技术转化，形成可复制的智慧公共安全解决方案。

This achievement leverages AI and 5G technologies to build an intelligent public safety system covering policing, transportation, emergency response, and more. It has been deployed across over 20 provinces, including Hebei, Beijing, and Jiangsu, delivering remarkable economic benefits—cumulative sales exceeding 3 billion yuan (with 3.727 billion added from 2021-2024) and profits of 647 million yuan. Its social impact is equally profound: supporting security for major events like the celebration of the 100th anniversary of the founding of the Communist Party of China and the Winter Olympics,helping Shijiazhuang earn “National Public Security Prevention Model City” title, and winning over 20 provincial/ministerial awards, including the China Industry-University-Research Collaboration Innovation Award and the MIIT 5G “Bloom Cup” First Prize. By enabling cross-level data fusion and intelligent early warning, it enhances governance efficiency and has been featured in authoritative media like CCTV and China Police Network. Industry-academia collaboration has driven technology transfer, creating replicable smart public safety solutions.



高效闭环处理

自动取证

摄像头+AI自动识别违法事件并触发告警。

自动立案

案事件场景模型自动触发，人工审核后即正式立案。

自动复核

摄像头+AI自动识别非现场整改情况，提交人工确认。

城市治理事件预警执法处置应用
Urban Governance Event Early Warning and Law Enforcement Application



社会治安跨时空智能分析实战应用
Cross-Spatiotemporal Intelligent Analysis for Public Security in Practical Applications

智能安防关键技术突破，引领产业升级新格局
Breakthroughs in Intelligent Security Tech Reshape Industry Upgrading

本成果对技术进步和产业结构优化产生深远影响：在技术层面，突破端边智能感知、多源数据融合等关键技术，形成 28 项专利及科研成果，获中国产学研合作创新奖等 28 项科技奖励，推动公共安全领域智能化升级。在产业层面，形成智能公共安全新业态，带动超 30 亿元规模的项目落地，促进通信、硬件、软件等产业链深度融合，构建 " 产学研用 " 协同创新体系。其成功实践不仅使落地城市获 " 示范城市 " 称号，更推动行业从传统安防向智慧治理转型，形成可复制的技术标准与商业模式，吸引资本持续投入，加速产业结构向智能化、集约化方向升级，彰显科技创新对产业变革的引领作用。

This achievement has profoundly advanced technology and industrial optimization: Technically, it has overcome key challenges in edge-device sensing and multi-source data fusion, yielding 28 patents and research outcomes, along with 28 awards, including the China Industry-University-Research Collaboration Innovation Award, accelerating intelligent upgrades in public safety. Industrially, it has spawned new business models, driving over 3 billion yuan in project investments and fostering deep integration across telecom, hardware, and software sectors, establishing an industry-academia-application innovation ecosystem. Its success not only helped cities win China's State Council "Model City" recognition but also spurred the industry's shift from traditional security to smart governance, creating replicable standards and business models that attract sustained capital investment. This accelerates the sector's transition toward intelligent, intensive development, showcasing how innovation leads industrial transformation.


为表彰河北省科学技术奖获得者，特颁发此证书。

项目名称：社会公共安全治理多模态智能分析技术与应用

奖种类别：科学技术进步奖

奖励等级：二等

获 奖 者：中移系统集成有限公司

河北省科学技术奖

证 书

2024年度·[illegible]-2024JB2004-D1


荣誉证书

HONORARY CREDENTIAL

中国移动通信集团广东有限公司、中国移动（成都）产业研究院、中移系统集成有限公司（雄安产业研究院）：

经专家评审委员会评定，贵单位的5G社会安全防控和无人机应用荣获：

2021公共安全优秀解决方案奖

特此证明，以资鼓励。

世界安防博览会组委员会　　广东省公共安全技术防范协会

二零二一年七月


Structured Attention Knowledge Distillation for Lightweight Networks

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Abstract: Knowledge distillation is to transfer the effective knowledge learned by the teacher networks to the student networks through the designed loss function, which helps the student network to get better performance with less calculation cost. However, when there is a great difference between the student network and the teacher network in terms of the network scale, the student network usually cannot learn enough knowledge from the teacher network to improve performance effectively. In order to improve this situation, this paper proposes structured attention distillation for lightweight networks. Structured attention distillation groups the features from models by channels, which helps student networks learn the feature extraction ability of teacher networks by refining the spatial attention maps. Our proposed method is evaluated on CIFAR100 and large-scale face recognition validation set (LFW, CFP-FP, Age-DB). Compared with other distillation methods, our proposed method achieves better accuracy on CIFAR100 and face recognition validation set.

Key Words: Knowledge Distillation, Lightweight Networks, Attention

1 INTRODUCTION

In recent years, deep learning has been widely used in various aspects of computer vision with remarkable performance. The appearance of AlexNet [1] attracted the attention of researchers because of its outstanding performance in the ImageNet competition. Subsequently, the researchers found the deeper the layers and more parameters of the convolutional neural network, the better the network perform. However, when there are more layers in the convolutional network, the network will be difficult to converge, because of the gradient disappearance. In order to solve this problem, the ResNet [2] and the HN [3] were proposed to enable the convolutional network to accommodate more parameters and layers. Although large deep convolutional neural network has achieved amazing results in various visual tasks, it is difficult to deploy it on embedded terminals or mobile devices due to the massive parameters and huge computing costs. Knowledge distillation is a prominent method of model compression. Knowledge distillation transfers the effective knowledge learned by the teacher networks to the student networks through the designed loss function, which helps the student model to get better performance with less calculation cost. In order to improve the performance of small networks, some methods of knowledge distillation have been proposed in [4-8]. Geoffrey Hinton et al. [4] introduced the concept of knowledge distillation and proposed using the output of the teacher network as a soft label to guide the student network. FitNet [5] proposed a method of feature distillation to make the student network imitate the hidden features of the teacher network, so as to improve the performance of the student network. Sergey Zagoruyko proposed attention transfer distillation [6], which guided the student networks by extracting the spatial attention diagram generated by the teacher networks. With the help of attention transfer distillation, student models can learn the ability of the teacher models to extract features. Channel distillation [7] calculates the channel attention of middle layers features to help the student learn the ability of the teacher model to recognize channel representation. ShrinkTeaNet [8] proposed a novel Angular Distillation Loss for distilling the feature directions and the sample distributions from the hypersphere of the teacher models to the student. However, considering the huge difference between the lightweight network and the teacher model, the number of parameters and the calculation cost are not at the same order of magnitude, and the dimensions and information of the extracted features are quite different. Therefore, it is hard for students to directly learn and imitate the output or features of the teacher models to achieve ideal results. Using MobileNetV2 [9] as the student and ResNet50 [2] as the teacher model, we conducted a comparative experiment on CIFAR100. In order to verify the effect of different knowledge distillation methods when there is a huge structural difference between the student and the teacher networks, we adjust the structure of MobileNetV2 and change the number of output channels into {16, 24, 32, 64}, and the number of output channels corresponding to ResNet50 is {256, 512, 1024, 2048}. In Table 1, it is easy to find that KD [4] and CD [7] reduce the accuracy of the student model, while AT [6] and SH [8] increase the accuracy a bit. It is apparent that structural differences between models do affect the effectiveness of knowledge distillation. In addition, in CD [7] and SH [8], in order to match the output size of the teacher network, the student needs to add layers and parameters, which is quite contrary to the original intention.

To solve the above problems, we propose a novel method of knowledge distillation to improve students' ability to extract features. We transfer the knowledge to the student by the method of Structured Attention Distillation (SA), which is a special attention distillation we will explain in detail in Section 2.1. Experimental results show that the proposed method is superior to other comparison methods in image classification and face recognition.

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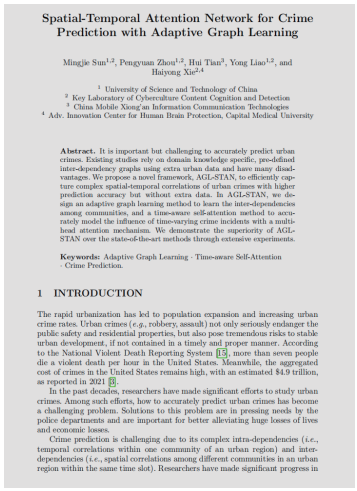
Spatial-Temporal Attention Network for Crime Prediction with Adaptive Graph Learning

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[3] China Mobile Xiong'an Information Communication Technologies
[4] Adv. Innovation Center for Human Brain Protection, Capital Medical University

Abstract. It is important but challenging to accurately predict urban crimes. Existing studies rely on domain knowledge specific, pre-defined inter-dependency graphs using extra urban data and have many disadvantages. We propose a novel framework, AGL-STAN, to efficiently capture complex spatial-temporal correlations of urban crimes with higher prediction accuracy but without extra data. In AGL-STAN, we design an adaptive graph learning method to learn the inter-dependencies among communities, and a time-aware self-attention method to accurately model the influence of time-varying crime incidents with a multi-head attention mechanism. We demonstrate the superiority of AGL-STAN over the state-of-the-art methods through extensive experiments.

Keywords: Adaptive Graph Learning · Time-aware Self-Attention · Crime Prediction.

1 INTRODUCTION

The rapid urbanization has led to population expansion and increasing urban crime rates. Urban crimes (*e.g.*, robbery, assault) not only seriously endanger the public safety and residential properties, but also pose tremendous risks to stable urban development, if not contained in a timely and proper manner. According to the National Violent Death Reporting System [15], more than seven people die a violent death per hour in the United States. Meanwhile, the aggregated cost of crimes in the United States remains high, with an estimated $4.9 trillion, as reported in 2021 [8].

In the past decades, researchers have made significant efforts to study urban crimes. Among such efforts, how to accurately predict urban crimes has become a challenging problem. Solutions to this problem are in pressing needs by the police departments and are important for better alleviating huge losses of lives and economic losses.

Crime prediction is challenging due to its complex intra-dependencies (*i.e.*, temporal correlations within one community of an urban region) and inter-dependencies (*i.e.*, spatial correlations among different communities in an urban region within the same time slot). Researchers have made significant progress in


证书号第7196349号

发明专利证书

发 明 名 称：视频流生成方法、装置、电子设备及存储介质

专 利 权 人：中移雄安信息通信科技有限公司,中移系统集成有限公司,中国移动通信集团有限公司

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申请日时发明人：杨培志,吴国英,贾卫林,赵朝凤

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局长　申长雨

2024年07月16日

第1页(共1页)

本成果所获奖项、论文、软著（部分）
Awards, Research Papers, and Software Copyrights (Partial) Related to This Achievement





设备运行数据、部件检测图像与安全规范文本融合，动态监测生产环节，筑牢绿色安全防线
Equipment operation data, component inspection images and safety specification texts are integrated to dynamically monitor the production process and build a solid green safety defense line

视觉语言大模型驱动的飞机绿色安全生产管控平台关键技术

Key Technologies of a Green and Safe Aircraft Production Management and Control Platform Driven by Vision-Language Large Models

同济大学
Tongji University

上海飞机制造有限公司
Shanghai Aircraft Manufacturing Co., Ltd.

上海通金信息科技开发有限公司
Shanghai Tongjin Information Technology Development Co., Ltd.

引言

本成果依托视觉语言大模型，构建飞机绿色安全生产管控平台，突破危险作业识别、语义解析与绿色治理等关键技术，已部署在中国飞机产线，保障安全交付超 176 架，安全隐患闭环率 95% 以上。

Introduction

This achievement leverages vision-language large models to build a green and safe aircraft production management and control platform, making breakthroughs in key technologies such as hazardous operation recognition, semantic parsing, and green governance. It has already been deployed on Chinese aircraft production lines, ensuring the safe delivery of over 176 aircraft, with a safety hazard closed-loop rate exceeding 95%.

视觉语言大模型赋能飞机绿色安全生产关键技术突破
Breakthroughs in Key Technologies for Green and Safe Aircraft Production Empowered by Vision-Language Large Models

飞机制造零部件极多、工序耦合深且高危作业密集，长期面临人工巡检低效、风险预警滞后、挥发性有机物与噪声粉尘治理不精准等痛点。本成果针对“危险作业实时识别—跨工位跨机型语义理解—能耗与排放协同优化”三大瓶颈，构建以视觉语言大模型为核心的民机绿色安全生产管控平台：多源视频 / 传感数据时空对齐与小样本自适应，驱动作业意图解析与违规要素抽取；风险因果图谱联动联锁策略，形成“人—机—环—管”闭环决策与在线调控。成果已在中国民用飞机生产中应用，经权威机构鉴定达到国际领先水平，为全球高端装备制造的绿色、安全与智能化转型提供了可复制、可扩展的通用范式。



查看并分析各一级危险点及重点管控区域视频出现的人员、物品等分类监测信息

View and analyze the classified monitoring information of personnel, items, etc. shown in the videos of each first-level hazard point and key control areas



实现多场景下细微风险因素实时捕获，防范安全事故发生

Realize real-time capture of subtle risk factors in multiple scenarios to prevent the occurrence of safety accidents

Aircraft manufacturing involves numerous components, deeply coupled processes, and intensive hazardous operations. It has long faced pain points such as inefficient manual inspections, delayed risk warnings, and inaccurate treatment of volatile organic compounds as well as noise and dust.

This achievement addresses three major bottlenecks—real-time recognition of hazardous operations, semantic understanding across workstations and aircraft models, and coordinated optimization of energy consumption and emissions—by building a civil aircraft green and safe production management and control platform driven by vision-language large models. Multi-source video and sensor data spatiotemporal alignment with few-shot adaptability supports operation intent parsing and violation element extraction; risk causal graphs enable linked interlocking strategies, forming a closed-loop decision-making and online regulation system covering “human–machine–environment–management.”

The achievement has already been applied in Chinese civil aircraft production. Identified by authoritative institutions as reaching an internationally leading level, it provides a replicable and scalable universal paradigm for the global green, safe, and intelligent transformation of high-end equipment manufacturing.

成果在中国民用飞机生产线规模化应用并显著增效
Large-Scale Application of the Achievement in Chinese Civil Aircraft Production Lines with Significant Efficiency Gains

本成果依托视觉语言大模型，已在某飞机制造企业 40 余部门完成规模化部署，形成了可复制、可推广的绿色安全制造新模式。在经济效益方面，单一模块年均节省人工与维护成本近 30 万元，整体安全运营成本降低 18%。在社会效益方面，平台实现危险作业违规率下降 41%、隐患闭环率提升至 95% 以上，建立全过程数字化审计机制，推动企业与 ISO45001 等国际标准体系对接，显著提升中国民用飞机的安全性与可信度。在生态效益方面，平台实现非甲烷总烃（NMHC）排放连续六年 100% 达标，年均减排约 1.5 吨，改善了作业区空气质量，并构建 EPI 指标模型支撑园区双碳目标。成果具备跨行业推广潜力，预计未来三年可扩展至航空发动机、轨交、船舶等高风险制造领域，带动产业链新增规模 750 亿元。

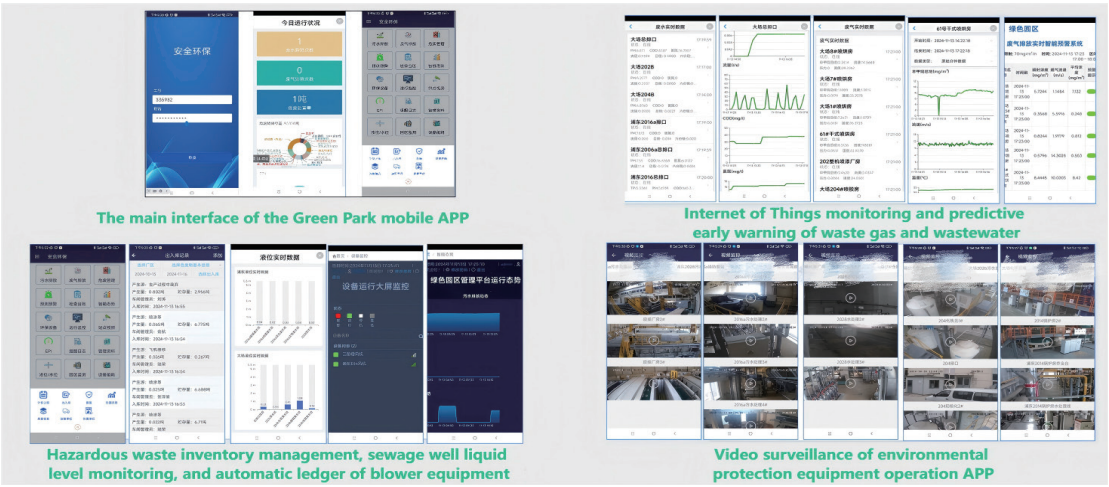
This achievement, relying on vision-language large models, has been deployed at scale in more than 40 departments of an aircraft manufacturing enterprise, forming a new green and safe manufacturing model that is replicable and extendable.

In terms of economic benefits, a single module saves nearly 300,000 RMB annually in labor and maintenance costs, and the overall safety operation cost is reduced by 18%. In terms of social benefits, the platform has reduced hazardous operation violation rates by 41%, increased the closed-loop rate of potential hazards to more than 95%, established a full-process digital auditing mechanism, promoted enterprise alignment with international standard systems such as ISO45001, and significantly improved the safety and credibility of Chinese civil aircraft.

In terms of ecological benefits, the platform has achieved 100% compliance of non-methane hydrocarbon (NMHC) emissions for six consecutive years, with an annual reduction of about 1.5 tons, improved air quality in the working area, and built an EPI indicator model to support the dual-carbon goals of the industrial park. The achievement has the potential for cross-industry promotion and is expected to expand in the next three years to high-risk manufacturing fields such as aero engines, rail transit, and shipbuilding, driving an additional 75 billion RMB in new scale across the industrial chain.



本成果在某飞机制造公司绿色园区管理平台应用
This achievement has been applied in the green park management platform of a certain aircraft manufacturing company



本成果在某飞机制造公司绿色园区管理平台应用

This achievement has been applied in the green park management platform of a certain aircraft manufacturing company

引领民机制造迈向绿色智能化
Leading Civil Aircraft Manufacturing Toward Green and Intelligent Development

本成果在技术进步层面以多模态数据治理为底座，打通设计—制造—质控—环保的数据链路，沉淀可迁移的任务本体与风险因果图谱，配套“边缘轻量化推理 + 云端持续学习”的边云协同体系与 A/B 灰度发布机制，显著提升隐患发现的前瞻性与处置的及时性，并实现能耗、排放与产能的联合优化。在产业结构优化层面，平台推动企业由“经验驱动、分散治理”转向“数据驱动、模型预测”，以模块化算子、标准接口与数字孪生校核形成可复制的解决方案包，支撑跨厂区、跨机型快速落地；同时催生“算法模型工厂—智能终端—平台集成—运维服务”的新型产业分工，带动 AI 算法迭代、工业相机与本安终端制造、工业中台与生态伙伴协同发展，构建面向航空制造的下一代工业软件与应用生态。



民用飞机交付阶段实现产业结构优化

Optimize the industrial structure during the delivery stage of civil aircraft

At the level of technological progress, this achievement builds on multimodal data governance as the foundation, connecting the data chain from design–manufacturing–quality control–environmental protection. It establishes transferable task ontologies and risk causal graphs, supported by an edge–cloud collaborative system that integrates “lightweight edge inference + continuous cloud learning” together with an A/B grayscale release mechanism. This significantly enhances the foresight in hazard detection and the timeliness of response, while achieving joint optimization of energy consumption, emissions, and production capacity.

At the level of industrial structure optimi-

zation, the platform drives enterprises to shift from “experience-driven, fragmented management” to “data-driven, model-predicted” approaches. Through modular operators, standard interfaces, and digital twin verification, it forms replicable solution packages that support rapid deployment across factories and aircraft models. At the same time, it fosters a new industrial division of labor spanning “algorithm model factories – intelligent terminals – platform integration – operation and maintenance services,” promoting the iteration of AI algorithms, the manufacturing of industrial cameras and intrinsically safe terminals, and the collaborative development of industrial middle platforms and ecosystem partners. Together, these efforts build the next-generation industrial software and application ecosystem for aviation manufacturing.

认知型制造平台引领民机智能化转型
Cognitive Manufacturing Platform Leading the Intelligent Transformation of Civil Aircraft

除核心技术突破与规模化应用外，本成果还在多方面取得重要成就与贡献。平台已在高危场景中安全运行数万小时，保障 3000 余人次和 170 余架次飞机生产交付任务安全，形成全流程问题闭环处理机制。团队在国际顶级期刊和会议上发表 24 篇论文，部分成果获评国际领先水平，填补了工业语义控制与绿色治理的关键空白。成果已获得 10 余项发明专利和软件著作权，并荣获“科学技术成果国际领先奖”“绿色工厂示范”等中国国家级荣誉。

In addition to core technological breakthroughs and large-scale application, this achievement has also made important accomplishments and contributions in multiple aspects. The platform has operated safely for tens of thousands of hours in high-risk scenarios, ensuring the safety of more than 3,000 personnel and over 170 aircraft production and delivery tasks, and establishing a full-process closed-loop problem handling mechanism. The team has published 24 papers in top international journals and conferences, with some results recognized as internationally leading, filling critical gaps in industrial semantic control and green governance. The achievement has obtained more than 10 invention patents and software copyrights, and has been awarded national honors in China such as the “International Leading Award for Scientific and Technological Achievements” and the “Green Factory Demonstration.”



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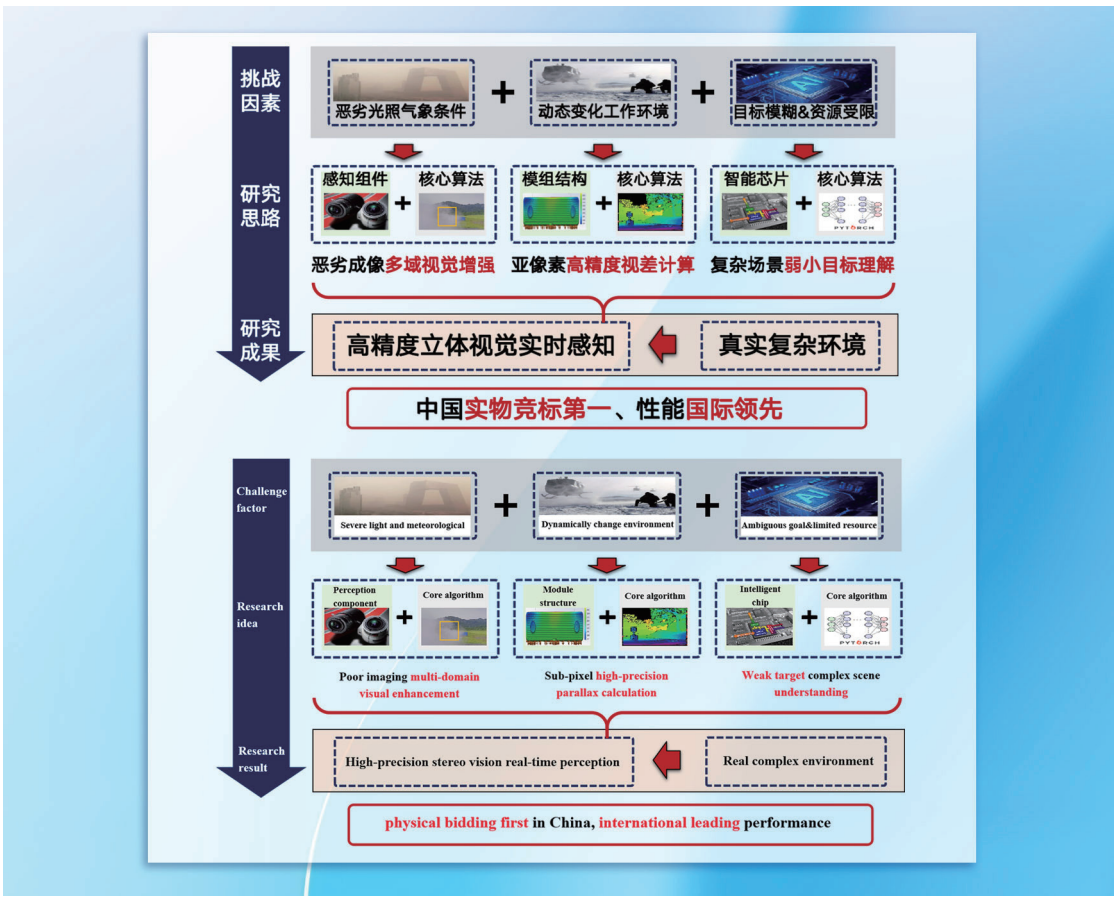


针对真实复杂环境下视觉成像与感知计算挑战，突破无人系统多波段立体视觉关键技术，研制系列化关键产品，实现立体视觉实时感知能力的全面提升，整体技术指标达到国际领先水平

In response to the challenges of visual imaging and perceptual computing in real-world complex environments, the project has broken through the key technologies of multi-band stereo vision for unmanned systems, developed a series of key products, achieved an all-round improvement in the real-time perception capability of stereo vision, and reached an internationally leading level in overall technical indicators

无人系统多波段立体视觉关键技术与装备

Key Technologies and Equipment for Multi-Band Stereo Vision in Unmanned Systems

大连理工大学
Dalian University of Technology

湖南视方达科技有限公司
Hunan Hyper Sensing Technology Co., Ltd.

北京中科慧眼科技有限公司
Beijing Smarter Eye Technology Co., Ltd.

苏州艾微视图像科技有限公司
Aview Image Technology Suzhou Co., Ltd.

引言

大连理工大学联合企业研发的无人系统多波段立体视觉关键技术与产品，突破低光照、雨雾烟尘等复杂恶劣环境下的视觉成像与感知计算难题，整体技术水平国际领先，广泛应用于汽车自动 / 辅助驾驶、智能机器人等产业领域，产生显著经济效益。

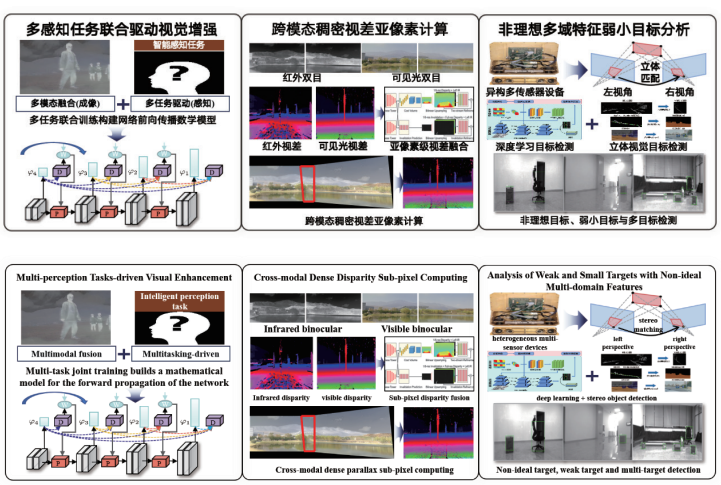
Introduction

Dalian University of Technology, in collaboration with enterprises, has developed the key technology and products for multi-band stereo vision of unmanned systems. This achievement has broken through the challenges in visual imaging and perceptual computing under complex and harsh environments such as low light, rain, fog, smoke and dust. With an internationally leading overall technical level, the technology and products have been widely applied in industrial fields including automotive automatic/assisted driving and intelligent robots, creating significant economic benefits.

无人系统多波段立体视觉“全时恶劣环境感知的多域协同视觉计算”关键技术体系

Key technology system for "multi-domain collaborative visual computing for all-time harsh environment perception" in multi-band stereo vision of unmanned systems

针对传统视觉感知技术在低光照、雨雾烟尘等恶劣环境中极易失效，且缺乏多源异构视觉数据协同计算手段的难题，项目团队突破“全时”感知与“多域”计算双重挑战，实现三大国际领先创新：一是提出多感知任务联合驱动的视觉增强技术，使非理想匹配下可见光 / 红外视觉融合性能提升 63%；二是开发结合亚像素视差预测与误差消除估计的稀疏视差能量传播技术，实现视差计算精度达 1/32 亚像素；三是建立非理想多域特征的弱小目标分析技术，显著性目标检测方法参数规模降低 76%，推理速度提高 12 倍以上。系统性能处于国际前列，技术指标超过 Stereolabs、Foresight 等公司的同类产品，获得多项技术竞赛和中国省部级奖励。



构建恶劣环境智能感知全新技术体系，突破“全时”感知与“多域”计算双重挑战

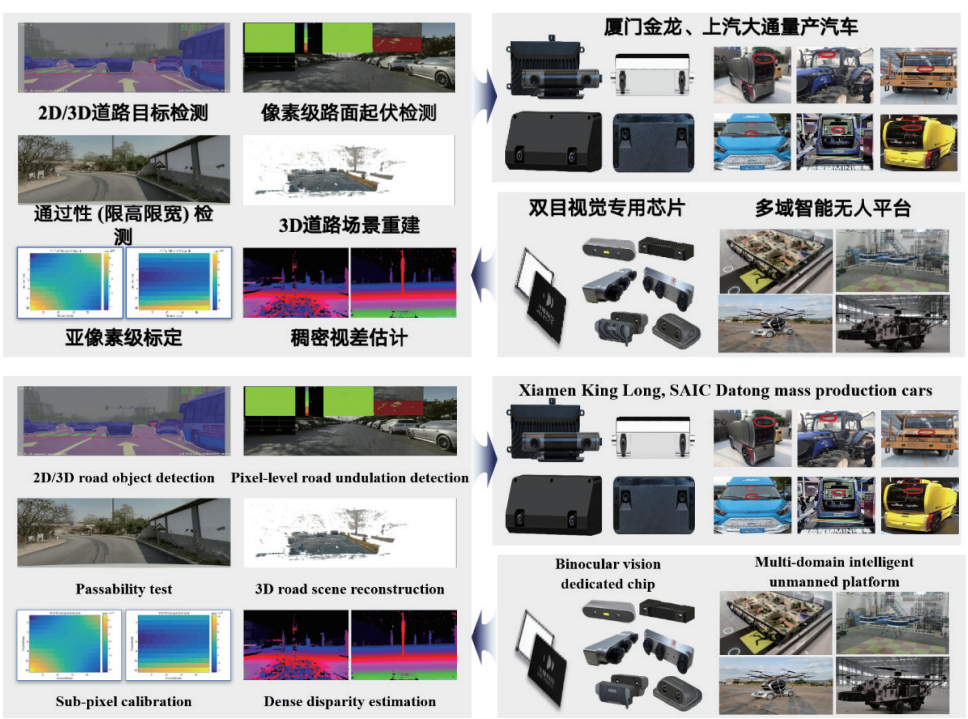
It has established a new technology system for intelligent perception in harsh environments and overcome the dual challenges of "all-time" perception and "multi-domain" computing

To address the challenges of traditional visual perception technologies—such as their high susceptibility to failure in harsh environments (e.g., low light, rain, fog, smoke, and dust) and the lack of collaborative computing methods for multi-source heterogeneous visual data—the project team has overcome the dual challenges of "all-time" perception and "multi-domain" computing, achieving three internationally leading innovations: it has proposed a vision enhancement technology driven by the collaboration of multiple perception tasks, which improves the fusion performance of visible/infrared vision by 63% under non-ideal matching conditions; developed a sparse disparity energy propagation technology that integrates sub-pixel disparity prediction and error elimination estimation, enabling the disparity calculation accuracy to reach 1/32 sub-pixel; and established a weak and small target analysis technology for non-ideal multi-domain features, which reduces the parameter scale of the salient target detection method by 76% and increases the inference speed by more than 12 times. The system performance ranks among the international forefront, with technical indicators exceeding those of similar products from companies such as Stereolabs and Foresight, and the team has won a number of awards in technical competitions as well as provincial and ministerial-level honors in China.

该技术已在自动 / 辅助驾驶、智能机器人等领域实现规模化应用
This technology has been applied on a large scale in fields such as automatic/assisted driving and intelligent robots

该技术已在汽车自动 / 辅助驾驶、智能机器人等领域实现规模化应用，创造直接经济价值 3.16 亿元。苏州艾微视图像科技有限公司应用亚像素级多目传感器联合标定技术，构建车载视觉传感器自动化组装与评测体系，推动商用车智能视觉组件标准化生产，创造直接经济价值 19371.2 万元；北京中科慧眼科技有限公司依托复杂恶劣环境立体视觉感知技术，攻克三维立体标定等核心技术难题，其双目立体车载相机成为百度“阿波罗”计划唯一官方指定视觉产品，应用于无人巴士等量产场景，创造经济价值 12262.4 万元。技术转让与科研项目形成多元收益：与湖南视方达、北京萌特博达成技术转让 3100 万元；另外，承担中国国家级 / 企业级重大重点类科研项目合计 20 余项，到账经费 4000 余万元，构建了“研发—转化—应用”良性循环。

This technology has been applied on a large scale in fields including automotive automatic/assisted driving and intelligent robots, creating a direct economic value of RMB 316 million. Specifically, Aview Image Technology Suzhou Ltd. has applied the sub-pixel-level multi-camera sensor joint calibration technology to establish an automated assembly and evaluation system for in-vehicle visual sensors, promoting the standardized production of intelligent visual components for commercial vehicles and generating a direct economic value of RMB 193.712 million; relying on the stereo vision perception technology for complex and harsh environments, Beijing Smarter Eye Technology Co., Ltd. has solved core technical problems such as 3D stereo calibration, and its binocular stereo in-vehicle camera has become the only officially designated visual product for Baidu's "Apollo" program, applied in mass-production scenarios like autonomous buses, with an economic value of RMB 122.624 million created. Diversified revenues have been generated from technology transfer and scientific research projects: a total of RMB 31 million in technology transfer agreements have been reached with Hunan Hyper Sensing Technology Co., Ltd. and Beijing Mengtebo Technology Co., Ltd.; in addition, the team has undertaken more than 20 major Chinese national-level/enterprise-level key scientific research projects, with over RMB 40 million in funds received, forming a sound "R&D-transformation-application" cycle.



技术应用在自动驾驶、智能机器人等多个领域
The technology is applied in multiple fields such as autonomous driving and intelligent robots

成果推动智能视觉技术升级与产业生态发展

The achievements promote the upgrading of intelligent vision technology and the development of the industrial ecosystem

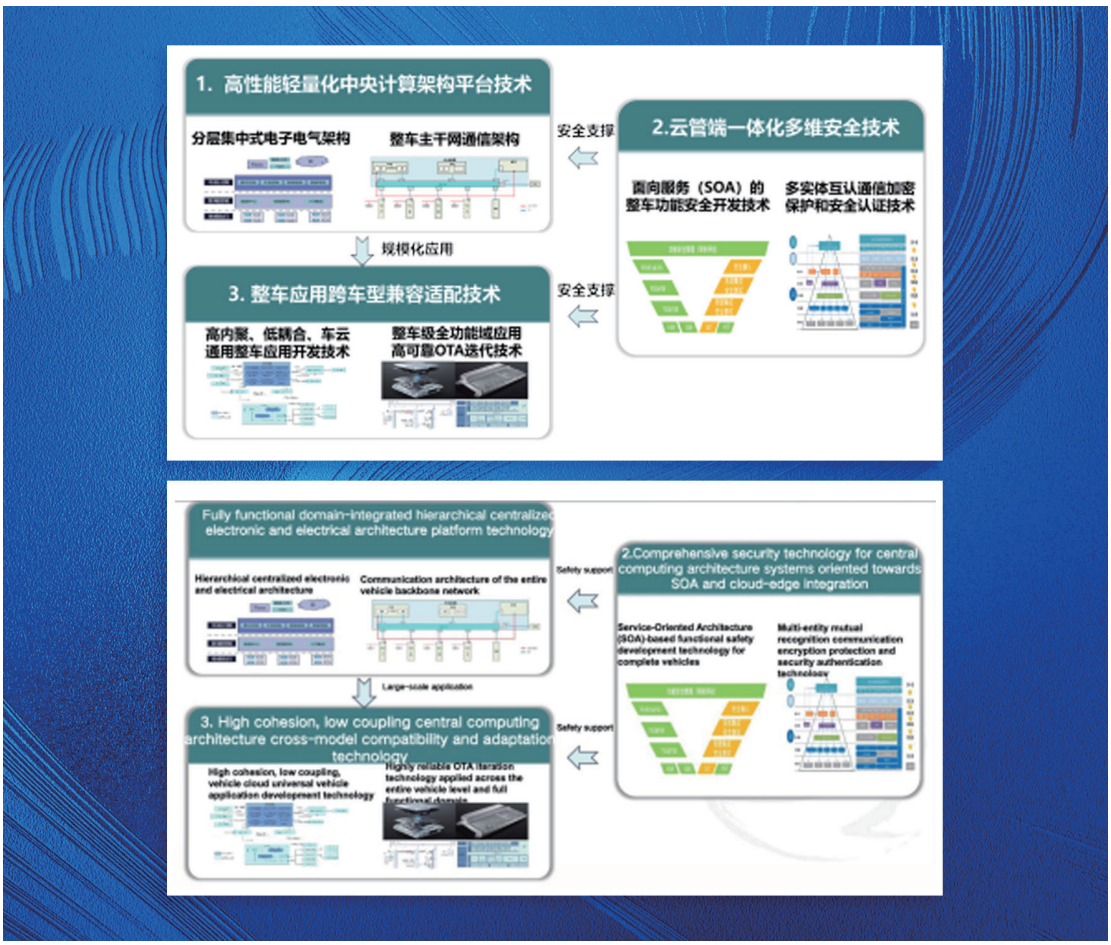
该成果通过突破亚像素级标定、多域视觉增强等关键技术，显著提升立体视觉系统在恶劣环境下的感知精度，达到国际领先水平，推动智能视觉技术从理论研究向规模化应用转化。构建“算法—芯片—设备”全链条创新体系，支撑中国首颗量产立体视觉专用芯片研发，形成具有广泛影响力的技术标准，加速全球智能视觉设备的产业化进程。依托技术转化，培育苏州艾微视、北京中科慧眼等代表性企业，催生多模态算法工程师等新兴岗位，促进“研发—转化—应用”生态闭环，带动上下游产业链协同发展。整体上显著提升智能装备的性能与竞争力，为智能无人系统发展提供核心支撑，有力推动产业结构向高端化、智能化方向优化升级，实现技术创新与经济效益的双重突破。

By breaking through key technologies such as sub-pixel-level calibration and multi-domain visual enhancement, this achievement has significantly improved the perception accuracy of stereo vision systems in harsh environments, reaching an internationally leading level and promoting the transformation of intelligent vision technology from theoretical research to large-scale application. It has established a full-chain innovation system covering "algorithms-chips-equipment", supported the R&D of China's first mass-produced dedicated chip for stereo vision, formulated technical standards with wide influence, and accelerated the industrialization process of global intelligent vision equipment. Relying on technology transformation, it has fostered representative enterprises including Aview Image Technology Suzhou Ltd. and Beijing Smarter Eye Technology Co., Ltd., spawned emerging positions such as multi-modal algorithm engineers, facilitated the ecological closed loop of "R&D-transformation-application", and driven the coordinated development of upstream and downstream industrial chains. On the whole, it has significantly enhanced the performance and competitiveness of intelligent equipment, provided core support for the development of intelligent unmanned systems, effectively promoted the optimization and upgrading of the industrial structure towards high-end and intelligent directions, and achieved a dual breakthrough in technological innovation and economic benefits.



授权技术发明专利 58 项，学术论文受到多位院士正面评价，获省部级奖励 4 项，完成成果转化三千余万元，创造直接经济价值 3 亿余元

It has obtained 58 authorized invention patents for technologies, received positive evaluations from multiple academicians on its academic papers, won 4 provincial and ministerial-level awards, completed technology achievement transformation worth over RMB 30 million, and created a direct economic value of more than RMB 300 million



项目的三项主要技术创新点：高性能轻量化中央计算架构平台技术、云管端一体化多维安全技术、整车应用跨车型兼容适配技术。这三大创新点构成了汽车电子电气架构技术研发和产业化应用的完整创新闭环

The three main technological innovations of the project are: high-performance lightweight central computing architecture platform technology, cloud-management-terminal integrated multi-dimensional security technology, and vehicle application cross-model compatibility and adaptation technology. These three major innovations constitute a complete innovation loop for the research and development of automotive electronic and electrical architecture technology and its industrial application

智能网联汽车中央计算电子电气架构平台关键技术及应用

Key Technologies and Applications of Intelligent Connected Vehicle Central Computing Electronic and Electrical Architecture Platform

岚图汽车科技股份有限公司
VOYAH Automotive Technology Co., Ltd.

武汉光昱明晟智能科技有限公司
Guangyu Mingsheng Intelligent Technology Co., Ltd.

武汉理工大学
Wuhan University of Technology

中汽研（天津）汽车工程研究院有限公司
China Automotive Engineering Research Institute (Tianjin) Co., Ltd.

引言

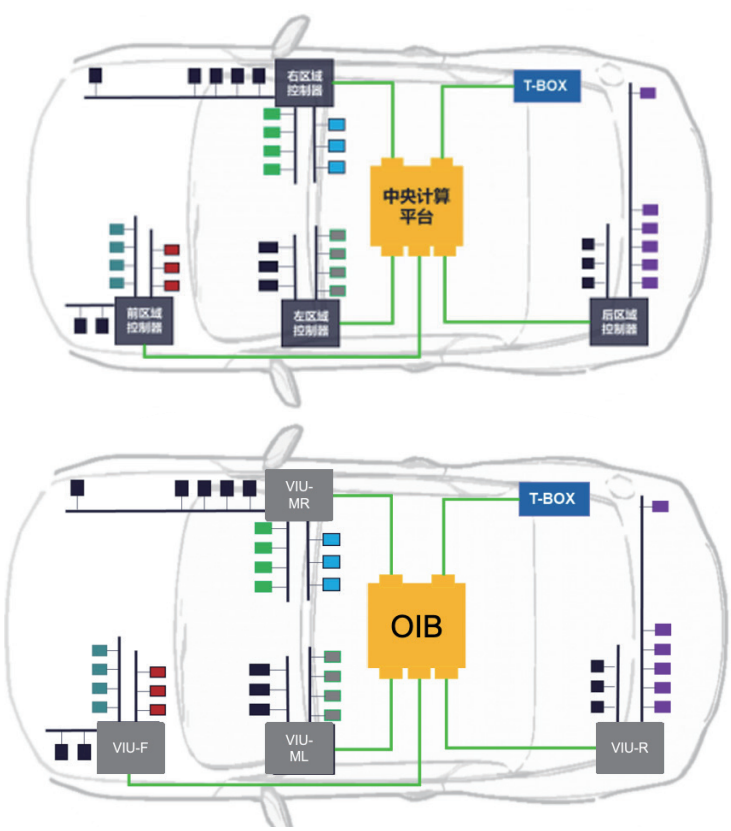
项目构建了 “中央计算、多维安全、多层解耦” 的新一代汽车电子电气架构技术及产品体系，突破了中央计算电子电气架构关键技术，打造了基于 “中央计算 + 区域控制” 协同的智能汽车技术底座，并实现大规模量产应用。

Introduction

The project has established a new generation of automotive electronic and electrical architecture technology and product system featuring "central computing, multi-dimensional security, and multi-layer decoupling". It has broken through key technologies in central computing electronic and electrical architecture, created an intelligent automotive technology foundation based on the synergy of "central computing + regional control", and achieved large-scale mass production applications.

中央计算与区域控制协同创新，赋能汽车智能化转型
Collaborative Innovation between Central Computing and Regional Control, Empowering the Intelligent Transformation of Automobiles

项目攻克“全功能域融合计算、整车级资源动态共享、云管端一体化多维安全、跨车型兼容适配、全功能域快速迭代” 五大技术难题，形成三项关键技术创新。一是高性能轻量化中央计算架构平台技术，构建兼顾高性能中央计算与高实时控制的集中式电子电气架构，开发了跨域高安全、高可靠、高实时通信网络，研制全功能域融合的可扩展中央计算平台，有效提升整车计算性能与控制实时性。二是云管端一体化多维安全技术，发明车云协同场景下多实体互认的通信加密保护与轻量化安全认证技术，构建云管端一体化安全态势感知及预警平台，增强多维安全防御能力。三是整车应用跨车型兼容适配技术，提出高内聚、低耦合、车云通用的应用开发方案，研发多并发多层级服务独立升级及多子网并行升级技术，提升多车型适配能力与应用迭代效率。技术成果经院士专家团队评价达到国际先进，并荣获中国汽车工程学会科技进步二等奖。



“中央计算 + 区域控制“协同的电子电气架构平台，构建了汽车的“大脑“与”神经系统”
The electronic and electrical architecture platform featuring the synergy of "central computing + regional control" constitutes the "brain" and "nervous system" of the automobile

The project has overcome five major technical challenges, namely "full-function domain fusion computing, dynamic resource sharing at the vehicle level, cloud-management-terminal integration for multi-dimensional security, cross-model compatibility and adaptation, and rapid iteration across all functional domains", resulting in three key technological innovations. The first is high-performance lightweight central computing architecture platform technology, which builds a centralized

electronic and electrical architecture that balances high-performance central computing and high real-time control. A cross-domain high-security, high-reliability, and high-real-time communication network has been developed, and a scalable central computing platform for full-function domain fusion has been developed, effectively enhancing the computing performance and real-time control of the entire vehicle. The second is cloud-management-terminal integration for multi-dimensional security technology, which invents communication encryption protection and lightweight security authentication technology for multi-entity mutual recognition in vehicle-cloud collaboration scenarios. A cloud-management-terminal integrated security situation awareness and early warning platform has been built to enhance multi-dimensional security defense capabilities. The third is vehicle application cross-model compatibility and adaptation technology, which proposes a high-cohesion, low-coupling, vehicle-cloud universal application development scheme. Multi-concurrent multi-level service independent upgrade and multi-subnet parallel upgrade technologies have been developed to enhance multi-model adaptability and application iteration efficiency. The technological achievements have been evaluated as internationally advanced by a team of academician experts and have won the second prize of the China Society of Automotive Engineers Science and Technology Progress Award.

多车型大规模量产应用，助力企业降本增效
Large-scale mass production application of multiple vehicle models, aiding enterprises in cost reduction and efficiency enhancement

项目成功研发的多域融合中央计算平台及基于物理区域布局的区域控制器，通过整合 ECU 和软硬件多层级解耦，加速功能迭代，助力企业快速响应用户需求；通过按物理区域布置零部件，大幅简化线束排布、缩短线束长度，助力企业在研产供销服全价值链降本增效，巩固价格竞争优势，增强市场核心竞争力。

技术成果已在岚图 Free、梦想家、追光及知音四个系列共 10 余款车型实现规模化应用，累计销量突破 20 万台，带动新增经济效益超 350 亿元，实现利润超 30 亿元。岚图梦想家 MPV 在细分市场表现突出，销量位居前列，广受市场认可与用户青睐。未来五年岚图公司凭借该技术支撑将新增产值超1000亿元。



已搭载岚图汽车 3 个产品品类、4 个车型系列，10 余个车型项目实现大规模量产应用；累计销量达 20 余万台，OTA 一次升级成功率超 99.9%

It has been equipped with three product categories, four vehicle series, and over ten vehicle models from Voyah Automotive, achieving large-scale mass production applications. The cumulative sales have reached over 200,000 units, with an OTA (Over-The-Air) upgrade success rate exceeding 99.9%

The project has successfully developed a multi-domain fusion central computing platform and a regional controller based on physical area layout. By integrating ECU and multi-level decoupling of software and hardware, it accelerates functional iteration and helps enterprises respond quickly to user demands. By arranging components according to physical areas, it significantly simplifies wire harness layout, shortens wire harness length, and helps enterprises reduce costs and increase efficiency across the entire value chain of research, production, supply, marketing, and service. This consolidates price competitive advantages and enhances market core competitiveness.

The technological achievements have been applied on a large scale in over 10 models across four series: Voyah Free, Dream, Passion, and Courage, with cumulative sales exceeding 200,000 units. This has driven new economic benefits of over 35 billion yuan and generated profits exceeding 3 billion yuan. The Voyah Dream MPV has performed outstandingly in the segment market, ranking among the top in sales and widely recognized and favored by the market and users. In the next five years, Voyah will leverage this technological support to increase its output value by over 100 billion yuan.

突破关键核心技术，带动产业链协同发展
Breakthrough in key core technologies to drive collaborative development of the industrial chain

项目突破核心技术，攻克高性能轻量化中央计算架构设计、车云一体化多维安全体系、整车应用迭代兼容适配等关键技术瓶颈，聚焦面向服务的车路云网一体化架构基础理论创新，推动中国电子电气架构基础研究迅速发展。项目累计申请发明专利 180 余项，授权发明专利 100 余项，牵头或参与制定行业标准 4 项。

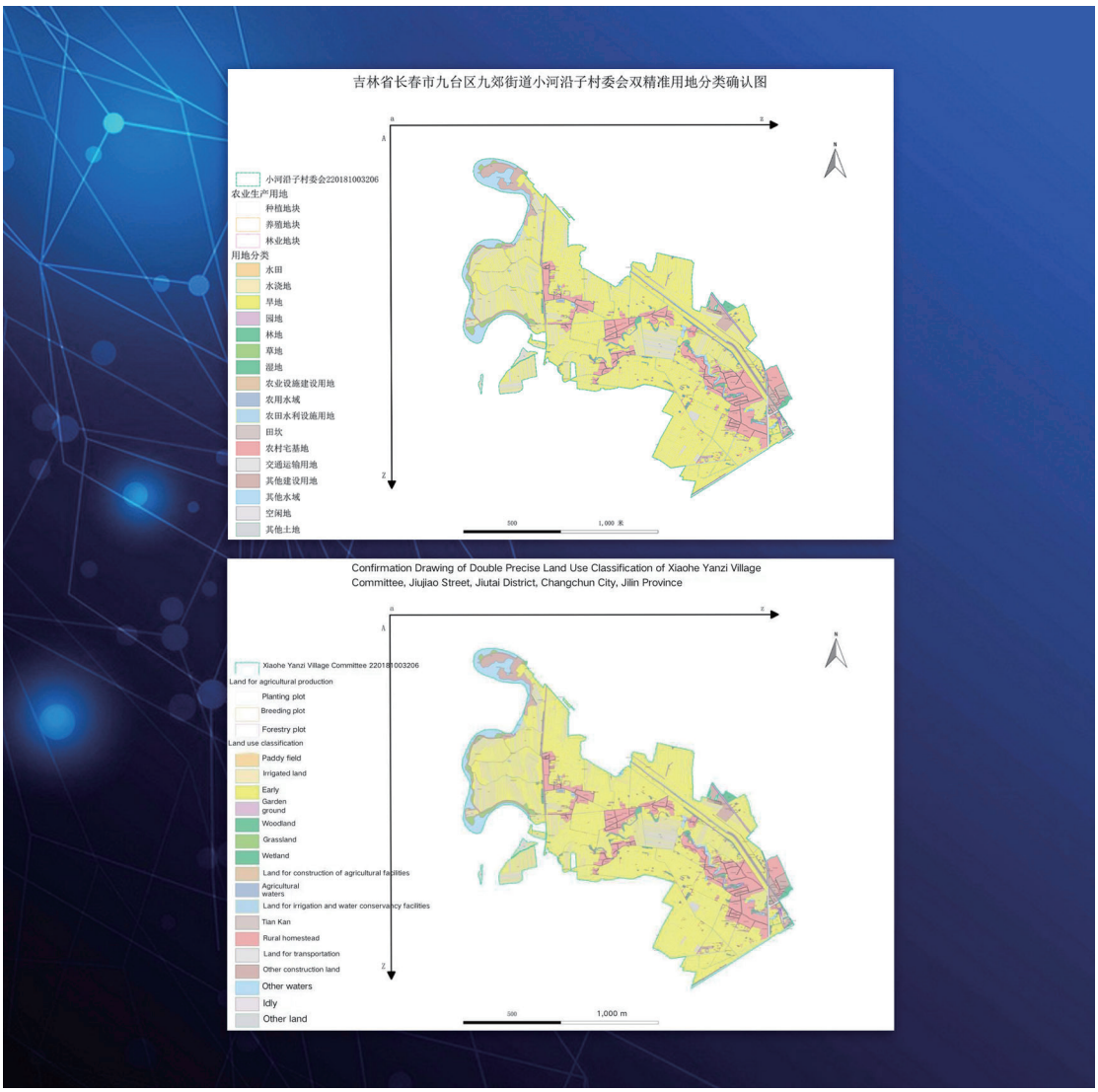
项目发挥链长作用，主动将核心零部件区域控制器和中央计算平台导入中国供应商体系，带动产业链协同发展，助力汽车电子电气架构生态发展。项目所选用的供应商已在市场中占据技术及市场先机，成为其细分领域的 “领头羊”。



左图区域控制器 , 右图中央计算平台
The left image shows the VIU(Vehicle Infranet Unit); the right image shows the OIB(One Intelligent Brain)

The project has made breakthroughs in core technologies, overcoming key technical bottlenecks such as the design of high-performance lightweight central computing architecture, multi-dimensional security system integrating vehicle and cloud, and iterative compatibility and adaptation of vehicle applications. It focuses on the innovation of basic theories for a service-oriented integrated architecture of vehicle, road, cloud, and network, accelerating the advancement of China's basic research in electronic and electrical architecture.. The project has applied for more than 180 invention patents and obtained more than 100 authorized invention patents, and has led or participated in the formulation of 4 industry standards.

The project plays a pivotal role in the supply chain, actively integrating core components such as regional controllers and central computing platforms into the Chinese supplier system. This initiative fosters collaborative development within the industrial chain, supports the growth of the automotive electronic and electrical architecture ecosystem. The suppliers selected for the project have already established technological and market leadership in their respective fields, becoming "leaders" in their niche markets.



基于多源遥感与 AI 技术构建的厘米级数字地图，实现作物识别与灾损评估

A centimeter-level digital map constructed using multi-source remote sensing and AI technology enables crop identification and disaster damage assessment

种植业保险“双精准”关键技术与应用

Precision Underwriting and Claims Settlement Key Technology and Application for Crop Insurance

中农阳光（吉林省）大数据集团有限公司
Sinoagri Sunshine (jilin) Big Data Group Co., Ltd.

引言

本成果通过融合卫星遥感、无人机、物联网与人工智能技术，构建“精准承保 + 精准理赔”双模式，实现农业保险的数字化、智能化与公平化，推动全球农业风险管理技术革新。

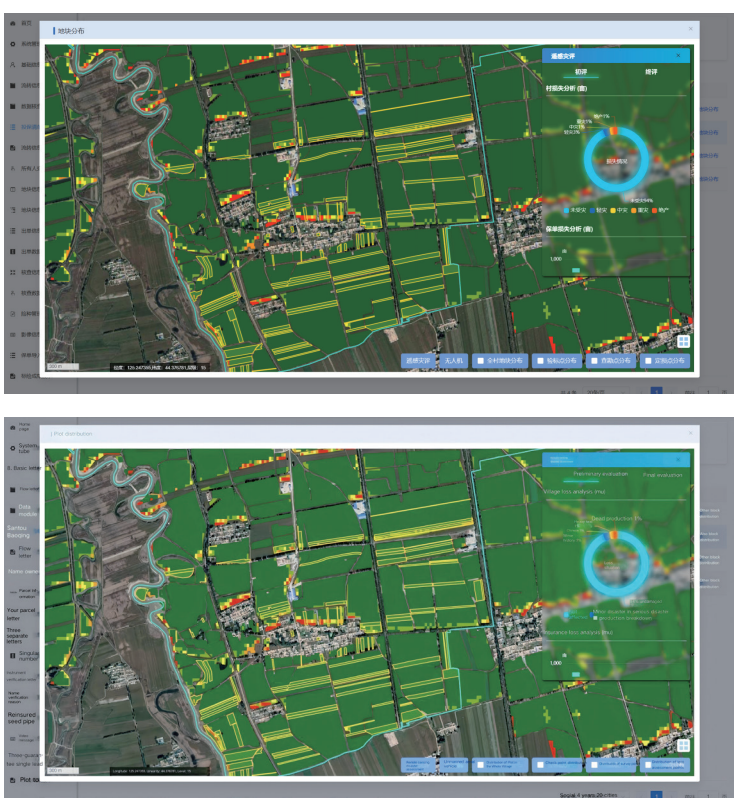
Introduction

This achievement integrates satellite remote sensing, UAV, IoT, and artificial intelligence technologies to establish a dual model of "Precision Underwriting + Precision Claims Settlement." It digitalizes, intellectualizes, and enhances the fairness of agricultural insurance, driving innovation in global agricultural risk management technology.

突破多源数据融合与智能分析技术，实现厘米级农业保险精准化管理

Breakthroughs in Multi-Source Data Fusion and Intelligent Analysis Technologies Enable Centimeter-Level Precision Management in Agricultural Insurance

本成果攻克了多源遥感数据时空配准、小地块边界识别、作物生长期动态监测等国际性技术难题。创新性地提出 " 卫星 - 无人机 - 物联网 " 三级数据融合架构，并突破时空配准技术，集成高分辨率遥感影像与深度学习算法，实现耕地、林地等地类特征的自动化识别，最终实现 10 厘米级高精度数字地图构建，地图分辨率≤ 10cm，为精准承保提供了包含唯一编码、坐标、面积及权属关系的可信空间数据基底；研发 NDVI/EVI/MSAVI 多指数融合模型与 SAR 雷达数据互补机制，基于遥感数据，采用多指数融合与时序分析技术，构建作物长势动态监测模型，实现三级预警机制，长势监测误差≤ 8%，有效解决多云地区监测盲区，监测频次提升 40%；建立 " 气象 - 土壤 - 作物 " 多要素耦合模型，整合气象、历史灾情及作物模型，运用机器学习算法建立灾害损失系统，实现灾害提前 5 天概率预测，估损偏差率控制在 12% 以内，损失评估准确率≥ 93%。相关技术获 14 项中国专利，在动态核保技术和灾害链式预测方面实现全球首创，整体达到国际领先水平。

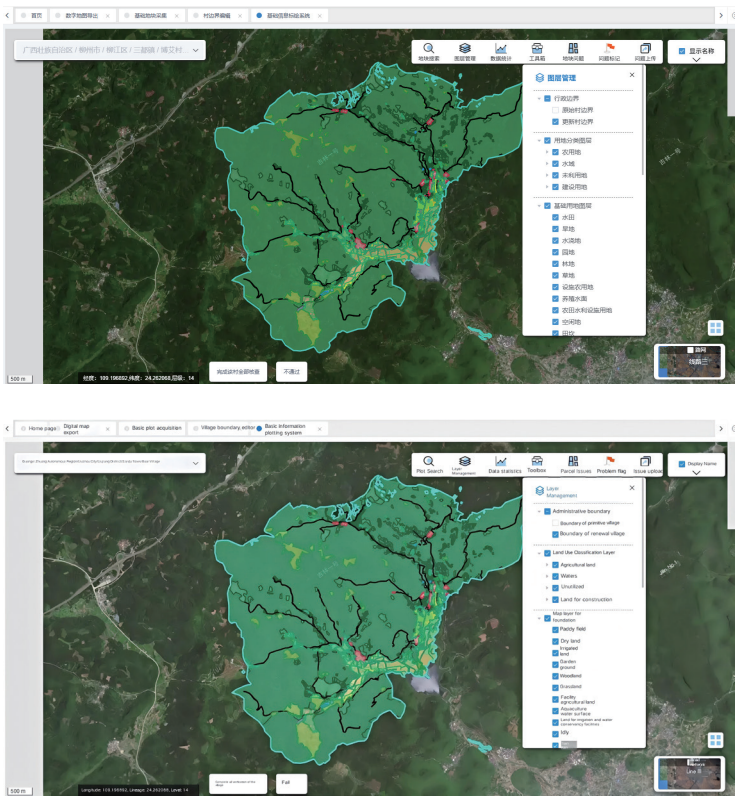


多源异构数据融合与智能分析

Multi-Source Heterogeneous Data Fusion and Intelligent Analysis

This achievement addresses international technical challenges such as spatiotemporal registration of multi-source remote sensing data, identification of small plot boundaries, and dynamic monitoring of crop growth stages. It innovatively proposes a three-tier "Satellite-UAV-IoT" data fusion architecture and breakthroughs in spatiotemporal registration technology. By integrating high-resolution remote sensing imagery and deep learning algorithms, it achieves automated identification of land features (e.g., cropland, forestland),

ultimately constructing a high-precision digital map at the 10-centimeter level (resolution ≤10 cm). This provides a trusted spatial data foundation for precision underwriting, including unique codes, coordinates, area, and ownership relationships.



多源异构数据融合与智能分析
Multi-Source Heterogeneous Data Fusion and Intelligent Analysis

The development of an NDVI/EVI/MSAVI multi-index fusion model and a complementary SAR radar data mechanism, combined with multi-index fusion and time-series analysis of remote sensing data, enables the construction of a dynamic crop growth monitoring model. This model implements a three-level early warning system with a growth monitoring error rate ≤8%, effectively addressing monitoring blind spots in cloudy regions and increasing monitoring frequency by 40%.

A "Meteorology-Soil-Crop" multi-factor coupling model integrates meteorological data, historical disaster records, and crop models. Using machine learning algorithms, a disaster loss assessment system was established, achieving probabilistic disaster forecasting 5 days in advance. The loss estimation deviation rate is controlled within 12%, and the loss assessment accuracy reaches ≥93%.

Related technologies have secured 14 Chinese patents, achieving global firsts in dynamic underwriting technology and disaster chain prediction. The overall technology reaches internationally leading standards.

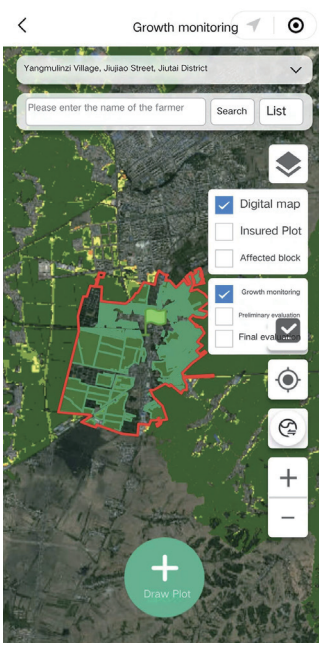
广泛应用于农业保险与数字农业服务，经济效益与社会效益显著
Wide Application in Agricultural Insurance and Digital Agriculture Services with Significant Economic and Social Benefits

本成果已在中国多个农业省份规模化应用，实现承保理赔全流程数字化。2023 年通过精准承保技术识别虚假投保 8.7 万亩，挽回经济损失 1.2 亿元；智能定损系统使理赔周期从 15 天缩短至 3 天，单案处理成本降低 62%（从 380 元降至 145 元）；实现了承保理赔的公平公正，使农户满意度提升 30%，通过区块链存证技术使定损争议率下降 78%，小农户参保率从 42% 增至 67%。在社会治理层面，成果助力县级农业农村部门监管能力提升 10 倍，人力成本降低 45%。带动遥感处理、智能农机等关联产业年规模达 53 亿元，推动农业保险综合成本率优化至 92%。此外，在农业增产方面，示范区单产波动率降低 35%，带动农户亩均增收 280 元。

This achievement has been deployed on a large scale across multiple agricultural provinces in China, achieving full-process digitalization of underwriting and claims settlement. In 2023, precision underwriting technology identified fraudulent applications covering 87,000 mu (approximately 5,800 hectares), recovering economic losses of 120 million RMB. The intelligent loss assessment system reduced the claims settlement cycle from 15 days to 3 days, and the cost per case decreased by 62% (from 380 RMB to 145 RMB).

It ensures fairness and transparency in underwriting and claims settlement, increasing farmer satisfaction by 30%. Through block-





chain-based evidence storage technology, the dispute rate in loss assessment decreased by 78%, and the participation rate of smallholder farmers rose from 42% to 67%.

At the social governance level, the achievement has enhanced the regulatory capacity of county-level agriculture and rural affairs departments by tenfold, while reducing labor costs by 45%. It has driven the annual output of related industries, such as remote sensing processing and intelligent agricultural machinery, to 5.3 billion RMB, and optimized the comprehensive cost ratio of agricultural insurance to 92%.

Furthermore, in terms of agricultural production increase, yield volatility in demonstration zones was reduced by 35%, leading to an average increase of 280 RMB per mu in farmers' income.





智能定损系统界面与移动端应用场景

Interface of Intelligent Loss Assessment System and Mobile Application Scenarios

推动全球农业保险技术标准升级，引领数字农业生态构建
Promoting the Upgrade of Global Agricultural Insurance Technical Standards and Leading the Construction of a Digital Agriculture Ecosystem

本成果在地块数据标准、动态核保技术、灾害链预测等方面实现全球首创，推动遥感影像处理技术从米级（1m）向厘米级（10cm）跨越，使国产高分辨率卫星数据处理能力达到国际领先水平。在农业 AI 算法领域，开发了首个面向农险的时序 NDVI 动态分析算法，并构建多模态融合的深度学习框架，使灾害识别准确率突破 90%。技术体系已形成地方标准 1 项，所建立的“四唯一”（编码、坐标、面积、权属）地块数据库标准已成为行业事实标准。成果显著带动中国农业科技研发投入年增长 35%，重点辐射至农业物联网终端、边缘计算设备及区块链存证系统等相关技术领域，促进 " 保险 + 科技 + 服务 " 产业共同体形成，深刻影响农业保险业商业模式创新，催生“按图承保、按图定损”新业态，推动纯保费率下降 18%，为全球农业可持续发展提供技术范式。

通过智能灌溉与精准施药技术，示范区亩均用水量减少 28%（从 550m^3 降至 396m^3），农药使用量降低 19%。成果还推动了农业的低碳发展，通过优化农事操作，降低了亩均碳排放强度。数字化施肥使土壤有机质含量年提升 0.3%。该技术体系不仅具备显著的生态效益与资源节约能力，更通过精准化的农业管理，为全球农业应对气候变化、实现可持续发展提供了可复制、可推广的综合性解决方案，具备巨大的全球推广价值。

This achievement has achieved global breakthroughs in areas such as plot data standards, dynamic underwriting technology, and disaster chain prediction. It has advanced remote sensing image processing technology from meter-level (1m) to centimeter-level (10cm) resolution, elevating China's high-resolution satellite data processing capabilities to internationally leading levels. In the field of agricultural AI algorithms, the first time-series NDVI dynamic analysis algorithm for agricultural insurance was developed, along with a multi-modal fused deep learning framework, pushing disaster identification accuracy beyond 90%.

The technical system has established one local standard, and the "Four Uniques" (code, coordinates, area, ownership) plot database standard has become a de facto industry benchmark. The achievement has driven a 35% annual growth in China's agricultural technology R&D investment, with significant spillover effects into related fields such as agricultural IoT terminals, edge computing devices, and blockchain-based evidence storage systems. It promotes the formation of an "Insurance + Technology + Service" industrial ecosystem, profoundly influences business model innovation in agricultural insurance, and fosters new practices such as "map-based un-





国际合作交流场景
International Cooperation and Exchange Scenarios

derwriting" and "map-based loss assessment," contributing to an 18% reduction in pure premium rates. This provides a technical paradigm for global agricultural sustainable development.

Through intelligent irrigation and precision pesticide application technologies, average water usage per mu in demonstration zones was reduced by 28% (from 550m³ to 396m³), and pesticide usage decreased by 19%. The achievement also advances low-carbon agricultural development by optimizing farming practices, reducing average carbon emission intensity per mu. Digital fertilization increases soil organic matter content by 0.3% annually.

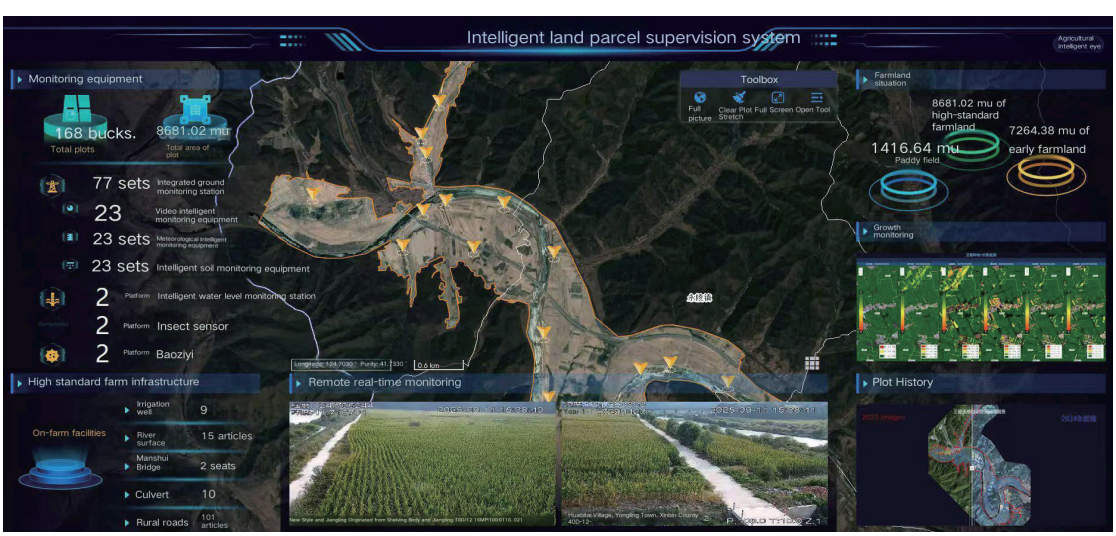
This technology system not only delivers significant ecological benefits and resource efficiency but also provides a replicable and scalable comprehensive solution for global agriculture to address climate change and achieve sustainable development through precision agricultural management. It holds immense potential for global adoption.

建绿色低碳农业技术体系，助力全球农业可持续发展
Building a Green and Low-Carbon Agricultural Technology System to Support Global Agricultural Sustainable Development

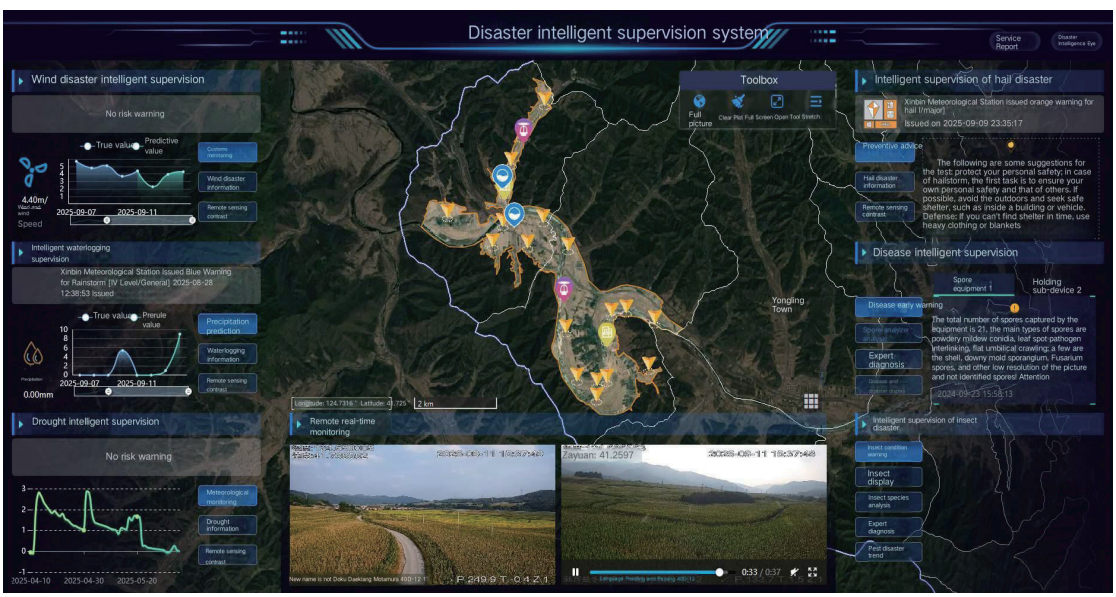
通过智能灌溉与精准施药技术，示范区亩均用水量减少 28%（从 550m^3 降至 396m^3），农药使用量降低 19%。成果还推动了农业的低碳发展，通过优化农事操作，降低了亩均碳排放强度。数字化施肥使土壤有机质含量年提升 0.3%。该技术体系不仅具备显著的生态效益与资源节约能力，更通过精准化的农业管理，为全球农业应对气候变化、实现可持续发展提供了可复制、可推广的综合性解决方案，具备巨大的全球推广价值。

Through intelligent irrigation and precision pesticide application technologies, the average water usage per mu in demonstration zones has been reduced by 28% (from 550m³ to 396m³), while pesticide usage has decreased by 19%. This achievement also promotes low-carbon agricultural development by optimizing farming practices, reducing the average carbon emission intensity per mu. Digital fertilization has increased soil organic matter content by 0.3% annually.
This technology system not only demonstrates significant ecological benefits and resource-saving capabilities but also provides a replicable and scalable comprehensive solution for global agriculture to address climate change and achieve sustainable development through precision agricultural management. It holds immense potential for global promotion and adoption.









绿色低碳农业技术应用

Application of Green and Low-Carbon Agricultural Technologies



主干网全流量安全态势智能感知关键技术体系架构
Key Technology Architecture for Intelligent Security Situational Awareness of Full Traffic in the Backbone Network

主干网全流量安全态势智能感知的关键技术研发及产业化

R&D and Industrialization of Key Technologies for Intelligent Security Situational Awareness of Full Traffic in the Backbone Network

东南大学
Southeast University

南京烽火星空通信发展有限公司
Nanjing Fiberhome StarrySky Communication Technology Co., Ltd.

引言

本项目在高速网络测量与行为分析领域取得关键进展，研制 100Gbps 流量采集器，提出网络行为特征测量、加密流量识别模型，并构建多维时空大数据平台。成果已应用于重大活动保障和关键信息基础设施安全，提升监测与分析能力。

Introduction

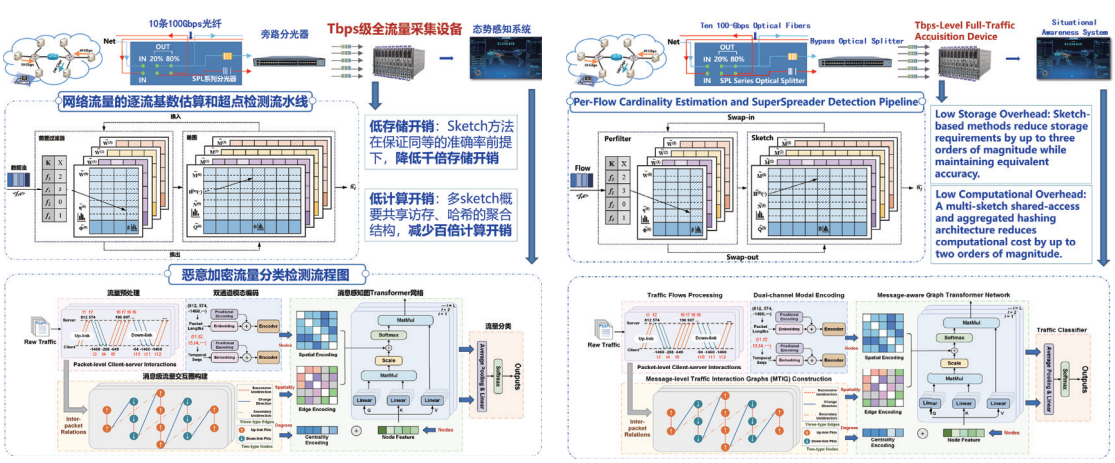
This project has achieved significant advances in high-speed network measurement and behavior analysis, including the development of a first-of-its-kind 100 Gbps traffic collector, the proposal of models for network behavior feature measurement and encrypted traffic identification, and the construction of a multi-dimensional spatiotemporal big data platform. The outcomes have been applied in major event security and the protection of critical information infrastructure, enhancing monitoring and analytical capabilities.

原创性理论引领 Tbps 级全流量态势感知性能飞跃
Original Theories Driving a Performance Leap in Tbps-Level Full-Traffic Situational Awareness System

网络安全态势感知以海量数据采集为基础，需在筛选可疑行为、识别网络威胁的同时呈现整体态势，但面临三大挑战：一是主干流量年均百万兆级增长，Tbps 级实时采集困难；二是海量流量中可疑行为高度聚集，有限资源难以有效筛选；三是互联网全加密趋势加剧，隐蔽威胁识别受限。

本项目取得多项原创性进展：其一，研制了面向态势感知的软硬件结合 100Gbps 流量探针，并提出基于熵值智能规则决策树的全流量在线分类方法，实现高效实时检测；其二，提出 Tbps 级全流量概要增量计算方法，支持在线大流与超点检测，相比国际主流技术显著降低存储和计算开销；其三，构建有害视频指纹库，提出切片时序矢量指纹识别方法，可在不解密情况下识别加密视频内容，准确率达 99%。

Network security situational awareness relies on large-scale data acquisition to screen suspicious behaviors, identify threats, and present an overall security posture. However, three fundamental challenges exist: (1) Backbone traffic grows annually at the scale of exabytes, making Tbps-level real-time acquisition highly challenging. (2) Suspicious behaviors are highly clustered within massive traffic, making efficient filtering under limited resources difficult. (3) The trend of pervasive encryption significantly constrains the detection



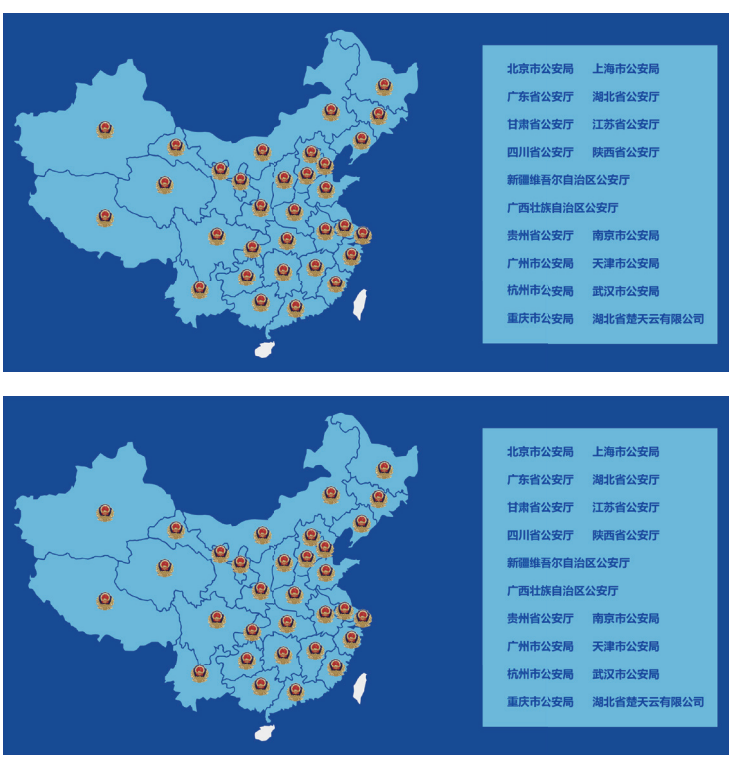
整体框架图
Overall Framework

of covert threats.

The project has made a series of original contributions: First, it developed a hardware–software integrated 100 Gbps traffic probe for situational awareness and proposed an online full-traffic classification method based on entropy-driven intelligent rule decision trees, enabling efficient real-time detection. Second, it introduced a Tbps-level incremental sketching method that supports online detection of large flows and superspreaders, significantly reducing storage and computational overhead compared with international state-of-the-art techniques. Third, it constructed a malicious video fingerprint database and proposed a sliced temporal-vector fingerprinting approach capable of identifying encrypted video content without decryption, achieving 99% accuracy.

支撑公安网信防护的网络安全核心成果
Core Cybersecurity Achievements Supporting Public Security and Cyberspace Protection

本项目的技术产品服务于公安、网信等 2000+ 单位，在中国市场占有率 65%，其中一二线城市占有率 90% 以上，构建自主可控的网络安全防护体系。已被广东省厅、南京市局等 47 家单位用于反诈，推送潜在受害人线索 30 万条，累计拦截次数超过 1000 万，辅助破获案件 19 万起，减少经济损失超千亿元。部署在 31 个省，281 个地级市，发现新疆暴恐音视频 30 余万条，辅助破获比特币传销、网络赌博等案件，总案值 150 亿元。自 2019 年市场化以来，累计实现销售收入 33.97 亿元、利润 2.49 亿元、税收 1.49 亿元。南京烽火星空通信发展有限公司累计销售软件 3780 余套，年均销售额超 8 亿元，带动形成完整产业链并促进就业。项目成果在杭州亚运会、进博会等国家大型活动网络安保中得到了验证，获得多项表彰。



全国公安局点部署图
National Deployment Map of Public Security Bureaus

The developed technologies and products are deployed in more than 2,000 institutions, including public security and cybersecurity authorities, with a market share of 65% nationwide and over 90% in first- and second-tier cities. They have been adopted by 47 agencies such as the Guangdong Provincial Department of Public Security and Nanjing Municipal Bureau for anti-fraud purposes, generating more than 300,000 victim-warning leads, blocking over 10 million fraudulent attempts, supporting the investigation of 190,000 cases, and preventing economic losses exceeding RMB 100 billion. The solutions have been deployed across 31 provinces and 281 prefecture-level cities, leading to the discovery of over 300,000 pieces of extremist video content in Xinjiang and aiding the investigation of cases including Bitcoin pyramid schemes and online gambling with a total value of RMB 15 billion. Since market deployment in 2019, the project has generated cumulative sales revenue of RMB 3.397 billion, profits of RMB 249 million, and taxes of RMB 149 million. Nanjing Fiberhome StarrySky Communication Technology Co., Ltd. has sold more than 3,780 sets of software, with an average annual sales volume exceeding RMB 800 million, fostering a complete industrial chain and creating significant employment opportunities. The project outcomes have been successfully validated in the cybersecurity assurance of major national events such as the Hangzhou Asian Games and the China International Import Expo, receiving multiple commendations.



国家大型活动网络安保表彰

Commendations for Cybersecurity Assurance in Major National Events

Tbps 级流式处理与加密流量识别成果获得国际学术认可
Tbps-Level Streaming and Encrypted Traffic Identification Recognized by the International Research Community

本成果在流式数据处理与网络安全领域取得重要进展。实现 Tbps 级流量采集，单台设备支持 5000 万条规则，性能优于国际同类系统；提出海量流量在线超点检测方法，存储消耗低于 0.1 比特 / 流，查询成本少于 4 次访存，国际上率先实现实时检测；研发加密视频内容识别技术，可在多路复用环境下提取 20 万条指纹，达到国际先进水平；融合时空态势感知与知识图谱，并在 281 个跨域节点部署，显著提升威胁监测。该成果获专家认可：沈昌祥院士认为加密视频指纹识别方法先进，管晓宏院士指出寄存器共享思路可用于基数估计，谷歌匿名化团队负责人 Damien Desfontaines 评价其流基数推理方法显著提升 HLL 效率。成果在国际学术界和产业界产生积极影响，提升中国在全球数字治理中的竞争力。



本项目获得国际 / 国内同行高度评价
Highly Recognized by International and Domestic Peer Researchers

This achievement has made significant progress in the fields of streaming data processing and cybersecurity. It realizes Tbps-level traffic collection, with a single device supporting 50 million rules, outperforming international peer systems. A novel method for online superspreader detection in massive traffic was proposed, achieving storage consumption below 0.1 bit per flow and query costs under four memory accesses, marking the world's first realization of real-time detection. Encrypted video content recognition technology was developed, capable of extracting 200,000 fingerprints in a multiplexed environment, reaching an internationally advanced level. By integrating spatiotemporal situational awareness with knowledge graphs, and deploying across 281 cross-domain nodes, the system significantly enhanced threat monitoring. The achievement has been recognized by experts: Academician Shen Changxiang praised the encrypted video fingerprinting method as advanced; Academician Guan Xiaohong noted that the register-sharing approach could be applied to cardinality estimation; and Damien Desfontaines, head of Google's anonymization team, commented that its stream-based cardinality inference method significantly improves the efficiency of HyperLogLog. This work has generated a positive impact in both the international academic community and industry, advancing China's cybersecurity development and strengthening its global competitiveness.

融合科研创新与实战应用的网络安全突破
Cybersecurity Breakthrough Integrating Scientific Innovation and Practical Application

本成果显著提升网络安全与治理能力。系统打击虚拟货币“挖矿”，发现矿场百余个，保护九十余万受害者，每日节电 26 万度；同时支撑疫情流调与人群聚集检测，实现轨迹溯源。建设示范性网络安全学院和研究基地培养高水平人才。科研方面提出加密视频识别技术，构建态势感知系统，已在两千余家机构应用。形成 3 项创新发明、23 件授权发明专利、12 件软件著作权和 70 篇论文，并在 281 个跨域节点实现 Tbps 级采集，推动网络安全技术进步与产业发展。

This achievement has significantly enhanced cybersecurity and governance capabilities. The system effectively combats cryptocurrency “mining,” uncovering over one hundred mining farms, protecting more than 900,000 victims, and saving 260,000 kWh of electricity daily. At the same time, it has supported pandemic-related contact tracing and crowd detection, enabling mobility trajectory analysis. In education, a model cybersecurity academy and research base were established to cultivate high-level talent. On the research front, encrypted video recognition technology was proposed and a situational awareness system was developed, which has already been applied in more than 2,000 institutions. The achievement has generated 3 innovative inventions, 23 granted invention patents, 12 software copyrights, and 70 academic papers, while also realizing Tbps-level traffic collection across 281 cross-domain nodes. Collectively, these contributions drive progress in cybersecurity technologies and promote industrial development.



本项目部分感谢函与平台建设情况
Acknowledgment Letters and Platform Development Status



无轨导全位置爬行焊接机器人 横焊
Track-Free All-Position Crawling Welding Robot - Horizontal Welding

自主决策式无轨导全位置爬行焊接机器人
Autonomous Decision-Making Track-Free All-Position Crawling Welding Robot

北京博清科技有限公司
Beijing Boqing Technology Co., Ltd.

博清科技 BOTSING

引言

本项目攻克大型复杂结构件全位置自动化焊接国际难题，成功研发国际领先的无轨导全位置爬行焊接机器人系统。创新性融合人工智能、高精度激光视觉跟踪、高性能永磁吸附等核心技术，构建了“高抗扰智能感知 - 数据驱动自主决策 - 高负载精准执行”一体化智能焊接体系。

Introduction

This project tackles the international challenge of achieving all-position automated welding for large, complex structural components, successfully developing a world-leading track-free all-position crawling welding robot system. It innovatively integrates core technologies such as artificial intelligence, high-precision laser vision tracking, and high-performance permanent magnetic adhesion, establishing an integrated intelligent welding system characterized by "High Anti-Interference Intelligent Perception - Data-Driven Autonomous Decision-Making - High-Load Precision Execution."

全球首创无轨导爬行焊机器人，破解大型复杂构件智能焊接难题

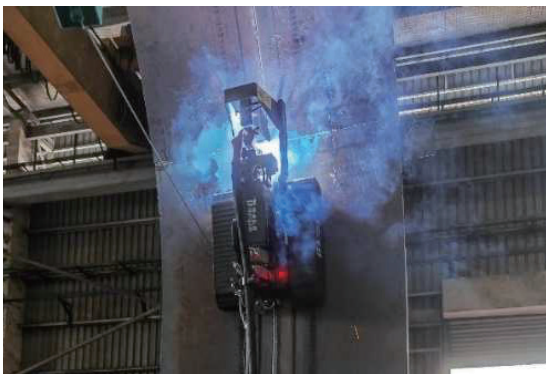
World's First Track-Free Crawling Welding Robot Solves Intelligent Welding Challenges for Large Complex Components

本项目成功解决了大型复杂结构件在无轨道条件下全位置自适应焊接这一长期困扰国际焊接领域的重大技术瓶颈，开发出全球领先的无轨导爬行焊接机器人系统。通过融合多模态传感、智能决策与高精度执行等跨学科技术，系统实现了强干扰环境下 ±0.1mm 动态跟踪精度、150°C高温持续作业、5:1 负载自重比及 8mm 越障能力等极端工艺性能，突破了国际现有技术极限。焊缝一次合格率达 100%，冲击韧性提升至传统焊接 2–3 倍，双面双弧协同工艺提升效率 130%，综合效能达人工 3–5 倍。技术已应用于全球 20 多个国家的能源、船舶、化工等重大工程，主导制定多项国际标准，获发明专利授权百余项，核心性能指标全面领先，推动了全球焊接制造范式的革新。

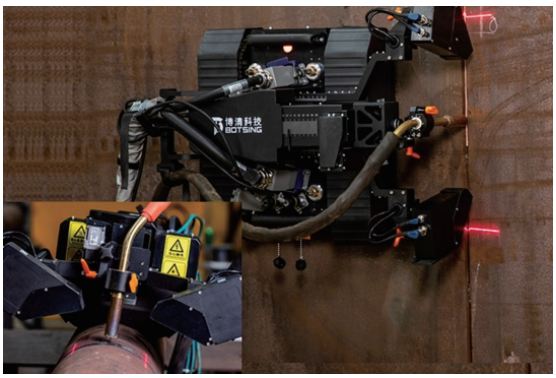


无轨导全位置爬行焊接机器人 - 立焊
Track-Free All-Position Crawling Welding Robot - Vertical Welding

This project successfully addresses the major technical bottleneck that has long perplexed the international welding community: achieving all-position adaptive welding for large, complex structural components without relying on tracks. It has resulted in the development of a globally leading track-free crawling welding robot system. By integrating interdisciplinary technologies like multi-modal sensing, intelligent decision-making, and high-precision execution, the system achieves extreme process capabilities including ±0.1mm dynamic tracking accuracy in strongly interfering environments, continuous operation at 150°C high temperatures, a 5:1 load-to-weight ratio, and the ability to overcome 8mm obstacles, surpassing existing international technological limits. The first-pass weld qualification rate reaches 100%, impact toughness is improved to 2-3 times that of traditional welding, the double-sided double-arc cooperative process increases efficiency by 130%, and overall effectiveness reaches 3-5 times that of manual welding. The technology has already been applied in major energy, shipbuilding, and chemical engineering projects in over 20 countries worldwide. It has led the formulation of multiple international standards, garnered authorization for over a hundred invention patents, and its core performance indicators lead comprehensively, driving innovation in the global welding manufacturing paradigm.



无轨导全位置爬行焊接机器人 - 环焊
Track-Free All-Position Crawling Welding Robot - Girth Welding



无轨导全位置爬行焊接机器人 - 激光扫描
Track-Free All-Position Crawling Welding Robot - Laser Scanning

全球多领域规模化应用，推动重大工程效能与绿色水平双跃升
Large-Scale Global Application Across Multiple Sectors, Driving Dual Leap in Major Project Efficiency and Green Performance

本成果已成功应用于全球 20 余个国家，在油气化工、船舶制造、海洋工程等六大领域获得广泛推广，服务于新加坡港机、刚果（金）矿业装备、日本 LNG 船等多项国际重大工程。凭借无轨导全位置爬行、强干扰智能感知与多机协同作业等技术突破，显著提升焊接效率 3-5 倍，降低综合成本 60%-80%，焊缝一次合格率达 100%。近三年实现直接经济效益数亿元，同时，技术为全球产业链注入了强劲增长动能，预计未来三年将催生



9Ni 钢 LNG 储罐焊接项目 - 江苏 南通
9Ni Steel LNG Tank Welding Project - Nantong, Jiangsu, China

超百规模的增量效益。

成果有效替代高危险、高强度人工作业，改善全球焊接职业健康安全环境，推动产业人才结构优化。通过精准焊接与一次合格率提升，降低焊材损耗 15%-20%，减少碳排放 15%-20%，为全球制造业绿色转型提供关键技术支撑。主导制定多项国际标准，布局 PCT 专利近百项，构建了“技术 - 专利 - 标准”联动创新体系，显著增强全球产业链韧性与可持续发展能力。

This achievement has been successfully applied in over 20 countries, gaining widespread adoption in six major sectors including oil & gas chemicals, shipbuilding, and offshore engineering, serving numerous international major projects such as Singapore port machinery, mining equipment in the Democratic Republic of Congo, and Japanese LNG carriers. Leveraging technological breakthroughs in track-free all-position crawling, intelligent perception in strong interference environments, and multi-robot collaborative operation, it significantly enhances welding efficiency by 3-5 times, reduces overall costs by 60%-80%, and achieves a 100% first-pass weld qualification rate. In the past three years, it has generated direct economic benefits amounting to hundreds of millions of RMB (several tens of millions USD). Furthermore, the technology injects robust growth momentum into the global industrial chain, with projected incremental benefits exceeding ten billion RMB (over one billion USD) in the next three years.

The achievement effectively replaces high-risk, high-intensity manual labor, improves the global occupational health and safety environment for welders, and promotes the optimization of the industrial talent structure. Through precise welding and the increased first-pass qualification rate, it reduces welding consumable waste by 15%-20% and decreases carbon emissions by 15%-20%, providing crucial technological support for the green transformation of global manufacturing. It has led the formulation of multiple international standards, nearly a hundred PCT patents have been filed, and a synergistic innovation system linking "technology-patents-standards" has been established, significantly enhancing the resilience and sustainable development capacity of the global industrial chain.



管道焊接项目 - 保加利亚
Pipeline Welding Project - Bulgaria

智能焊接机器人定义产业未来，引领全球高端制造新变革
Intelligent Welding Robot Defines the Industry's Future, Leading a New Global Transformation in High-End Manufacturing

本成果以颠覆性技术重塑全球焊接产业格局，实现了从技术突破到产业赋能的全面跨越。其首创的“无轨导爬行 +AI 决策”技术体系，攻克了大型复杂结构件全位置自动化焊接的世界性难题，推动焊接技术由传统“经验工艺”迈向“数据智能”新纪元，主导制定了多项国际标准并构建了覆盖全球的专利壁垒，确立了技术全球引领地位。

在驱动产业升级方面，本成果全面赋能能源、船舶、海洋工程等战略行业，实现焊接效率提升 3–5 倍、成本降低 60% 以上，彻底变革传统作业模式，实现了制造模式的根本性变革。通过领先的技术输出与深度国际合作，已成功应用于全球多个重大工程项目中，不仅大幅增强全球高端装备制造能力与产业链韧性，更带动超百亿规模的经济效益，积极推动全球焊接产业向智能化、绿色化与高附加值方向转型升级，对全球高端制造领域的竞争格局产生了深远而积极的影响。

This achievement reshapes the global welding industry landscape with disruptive technology, accomplishing a comprehensive leap from technological breakthrough to industrial empowerment. Its pioneering "track-free crawling + AI decision-making" technological system solves the world-class challenge of all-position automated welding for large, complex structures, propelling welding technology from a traditional "experience-based craft" into a new era of "data intelligence." It has led the formulation of multiple international standards and built a global patent barrier, establishing a position of global technological leadership.

In driving industrial upgrading, this achievement comprehensively empowers strategic sectors such as energy, shipbuilding, and offshore engineering, achieving a 3-5 times increase in welding efficiency and over 60% cost reduction, fundamentally transforming traditional operational modes and revolutionizing manufacturing paradigms. Through advanced technology exports and deep international cooperation, it has been successfully applied in numerous major engineering projects worldwide. This not only significantly enhances global high-end equipment manufacturing capabilities and industrial chain resilience but also generates economic benefits exceeding ten billion RMB (over one billion USD). It actively drives the transformation and upgrading of the global welding industry towards intelligentization, greenization, and high value-added development, exerting a profound and positive impact on the competitive landscape of the global high-end manufacturing sector.



博清科技推动行业智能化转型升级
Botsing Technology Driving Intelligent Transformation and Upgrading in the Industry



世界互联网大会
领先科技奖收录成果

Collection of World Internet Conference
Awards for Pioneering Science and Technology



02

世界互联网大会
领先科技奖收录成果

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Awards for Pioneering Science and Technology

工程研发组

Engineering Research and Development Group





仝舟 AIGC 生产管线
Tongzhou AIGC Production Pipeline

AIGC 生产管线应用实践
Practical Application of AIGC Production Pipeline

咪咕文化科技有限公司
MIGU Co., Ltd.

引言

咪咕公司自主研发的“仝舟 AIGC 生产管线”构建一站式端到端视频创作解决方案，使视频制作成本降低 83.56%、周期缩短 75%，产出超百部 AIGC 视频，累计创收 3031 万元，播放量破 30 亿次，获 17 项发明专利，推动 AI 视频产业标准化发展。

Introduction

Migu's independently developed "Tongzhou AIGC Production Pipeline" builds an one-stop end-to-end video creation solution. It reduces video production costs by 83.56% and shortens the cycle by 75%, produces over 100 AIGC videos, achieves cumulative revenue of 30.31 million yuan, reaches 3 billion views, and obtains 17 invention patents, driving the standardization of the AI video industry.

咪咕“仝舟 AIGC 生产管线”创 AI 视频工业化生产国际领先标杆
Migu’s “Tongzhou AIGC Production Pipeline” Sets an Internationally Leading Benchmark for AI Video Industrial Production

该成果攻克 AI 视频连贯性差、工具链割裂等全球性难题，实现三大核心突破：一是创新多模态生成技术矩阵，文本到视频全流程自动化，连贯性 92.5%、效率提升 4 倍，4K 超分及横转竖技术降本 50%；二是构建企业级 MaaS 架构，支持多模型快速接入，2000 QPS 峰值下 8 秒响应，支撑单日 10 万 + 视频生成；三是主导 16 项技术标准、提交 12 篇国际提案，建立安全版权体系。其适配自主研发片并开源技术，拉动产业链超 20 亿元，首次实现 AI 视频一站式工业化生产，技术、商业化及标准引领性均达国际领先。

This achievement has solved global challenges such as poor AI video coherence and fragmented toolchains, achieving three core breakthroughs. Firstly, it innovates a multi-modal generation technology matrix, enabling full-process automation from text to video with a coherence rate of 92.5% and 4x efficiency improvement. Its 4K super-resolution and horizontal-to-vertical conversion technologies reduce costs by 50%. Secondly, it builds an enterprise-level MaaS architecture that supports quick access of multiple models, achieving an 8-second response under a peak of 2000 QPS and supporting the generation of over 100,000 videos per day. Thirdly, it leads the development of 16 technical standards, submits 12 international proposals, and establishes a secure copyright system. Adapted to independently developed chips and with open-sourced technologies, it drives the industrial chain by over 2 billion yuan. It has realized one-stop industrial production of AI videos for the first time, leading internationally in technology, commercialization and standardization.



咪咕“仝舟 AIGC 生产管线”创 AI 视频工业化生产国际领先标杆
Migu’s “Tongzhou AIGC Production Pipeline” Sets an Internationally Leading Benchmark for AI Video Industrial Production

咪咕 AIGC 视频技术应用成熟 经济效益与产业价值双向释放
Migu's AIGC Video Technology Boasts Mature Application, Unleashing Dual Value in Economic Benefits and Industrial Impact

该成果应用成熟，已落地影视、广告等 8 大行业，累计营收 3031 万元，B 端复购率 72%。经济效益显著：企业视频制作成本平均降 83.56%、周期压缩 75%，人力及算力成本分别缩减 70%、35%；适配自主研发芯片，3 年内预计带动产业链超 20 亿元。社会与产业价值突出，赋能中小微企业降本增效，未来将拓展至教育、电商等领域，2026 年市场规模有望破 20 亿元，同时规划出海输出技术，进一步放大技术创新的市场辐射力与产业带动作用。

This achievement has been maturely applied, having landed in 8 industries including film and television, and advertising, with cumulative revenue of 30.31 million yuan and a B-end repurchase rate of 72%. The economic benefits are remarkable: it reduces enterprises' average video production costs by 83.56%, shortens the cycle by 75%, and cuts labor and computing costs by 70% and 35% respectively. Adapted to independently developed chips, it is expected to drive the industrial chain by over 2 billion yuan within 3 years. It also demonstrates prominent social and industrial value by empowering micro, small and medium-sized enterprises to cut costs and boost efficiency. In the future, it will expand into education, e-commerce and other fields, with the market scale expected to exceed 2 billion yuan by 2026. Meanwhile, it plans to go global and export technologies, further expanding the market radiation and industrial driving force of technological innovation.



咪咕 AIGC 视频技术应用成熟
Migu's AIGC Video Technology Boasts Mature Application

仝舟 AIGC 生产管线创经济社会效益双高，引领产业升级
Tongzhou AIGC Production Pipeline Achieves High Economic and Social Benefits, Leading Industrial Upgrading

该成果影响深远，经济上直接创收超 3000 万元，降低行业成本 80%+，适配自主研发带动产业链发展，未来 3 年将拉动上下游超 100 亿元。社会价值突出：赋能 2000+ 中小微企业，助力乡村振兴（云南保山咖啡视频播放破 5 亿次），推动非遗数字化传播；建立安全审核与版权保护体系，保障 30 亿次播放合规；催生新职业，培养 2000+ 人才，还计划开源激活生态。同时减少行业碳足迹，实现经济与社会效益双重突破。

This achievement has far-reaching impacts. Economically, it has directly generated over 30 million yuan in revenue, reduced industry costs by more than 80%, and driven the development of the industrial chain through adaptation to independent R&D. It is expected to drive the upstream and downstream industries by over 10 billion yuan in the next 3 years. Its social value is prominent: it has empowered more than 2,000 micro, small and medium-sized enterprises, assisted in rural revitalization (with videos of Baoshan coffee in Yunnan gaining over 500 million views), and promoted the digital communication of intangible cultural heritage. It has established a safety review and copyright protection system to ensure the compliance of 3 billion views. In addition, it has spawned new occupations, trained over 2,000 talents, and plans to open source technologies to activate the ecosystem. Meanwhile, it reduces the carbon footprint of the industry and enhances international discourse power in China's AIGC sector, achieving dual breakthroughs in economic and social benefits.



仝舟 AIGC 生产管线创经济社会效益双高
Tongzhou AIGC Production Pipeline Achieves High Economic and Social Benefits



安全智能体“以模制模”技术创新及应用（产品名称：360 大模型安全卫士）
Technological Innovation and Application of Security AI Agents "Using AI to Combat AI" (Product Name: 360 Large Model Security Guardian)

安全智能体“以模制模”技术创新及应用

Technological Innovation and Application of Security AI Agents "Using AI to Combat AI"

360 数字安全集团
360 Digital Security Group

360数字安全
数 字 安 全 的 领 导 者

引言

360 秉持“以模制模”理念，依托自研安全大模型基座，通过训练垂直领域智能体专家，将安全智能体深度融入大模型全生命周期安全防护体系，以应对人工智能发展带来的内容安全、供应链安全、幻觉、智能体行为管控等挑战。

Introduction

Adhering to the philosophy of "Using AI to Combat AI," 360 leverages its self-developed security large model as its base to train expert AI agents specialized in vertical-domains. Such security agents are deeply integrated into the full life-cycle security system of large models, addressing challenges such as content security, supply chain security, hallucinations, and agent behavior control brought by the development of artificial intelligence.

以垂直领域专家智能体构建原生安全解决方案
Building Native Security Solutions with Expert AI Agents Specialized in Vertical-Domains

360 依托原生安全大模型构建安全智能体，以其为载体将安全专家经验、专业知识及系列工具智能化落地到客户端，打造了能够理解攻防逻辑、产品意图和业务流程的数字安全专家，为用户 AI 转型提供主动化的、智能化的安全防御方案。

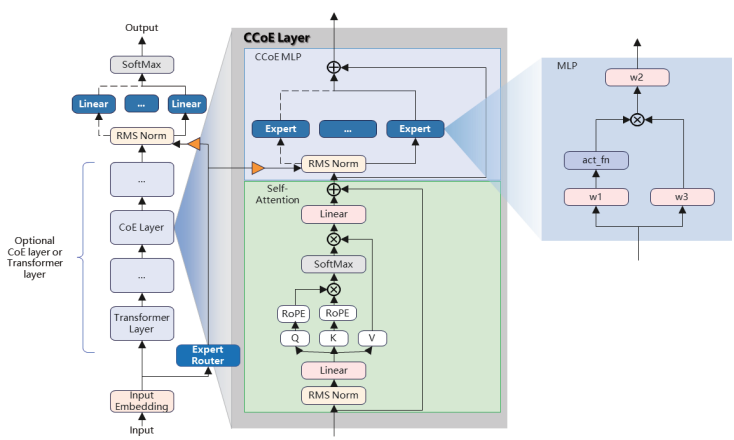
针对安全垂直领域多场景化的应用需求，360 独创紧凑型多专家协同（CCoE）架构，使得专项任务无需训练大规模基座参数。在模型基座之上，360 针对各类安全研判、分析、生成等任务设计了相互独立的“专家智能体”，即插即用，少许训练路由参数就能即可完成新任务“专家”扩展工作。

此外，360 独创开源强化学习 LoRA（Low-Rank Adaptation）训练方案，在保持模型泛化能力的前提下，体积仅为原始全参数模型的 1%-5%，实现专项微调显存占用降低、训练效率提升、集约化部署应用。

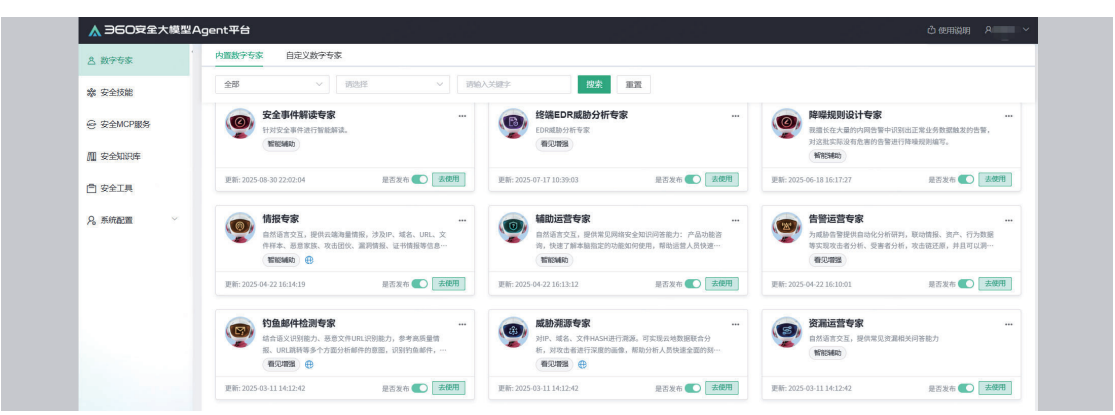
Building on its native security large model, 360 constructs Security AI Agents that serve as carriers to intelligently implement security expertise, professional insights, and a suite of tools of security specialists on the client side. It creates digital security experts capable of understanding attack and defense logic, product intention, and business processes, thus providing users with proactive and intelligent security defense solutions for their AI transformation.

To address the multi-scenario application needs in the security vertical-domains, 360 has pioneered the Compact LLM with Collaboration of Experts (CCoE) architecture. It enables specific tasks to be accomplished without training large-scale foundation model parameters. On top of its model foundation, 360 has designed independent "expert AI agents" for various security evaluation, analysis, generation tasks and beyond. These are plug-and-play agents that only require minimal training of routing parameters to expand new task-specific "experts".

Additionally, 360 has developed an innovative open-source reinforcement learning LoRA (Low-Rank Adaptation) training program. While maintaining the generalization capability of the model, its size is only 1%–5% of the original full-parameter model. This approach delivers reduced memory usage for specialized fine-tuning, improved training efficiency, and intensive application deployment.



紧凑型多专家协同（CCoE）架构
Compact LLM with Collaboration of Experts (CCoE) Architecture



基于安全大模型平台打造的专家智能体
Expert AI Agents Created Based on the Security Large Model Platform

破解 AI 安全难题，夯实智能化发展基座
Addressing AI Security Challenges with Strengthened Foundation for Intelligent Development

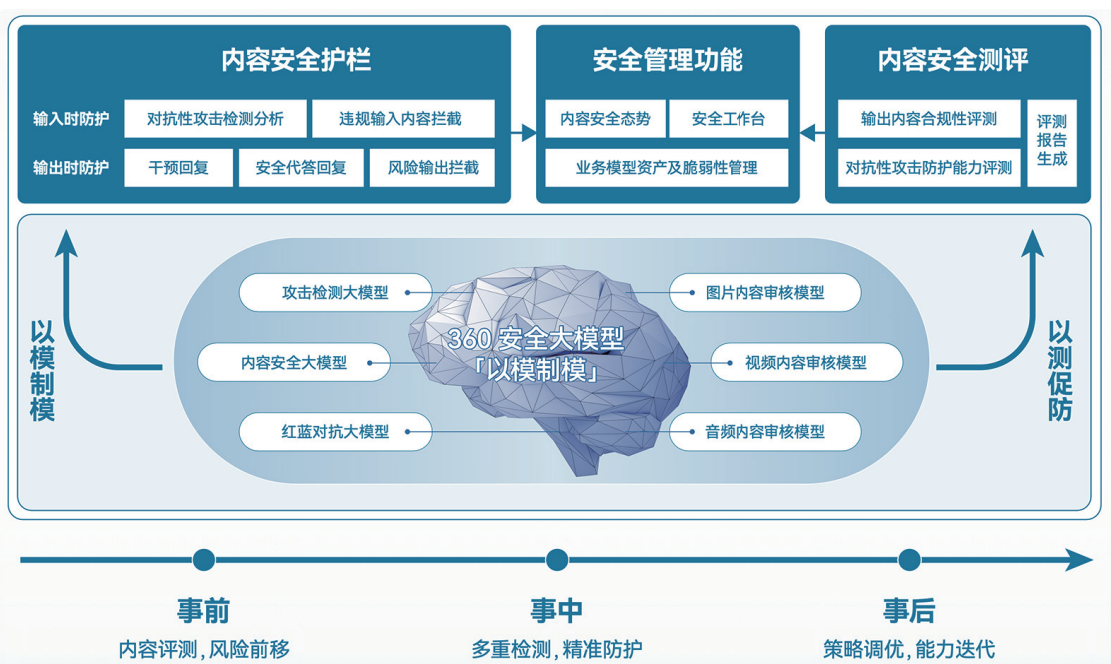
经济效益方面，安全智能体“以模制模”技术创新及应用已经成熟。从范围上看，已在政府、金融、医疗、教育等重点行业完成落地；从数量上看，各类数字专家超 100 个。在大模型内容安全保障场景中，日均检测不良内容 1000 余条，回复安全率超 99%，识别准确率达 99% 以上，有效兼顾业务安全性和实用性。

社会效益方面，本方案通过提供高效、智能的安全防护手段，有效遏制了大模型发展带来的安全问题，助推相关技术的标准化和规范化，积累专项评测数据集超 100 万条，提供了强有力的数据支持与决策依据，保护了公民的个人信息安全和企事业单位的平稳运行。

从技术创新价值来看，安全智能体“以模制模”方案提供了大模型安全防护新的解决方案，推动企业安全转型与 AI 数字环境健康发展。

From an economic perspective, the technological innovation and application of Security AI Agents "Using AI to Combat AI" have reached maturity. Scoping-wise, it has been implemented in key sectors such as government, finance, healthcare, and education. By quantity, there are over 100 digital experts of various kinds. In large model content security scenarios, they detect over 1,000 pieces of harmful content on a daily basis, with a security response rate exceeding 99% and an identification accuracy rate above 99%. It strikes an effective balance between operation security and practicality.

From a societal perspective, the solution provides efficient and intelligent security measures for protection, delivering effective results in curbing security issues arising from the development of large models. It also contributes to the standardization and regulation of related technologies, accumulating over one million specialized evaluation datasets, thus providing robust data support and basis for decision-making towards protection of the personal information of citizens and smooth operation of enterprises and public institutions. Considering its value in technological innovation, the Security AI Agents "Using AI to Combat AI" as a solution presents a new approach to large model security, advancing corporate security transformation and the healthy development of the AI digital environment.



“以模制模”大模型安全防护方案
Large Model Security Solutions "Using AI to Combat AI"

人工智能 + 安全创新成果显著，赋能千行百业高质量发展
Remarkable Innovations in AI + Security to Empower High-Quality Development Across Numerous Industries

本方案以自研大模型为基础，在模型结构、推理程序等模型底层进行创新，独创“类脑分区协同（CoE）”安全大模型结构，真正实现了大模型在安全领域的深度应用，推动“人工智能 + 安全”走向可靠、可信、可控、向善新阶段。已服务于政府、金融、医疗、教育等领域，借助安全智能体将高阶大模型安全能力赋能用户本地，在协助用户解决大模型应用过程中的安全问题起到了关键作用，是不可或缺的重要助手，帮助用户安全、高效的获取大模型强大能力。

本方案核心组成 360 安全智能体是 IDC《中国 AI Agent 市场剖析及厂商推荐，1Q25》中唯一推荐的安全厂商产品。同时，360 大模型安全产品入选中国工业和信息化部 2024 年未来产业创新发展优秀典型案例和中国人工智能大赛大模型安全攻防赛题 A 级证书。

The solution is built upon a self-developed large model, introducing innovations at the foundational level of model architecture and inference processes. It pioneers a brain-like partitioned architecture of security large model with Collaboration of Experts (CoE). It truly materialized the deep application of a large model in the security domain, advancing "AI + Security" into a new phase characterized by reliability, credibility, controllability and commitment to the greater good. It has been deployed to serve government, finance, healthcare, and education sectors. By delivering advanced large model security capabilities to user endpoints through Security AI Agents, it plays a critical role in assisting users to address security challenges during the application of large models. It serves as an indispensable assistant, helping users to securely and efficiently harness the powerful capabilities of large models.

The core component of this solution, the 360 Security AI Agent, is recognized as the only security vendor product recommended in China AI Agent Market Analysis and Vendor Recommendations, 1Q25 by IDC. Additionally, the large model security product of 360 has been listed as an exemplary case for future industrial innovation by the Ministry of Industry and Information Technology of China in 2024. It has received a Class-A certificate in the large model security attack and defense challenge of the China AI Competition.



全球规模最大、安全稳定可靠、多元异构融通
World's Largest in Scale, Secure, Stable and Reliable, with Integrated Heterogeneous Resources

超大规模云化网络算力高可靠与生成式运维技术创新应用

Technological Innovation and Application in Large-Scale High-Reliability NFV Computing Resource and GenAI-driven O&M

中国移动通信集团有限公司
China Mobile Communications Group Co., Ltd.

清华大学
Tsinghua University

STC 沙特电信公司
STC (Saudi Telecom Company)

华为技术有限公司
Huawei Technologies Co., Ltd.

引言

中国移动联合国内外先进单位围绕云化网络算力 (NFV) 开展高可靠保障关键技术创新和应用，完成“标准输出、技术研发、规模部署、生态共建”创新闭环，有力推动中东、欧亚等“一带一路”国家云化网络算力健康发展。

Introduction

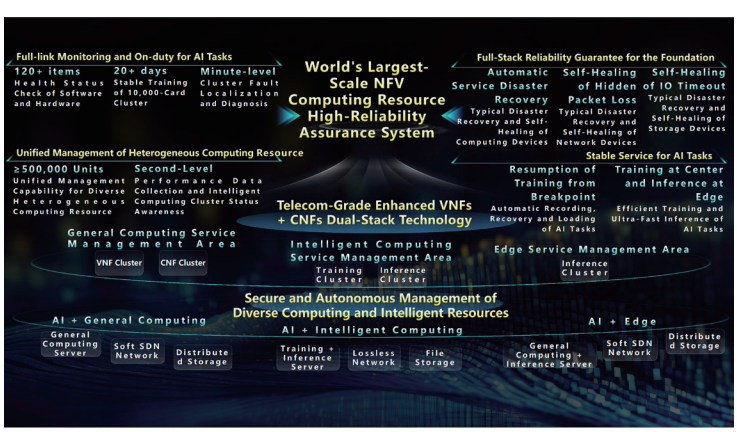
China Mobile, together with leading domestic and international partners, has carried out key technological innovations and applications to ensure high reliability in cloudified network computing resource (NFV). This has resulted in an innovation closed loop of "standards output, technology R&D, large-scale deployment, and ecosystem co-construction," strongly promoting the healthy development of cloudified network computing resource in Belt and Road countries such as those in the Middle East and Eurasia.

规模、韧性、应用全面突破，加速全球通信网络云化变革

Comprehensive Breakthroughs in Scale, Resilience, and Applications Accelerate the Global Cloudification Transformation of Communication Networks

中国移动突破全球最大规模 NFV 算力高可靠保障难题，支持电信级增强 VNFs+CNFs 双栈技术、电信级软硬件协同全栈技术、5G/5G-A 核心网络功能 100% 虚拟化部署、DPU 算力分担卸载 +GPU/NPU 并行计算加速、RoCE 无损网络，支持毫秒级故障隐患感知、秒级 RPO 数据恢复、分钟级 RTO 业务恢复，完成全球千万级用户业务容灾高稳安全保障，打造 NFV 与算力编排调度体系全生命周期的数字原生智慧运营管理，相关技术在 ITU-T、3GPP、ETSI、IETF、CCSA 发布全球技术标准近 200 篇。





全球最大规模商用网络 NFV 算力高可靠保障技术体系
High-Reliability Assurance Technology System for NFV computing resource in the World's Largest Commercial Network

China Mobile has overcome the global challenge of ensuring high reliability for the world's largest-scale NFV computing resource. It supports telecom-grade enhanced VNFs + CNFs dual-stack technologies, telecom-grade full-stack software–hardware co-optimization, 100% virtualized deployment of 5G/5G-A core network functions, DPU-based computing offload with GPU/NPU parallel acceleration, and RoCE lossless networking. The system enables millisecond-level fault risk detection, second-level RPO data recovery, and minute-level RTO service restoration, achieving disaster recovery and robust security protection for services of tens of millions of global users. It has also built a digitally native intelligent O&M system covering the full lifecycle of NFV and computing resource orchestration and scheduling. Related technologies have contributed nearly 200 global technical standards released by ITU-T, 3GPP, ETSI, IETF, and CCSA.

原创新型 NFV 岗位型多智能体应用，升级现网已有小模型和工具，形成丰富的 VNF/CNF 工具型智能体能力，创新性地融入监控排障、变更管控、业务开通三条生产流，利用 Workflow + LLM Based Multi-Agent 开发框架，重塑 NFV 自动化和智能化运维能力，相关技术获 GSMA、TMF 众多全球大奖。

An innovative NFV post-oriented multi-agent application has been developed by upgrading existing small models and tools in live networks, forming a rich set of VNF/CNF tool-agent capabilities. By innovatively integrating monitoring & troubleshooting, change management, and service provisioning into three production workflows, and leveraging a Workflow + LLM-Based Multi-Agent development framework, China Mobile has reshaped NFV automation and intelligent O&M capabilities. These related technologies have won numerous global awards from GSMA and TMF.

促进全球通信网络创新发展，弥合人类数字鸿沟
Driving Global Communication Network Innovation and Bridging the Digital Divide

中国移动联合全球领先的运营商、国际组织、科研高校打造的 NFV 算力高可靠标准技术、新增 GenAI 驱动的“数字员工”，共承载移动通信网络用户 11 亿 +、有线宽带用户 3 亿 +、3000 万 + 重要政企用户数据流量，提升全球近 1/5 互联网用户的业务稳定性、可靠性，预计带动上下游产业效益超百亿元。

China Mobile, together with leading global operators, international organizations, and top research universities, has developed high-reliability NFV computing resource standards and technologies, and introduced GenAI-driven “digital employees.” These innovations jointly support over 1.1 billion mobile communication network users, over 300 million fixed broadband users, and more than 30 million key government and enterprise users’data traffic. They enhance the service stability and reliability for nearly one-fifth of global Internet users and are expected to generate industrial benefits of over 10 billion RMB across upstream and downstream sectors.



中国移动打造世界一流算力供给，促进全球通信网络云化创新发展、弥合人类数字鸿沟

China Mobile is building world-class computing resource supply to promote innovative development of global communication network cloudification and bridge the human digital divide

在 STC、IOH、Vodafone Turkey、Ericsson 的 NFV 技术应用中，将传统网络功能虚拟化、服务化，实现通信网络资源的统一调度和管理，低时延、高吞吐的网元业务灵活分配，相比传统网络设备可节省至少 20% 的资源容量、网络稳定性提升 30%+，显著降低了通信网络的投入成本，有效改善欠发达地区网络服务的可扩展性和业务运营效率。综合 NFV 资源优化和动态节能技术，预估每年可节省≥ 1 亿度电，减少的碳排放量相当于植树超百万棵。

In NFV technology applications with STC, IOH, Vodafone Turkey, and Ericsson, traditional network functions have been virtualized and service-oriented, enabling unified scheduling and management of communication network resources. Network element services are flexibly allocated with low latency and high throughput. Compared with traditional network equipment, this approach saves at least 20% of resource capacity, improves network stability by over 30%, significantly reduces investment costs in communication networks, and effectively enhances the scalability of network services and operational efficiency in underdeveloped regions. By integrating NFV resource optimization with dynamic energy-saving technologies, it is estimated that more than 100 million kWh of electricity can be saved annually, with carbon emission reductions equivalent to planting over one million trees.

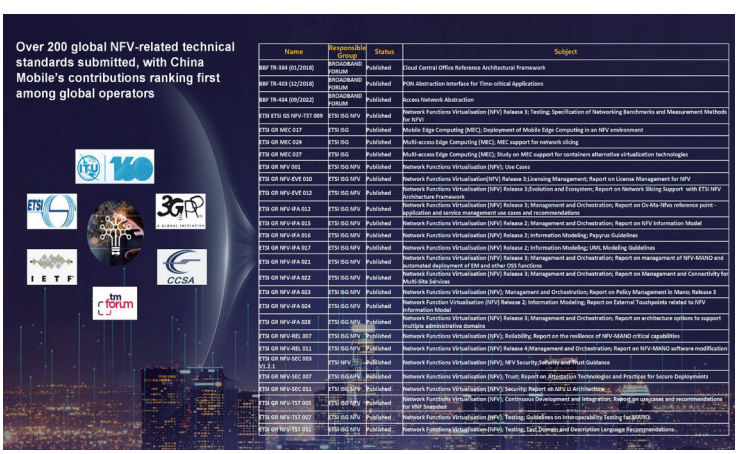
推动全球通信网络产业上下游新一代演进，赋能千行百业价值提升

Driving the Next-Generation Evolution of the Global Communication Network Industry Value Chain and Empowering Thousands of Industries

中国移动积极推进 NFV 相关标准体系构建，并吸引 Ericsson、Nokia、Verizon、Cisco、Accenture 等全球领先运营商、设备商、顶级咨询公司的积极署名支持，在 ITU-T、3GPP、ETSI、IETF 成立多个国际标准工作组，新增算力自智网络生态联盟，累计发布全球技术标准近 200 篇。

China Mobile has actively advanced the development of NFV-related standard systems, attracting strong endorsement and support from global leading operators, equipment vendors, and top consulting firms such as Ericsson, Nokia, Verizon, Cisco, and Accenture. Multiple international standardization working groups have been established within ITU-T, 3GPP, ETSI, and IETF, alongside the launch of the Computing resource Autonomous Network Ecosystem Alliance. In total, nearly 200 global technical standards have been released.





结合中国移动全球规模最大的云化核心网络运营经验，在中东、印尼、欧亚部署 NFV 算力高可靠系统，显著改善当地网络服务扩展瓶颈、容灾能力不足的低可用性问题，助力为“一带一路”国家和人民提供高品质移动通信网络服务。

Leveraging China Mobile's experience in operating the world's largest cloudified core network, NFV computing resource high-reliability systems have been deployed across the Middle East, Indonesia, and Eurasia. These deployments have significantly improved local network service scalability, strengthened disaster recovery capabilities, and addressed issues of low availability—helping deliver high-quality mobile communication network services to Belt and Road countries and their people.

在产业影响力方面，该项目带动集成电路生产、通信设备制造、IDC 工程建设等 1000 余家企业发展，总产值近千亿人民币，相关技术创新、超大规模应用部署得到国内外权威机构广泛认可，获得 MWC、TMF、AMO、SDN/NFV 世界大会等 10 余项全球通信网络行业重量级奖项。

In terms of industry impact, this project has driven the growth of more than 1000 enterprises across integrated circuit production, telecommunications equipment manufacturing, and IDC engineering construction, generating a total output value of nearly 100 billion RMB. The related technological innovations and ultra-large-scale deployment have been widely recognized by authoritative institutions worldwide, earning over 10 prestigious global awards in the communications industry, including from MWC, TMF, AMO, and the SDN/NFV World Congress.

推动全球通信网络云化标准发展

Promoting the Development of Global Cloudified Communication Network Standards



项目成果九章爱学智能学伴
Project Achievement: AI Learning Companion MathGPT

多模态大模型赋能的智能学伴关键技术及应用

Key Technologies and Applications of Multimodal Large Models Empowered Intelligent Learning Companion

北京世纪好未来教育科技有限公司
Beijing Century TAL Education Technology Co., Ltd.

暨南大学广东智慧教育研究院
Guangdong Institute of Smart Education

TAL好未来
广东智慧教育研究院 GUANGDONG INSTITUTE SMART EDUCATION

引言

结合行业顶尖技术与教育理念，探索开发支持多模态实时交互、具备“能感知、会思考、可共情”特质的“理科智能学伴”，以 AI 原生内容为学生提供情感陪伴、全理科智能答疑以及心理疏导服务。

Introduction

Integrating cutting-edge industry technologies with advanced educational concepts, this initiative aims to develop a "Science Intelligent Learning Companion" characterized by real-time multimodal interaction and the ability to perceive, reason, and empathize. Leveraging AI-native content, it provides students with emotional companionship, intelligent solutions to science-related inquiries, and psychological support services

提升推理、强化运算、优化答疑，突破大模型幻觉瓶颈
Enhancing Reasoning, Strengthening Computation, and Optimizing Q&A to Overcome the Bottleneck of Large Model Hallucinations

一是提出步骤级奖励模型在数学推理中的应用，通过过程监督或基于强化学习的步骤级偏好对齐显著提升推理性能。不仅促进各步骤内的准确计算，还在评估数学语言中的逻辑一致性上表现突出。

二是提出了一个增强大型语言模型高级运算能力的 ArithmeticGPT 框架，以提升大型语言模型在高级运算计算方面的精度和准确性。ArithmeticGPT 模型在计算精度和语言理解方面显现出显著的优越性，并在与超过 17 个最先进的 LLM 基准的比较中显示出卓越的性能，高级运算能力提升 20%-35%，与 GPT4 相关能力持平。

三是研制了中国首个专为数学打造的多模态讲题大模型，其内容讲解模块能够通过多种讲解模型（例如苏格拉底讲题模型、知识点精讲模型、过渡讲解模型等），为学生提供分步、详细的解题过程和知识点讲解。



基于讲题大模型的多模态智能答疑系统能力示意图
Capability Diagram of a Multimodal Intelligent Q&A System Based on MathGPT

1.Proposing Step-Level Reward Models for Mathematical Reasoning.This approach introduces step-level reward models for enhancing mathematical reasoning, utilizing process supervision or step-level preference alignment based on reinforcement learning to significantly improve reasoning performance. It not only ensures accurate calculations within each step but also excels in evaluating logical consistency within mathematical language.

2.Introducing the ArithmeticGPT Framework to Enhance Advanced Computational Capabilities.The ArithmeticGPT framework is designed to boost large language models' precision and accuracy in advanced computation tasks. Demonstrating significant advantages in both computational accuracy and language comprehension, the ArithmeticGPT model outperforms over 17 state-of-the-art LLM benchmarks, achieving a 20%-35% improvement in advanced computational capabilities, comparable to GPT-4.

3.Developing China's First Multimodal Large Model Specifically for Mathematical Problem Explanation.This groundbreaking multimodal model is tailored for mathematics and features a content explanation module that utilizes various explanation approaches (e.g., the Socratic Problem-Solving Model, Knowledge Point Precision Explanation Model, and Transition Explanation Model). It provides students with step-by-step, detailed problem-solving processes and knowledge point explanations.

赋能校园数字化转型，推动人工智能 + 教育政策落地
Empowering Digital Transformation in Campuses and Advancing the Implementation of AI + Education Policies

本项目正以低成本、易落地、见效快、优质丰富的学习资源等特点，成为中国多省市落实“人工智能 + 教育”政策、发展智慧校园的重要抓手，已在北京、上海、广东、山东、广西、湖北等多个省市落地。

本项目不仅上线中国国家智慧教育开放平台、广东省教育综合服务平台“粤教翔云”、广西智慧教育公共服务平台“桂教通”，还与上百所中小学达成合作意向，通过共建智慧教室、AI 自习室、成品 SDK 接入、开放 API 接口等多种方式，帮助学校建设智慧校园，实现科学地配置教育资源、增强家校协同育人能力。



学生在基于本项目打造的 AI 自习室里学习
Students study in AI-powered self-study rooms developed under this project

此外，项目关键技术能力全方位应用于好未来 123 万台学而思智能学习机中，为学生提供 AI 伴学服务。

This project, characterized by its low cost, easy implementation, rapid impact, and rich, high-quality learning resources, has become a key driver for multiple provinces and cities in China to implement "AI + Education" policies and develop smart campuses. It has already been successfully deployed in Beijing, Shanghai, Guangdong, Shandong, Guangxi, Hubei, and other regions.

The project has not only been integrated into China's National Smart Education Platform, the Guangdong Education Comprehensive Service Platform "Yuejiaoxiangyun," and the Guangxi Smart Education Public Service Platform "Guijiaotong," but has also reached cooperation agreements with over 100 primary and secondary schools. Through initiatives such as building smart classrooms, AI study rooms, integrating ready-made SDKs, and providing open API interfaces, the project helps schools develop smart campuses, enabling scientific allocation of educational resources and enhancing collaboration between schools and families in nurturing students.

Furthermore, the project's core technological capabilities have been fully applied to 1.23 million units of TAL's AI Learning Devices, offering AI-powered learning companion services to students.

推动数字化转型，助力教育公平
Advancing Digital Transformation to Foster Educational Equity

本项目成果推广应用至中国多个地区公共教育平台、上百所学校、百万台智能学习设备。项目活跃用户上百万，受益师生近千万，累计节约教育成本上亿。项目累计在人工智能领域顶级会议和期刊上发表论文 24 篇；关键技术获得美国授权发明专利 4 项，中国授权发明专利 35 项；开源多个优质教育数据集，填补中国在教育数据多项空白，弥补教育领域开源数据不足短板。

凭借着国际领先的技术水平与广泛应用效果，项目得到了以工业和信息化部、北京市科委、中国互联网协会、中国信息通信研究院等为代表的政府、行业协会以及重点研究机构认可，获得众多官媒点赞。

本项目的落地应用不仅有效提高中国教育行业技术发展和数字化转型，还通过提供免费、优质的个性化学习资源有效缓解了数字鸿沟带来的教育不公平。





行业反馈
Industry Feedback

The outcomes of this project have been widely implemented across public education platforms in various regions of China, over 100 schools, and millions of intelligent learning devices. With millions of active users, the project has benefited nearly ten million teachers and students, cumulatively saving billions in education costs. To date, the project has published 24 papers in top-tier conferences and journals in the field of artificial intelligence, secured 4 U.S. invention patents and 35 Chinese invention patents, and open-sourced several high-quality educational datasets. These efforts have filled significant gaps in China's educational data landscape and addressed the shortage of open-source data in the education sector.

Leveraging its internationally leading technological capabilities and broad application impact, the project has gained recognition from government bodies, industry associations, and key research institutions, including the Ministry of Industry and Information Technology of China, the Beijing Municipal Science and Technology Commission, the China Internet Association, and the China Academy of Information and Communications Technology. It has also received widespread acclaim from official media outlets.

The implementation of this project has not only significantly boosted the technological development and digital transformation of China's education sector but also effectively alleviated educational inequities caused by the digital divide by providing free, high-quality, and personalized learning resources.



分布式制造模式下的工业互联网平台
Distributed Manufacturing Mode Under Industrial Internet Platform

分布式制造模式下工业互联网平台关键技术及应用

Key Technologies and Applications of Industrial Internet Platforms Under Distributed Manufacturing Mode

宝信软件股份有限公司
Baosight Software Co., Ltd.

清华大学
Tsinghua University

宝山钢铁股份有限公司
Baoshan Iron & Steel Co., Ltd.

同济大学
Tongji University

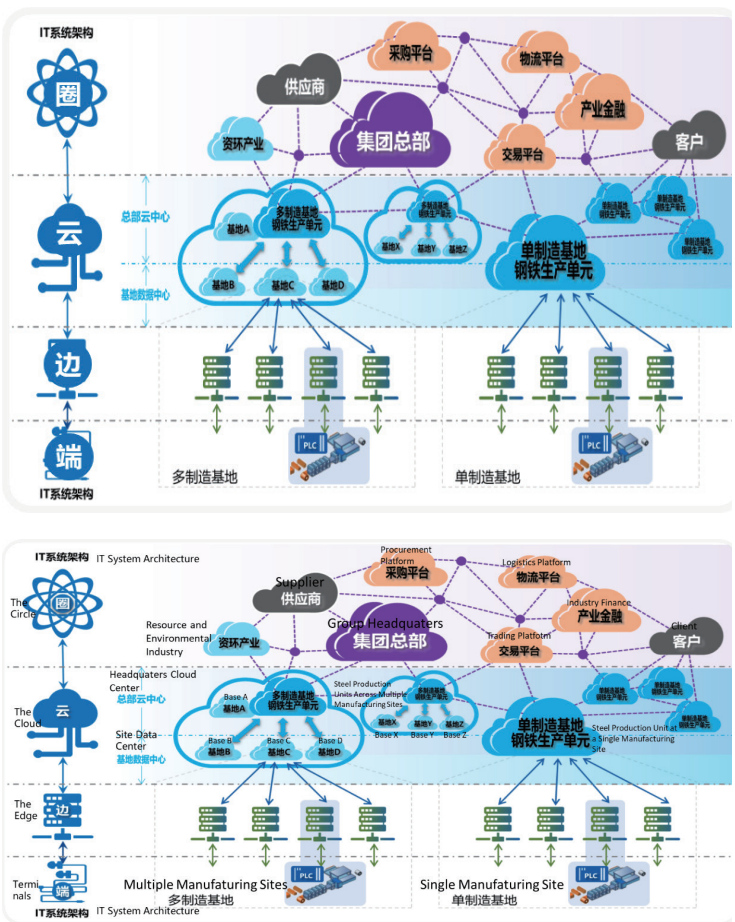
引言

超大规模钢铁企业存在“超复杂应用场景、超大规模数据处理、跨产业跨地域协同；全链条生态环节多、不确定因素多“的重大挑战，需要破解分布式制造中的互联互通、海量数据应用、一体化运营等技术难题，并实现创新。

Introduction

Mega-scale steel enterprises face significant challenges such as “hyper-complex application scenarios, mega-scale data processing, and cross-industry, cross-regional collaboration; numerous links in the entire ecosystem chain and many uncertain factors.” It is necessary to resolve technical difficulties in distributed manufacturing, including interoperability, massive data application, and integrated operations, and to achieve innovation.

高性能、超融合工业互联网平台及应用
High-performance, Hyper-converged Industrial Internet Platform and Application



新一代工业互联网体系架构
New Generation Industrial Internet Architecture

首创钢铁行业分布式制造模式下平台级联架构技术，解决超大型企业互联互通和跨域集成、海量工业大数据高并发高稳定高可靠关键技术、现场数据量大响应快、设备协议多跨层级实时融合难度大等问题。

首创钢铁制造全流程、全要素、高动态大数据智能管控技术，解决实时海量钢铁工业大数据存储与检索、钢铁全流程动态数据智能分析与决策等难题。

提出钢铁生态圈一体化协同决策技术，解决分布式制造运营与协同管控、不确定制造环境下的高动态智能化决策、产业链 / 供应链生态化协同等难题。

中国工程院桂卫华、蒋昌俊、谭建荣三位院士领衔的资深专家组评价：成果技术难度大，创新性强，总体技术达到了国际先进水平，其中分布式集群智联技术达到国际领先水平。

Pioneered platform cascade architecture technology for the distributed manufacturing model in the iron and steel industry, solving problems such as interconnection, interoperability, and cross-domain integration for super-large enterprises; key technologies for high concurrency, high stability, and high reliability of massive industrial big data; difficulties related to large volumes of field data requiring fast

response, and the significant challenge of real-time fusion for numerous equipment protocols across different levels.

Pioneered intelligent management and control technology for whole-process, all-factors, and highly dynamic big data in steel manufacturing, solving difficulties like the storage and retrieval of real-time massive steel industrial big data, and intelligent analysis and decision-making for dynamic data across the entire steel production process.

Proposed integrated collaborative decision-making technology for the steel ecosystem, solving challenges including distributed manufacturing operation and collaborative management control, highly dynamic intelligent decision-making in uncertain manufacturing environments, and ecological collaboration across the industrial chain/supply chain.

A senior expert group led by Chinese Academy of Engineering academicians Gui Weihua, Jiang Changjun, and Tan Jianrong evaluated that: the achievement involves high technical difficulty and strong innovation; its overall technology has reached an internationally advanced level, with its distributed cluster intelligent connectivity technology reaching an internationally leading level.

深化多领域多维度协同，释放协同效应
Deepened collaboration across multiple fields and dimensions to unleash synergistic effects

宝联登工业互联网平台提供工业大数据、工业智能和平台化工业软件开发能力，2021 至 2023 年，累计实施了 277 个工业互联网工程项目，直接经济效益 63.96 亿元，净利润 20.47 亿元。

宝钢股份基于宝联登平台实施智慧制造转型战略，旗下多家企业或工厂获评“灯塔工厂”、“数字领航企业”，整合融合的管理创新实践荣获第二届“拉姆·查兰管理实践奖”。基于平台的集约化生产、动态资源调整、多基地协同制造等应用年化效益超过 1.4 亿元，确保行业示范者、引领者地位。

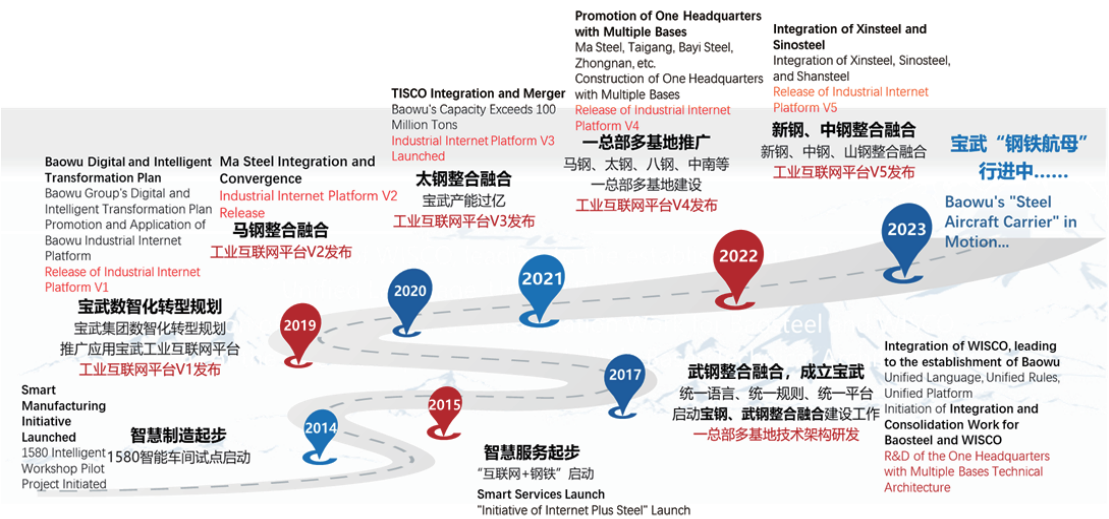
基于宝联登工业互联网平台，快速将宝钢股份的先进管理思想和体系在宝武集团内推广应用，实现中国宝武 19 个制造基地、300 万设备、亿吨物流、万亿资金流快速整合融合，支撑宝武实现了跨越式发展，规模位居全球第一。

XIn3 Plat provides capabilities in industrial big data, industrial intelligence, and platform-based industrial software development. From 2021 to 2023, it cumulatively implemented 277 industrial Internet engineering projects, generating 6.396 billion CNY in direct economic benefits and 2.047 billion CNY in net profit.

Baoshan Iron & Steel Co., Ltd., leveraging the xIn3 Plat, implemented a smart manufacturing transformation strategy. Multiple subsidiaries and factories under its umbrella were recognized as “Lighthouse Factories” and “Digital Leading Enterprises”. Its integrated management innovation practices were awarded the second “Ram Charan Management Practice Prize.” Applications such as centralized production, dynamic resource adjustment, and multi-site collaborative manufacturing based on the platform yielded annualized benefits exceeding 140 million CNY, solidifying its role as an industry demonstrator

and leader.

Built on the xIn3 Plat, Baosteel's advanced management philosophies and systems were rapidly promoted and applied within the China Baowu Steel Group, enabling the rapid integration of 19 manufacturing bases, 3 million pieces of equipment, billion-ton logistics operations, and trillion-yuan capital flows. This supported Baowu's leapfrog development, elevating its scale to rank first globally.



宝武集团整合融合进程
The integration and convergence process of China Baowu Steel Group

构建制造业智慧化转型新范式
Building a New Model for Smart Manufacturing Transformation

宝联登平台在钢铁行业得到规模化推广应用，典型企业包括鞍钢股份、本钢集团、首钢集团、三明钢铁、新兴铸管、宏旺集团等。

基于平台建设鞍钢股份一体化运营管控系统，覆盖三地二线、九大业务领域，大幅度提升了鞍钢股份“制造 + 服务”的核心竞争力，实现“一体化运营管控、多基地协同制造、供应链优质高效”等管理目标，为建设智慧鞍钢、数字鞍钢作出巨大贡献。建设首钢钢铁产销一体化经营管理系统，实现了“一业四基地”产销一体化、管控一体化、业财一体化，提升了首钢“制造 + 服务”的核心竞争力。

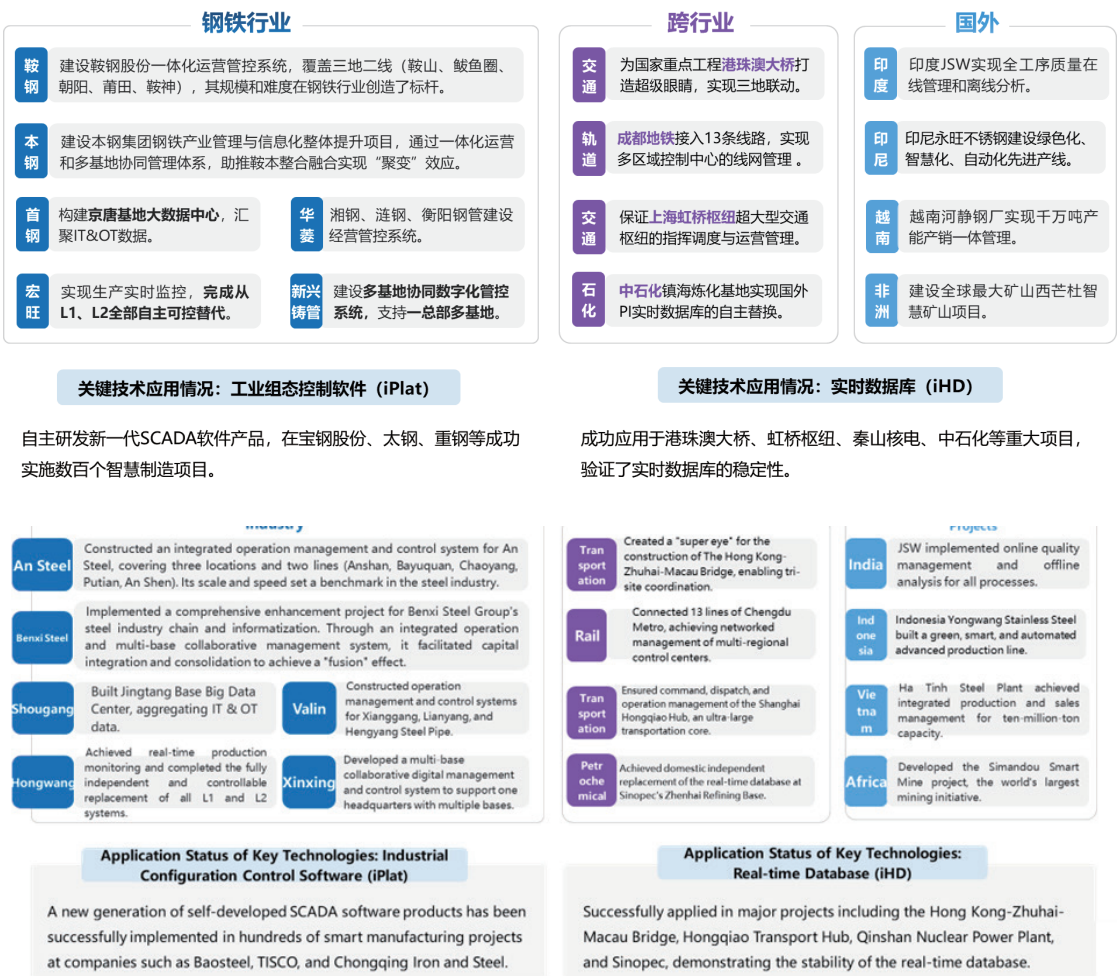
项目成果还形成跨行业 9 大领域 50 多个解决方案，应用覆盖钢铁、有色、采矿、轨道、能源等 11 大行业，极大促进实体制造业高质量发展。

XIn3 Plat has achieved large-scale adoption within the steel industry, with prominent enterprise users including Angang Steel Co., Ltd., Benxi Steel Group, Shougang Group, Sanming Steel, Xinxing Ductile Iron Pipes (Pioneer Ductile Cast Iron Pipes), and Hongwang Group (Tsingshan Group).

Leveraging the platform, an integrated operational management and control system was built for Angang Steel. This system covers two production lines across three locations and nine major business domains, significantly enhancing Angang Steel's core competitiveness in “manufacturing + services”. It has realized management objectives such as unified operational control, multi-base collaborative manufacturing, and a high-quality, efficient supply chain, making substantial contributions to developing an Intelligent Angang and a Digital Angang.

Similarly, an integrated production and sales management system was constructed for Shougang Steel, achieving the integration of production and sales, management and control, and business and finance across “one business and four manufacturing bases”. This has significantly boosted Shougang’s core competitiveness in “manufacturing + services”.

The project’s outcomes have also crystallized into over 50 solutions across nine major sectors, extending beyond steel to 11 industries including nonferrous metals, mining, rail transportation, and energy. This broad application has significantly promoted the high-quality development of the real manufacturing economy.



宝联登平台典型应用案例
Typical Application Cases of xIn3 Plat





电信自主研发高可靠 5G 技术全球领先新标杆
China Telecom independently develops highly reliable 5G technology, leading the world and setting a new benchmark

高可靠 5G 网络技术方案研发与应用

Research and Application of Highly Reliable 5G Network Technology Solution

中国电信集团有限公司
China Telecom Corporation Limited

引言

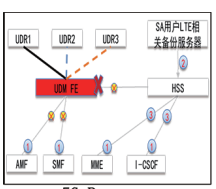
中国电信股份有限公司研发的“高可靠 5G 网络技术方案”在核心网容灾、物联网流量智能调控和高铁场景信号增强等方面实现多项技术突破。该成果显著提升了网络可靠性和业务体验，为 5G 新基建高质量发展提供了重要支撑。

Introduction

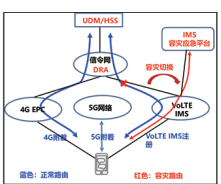
The "High Reliability 5G Network Technology Solution" developed by China Telecom has achieved multiple technological breakthroughs in core network resilience, intelligent control of IoT traffic, and signal enhancement in high-speed rail scenarios. This achievement significantly improves network reliability and service experience, providing important support for the high-quality development of 5G new infrastructure.

首创 5G 容灾体系，攻克核心技术与高铁难题
Pioneering 5G disaster recovery system, tackling core technology and high-speed rail challenges

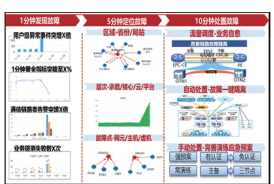
本成果在 5G 网络高可靠性技术上实现多项国际与业界首创。在核心网容灾方面，首创“5G Bypass + UPF 容灾增强”技术，攻克了 DC 级灾难性故障下业务“零中断”的难题；业界首次提出“IMS 容灾应急平台及刷新注册优化”方案，被 3GPP 标准采纳；构建了基于 AI 的端到端智能故障管控体系，实现“1-5-10”分钟级自愈。在物联网流量智控方面，创新性提出“2+4+31”新型网络架构与路由策略，突破传统大区集约瓶颈，实现流量精准本地卸载与 47% 时延降低；自主研发单机承载百万用户、200Gbps 吞吐的大容量 5GC 网元。在高铁信号升格方面，攻克多普勒频移与波束追踪难题，成功研制自主知识产权的新型高铁专用天线，集成异构波束赋形等技术，在体积缩减 40% 的同时信号强度提升 5.2dB。



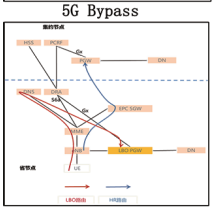
5G Bypass

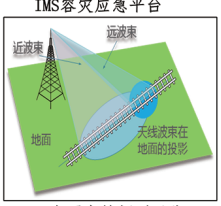


IMS容灾应急平台

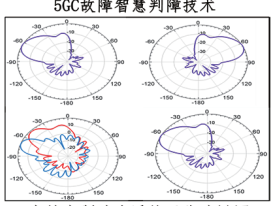


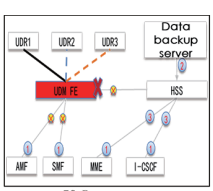
5GC故障智慧判障技术


物联网流量智控

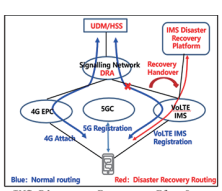


自研高铁新型天线

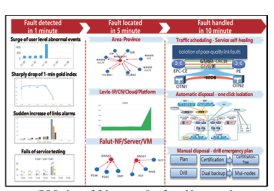

高铁定制波束透镜天线波瓣图



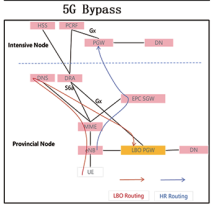
5G Bypass



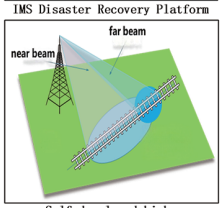
IMS Disaster Recovery Platform



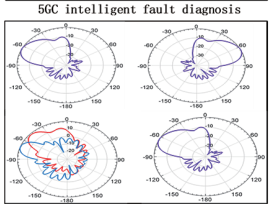
5GC intelligent fault diagnosis



IoT traffic intelligent control



Self developed high-speed rail antenn


Lobe synthesis of customized beam lens antenna for high-speed rail

This achievement has achieved multiple international and industry firsts in high reliability technology for 5G networks. In terms of core network disaster recovery, the first "5G Bypass+UPF Disaster Recovery Enhancement" technology has overcome the problem of "zero interruption" of service under Data-center level catastrophic failures. The industry first proposed the "IMS Disaster Recovery Emergency Platform and Refresh Registration Optimization" solution was adopted by the 3GPP. An AI based end-to-end intelligent fault management system is built, achieving "1-5-10" minute self-healing. In terms of intelligent control of IoT traffic, an innovative "2+4+31" new network architecture and routing strategy have been proposed to break through the bottleneck of traditional regional clustering, achieve precise local offloading of traffic, and reduce latency by 47%. Independently developed high-capacity 5GC IOT network equipment is capable of carrying millions of users and 200Gbps throughput. In terms of upgrading high-speed rail signals, the difficulties of Doppler frequency shift and beam tracking are overcome. We developed a new type of high-speed rail dedicated antenna with independent intellectual property rights, integrated heterogeneous beamforming and other technologies, and improved signal strength by 5.2dB while reducing volume by 40%.

首创 5G 多专业容灾提升体系
Pioneering 5G Multi Majors Disaster Recovery Enhancement System

年省超九亿，保障亚运会等高可靠通信
Annual savings exceed 900 million, ensuring high reliability communication for events

核心网容灾增强技术将 5GC 可用性提升至 99.999%，年故障时间减少 257 分钟，全网推广后预计降低故障损失 1.25 亿元，节省设备扩容成本超 5 亿元。物联网流量智控方案在 21 省部署，无感迁移 3105 万用户，本地卸载 4.14Tbps 流量，节省主设备投资 3 亿元。高铁新型天线在 10 省以上规模部署，覆盖超 7300 公里，并于 2024 上海 MWC 世界移动通信大会上发布，标志着中国在超高速移动通信这一尖端领域取得了国际引领性突破。成果有力提升了 5G 网络可靠性，为数字经济发展筑牢底座；自主研发的关键设备与技术提升了产业核心竞争力；并为杭州亚运会、中亚峰会等重大活动提供了高质量的通信保障。

The core network disaster recovery enhancement technology has increased the availability of 5GC to 99.999%, and reduced the annual failure time by 257 minutes. It is expected to reduce failure losses by 125 million yuan and save equipment expansion costs of over 500 million yuan after the full network promotion. The IoT traffic intelligent control solution has been deployed covering 21 provinces of China Telecom's network, migrating 31.05 million users without sensing, locally uninstalling 4.14Tbps traffic, and saving 300 million yuan in main equipment investment. The new high-speed rail antenna has been deployed in more than 10 provinces, covering over 7300 kilometers, and was unveiled at the 2024 Shanghai MWC World Mobile Communication Conference, marking China's international leading breakthrough in the cutting-edge field of ultra high speed mobile communication. The achievements have significantly improved the reliability of 5G networks and laid a solid foundation for the development of the digital economy; The key equipment and technology independently developed have enhanced the core competitiveness of the industry; And provided high-quality communication support for major events such as the Hangzhou Asian Games and the China Asia Summit.



2024 年上海 MWC 会议，高铁专用新型天线产品对外发布
The new type of antenna product dedicated to high-speed rail was unveiled to the public at the 2024 MWC conference in Shanghai

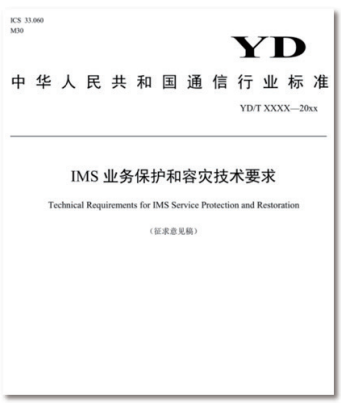
方案获 3GPP 采纳，高铁速率 770Mbps 全球领先
Resilience solution has been adopted in 3GPP speed rate in high-speed rail leads globally

本成果已成为行业标杆，产生了深远的国际影响力。核心网容灾方案在中国电信全国网络部署，实现 UDM 全故障下 99% 业务不中断，DC 级故障下语音零受损，相关方案在 3GPP 中提出，得到全体单位一致认可并写入 3GPP 标准中，获《人民邮电报》头版报道，其技术理念与标准贡献为全球 5G 高可靠网络建设提供了“中国方案”。物联网智控方案高效解决了省内流量疏导难题，其创新的架构与自研 5GC 产品已在五省试商用，推动了物联网从“连接管理”向“价值与体验管理”的演进，引领了产业技术方向。高铁通信解决方案性能指标全球领先，在 347km/h 时速下实现 770Mbps 的峰值速率，较传统方式提升 296%。

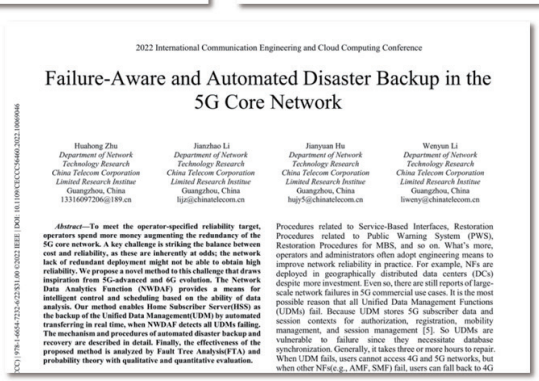
The project achievements have become industry benchmarks and have generated profound international influence. The core network disaster recovery solution has been deployed in China Telecom's national network, achieving 99% uninterrupted service under UDM full failure and zero voice damage under DC level failure. The relevant plan was proposed and adopted in 3GPP, and was reported on the front page of the People's Posts and Telecommunications Daily. The technical concept and standard contribution provide a "Chinese solution" for the construction of global 5G high reliability networks. The IoT intelligent control solution efficiently solves the problem of traffic diversion within the province. Its innovative architecture and self-developed 5GC products are commercially online in five provinces, promoting the evolution of IoT from "connection management" to "value and experience management" and leading the direction of industrial technology. The performance of high-speed rail communication solution is globally leading, achieving a peak speed of 770Mbps at a speed of 347km/h, which is 296% higher than traditional techniques.


3GPP TR 29.866 V19.0.0 (2025-03)
Technical Report
3rd Generation Partnership Project;
Technical Specification Group Core Network and Terminals;
Study on IMS Disaster Prevention and Restoration Enhancement (Release 19)


中华人民共和国通信行业标准
2024-0014T-YD
5G 移动通信网 核心网网络功能故障恢复流程测试方法
Test Method for NFs Restoration Procedure of 5G Mobile Telecommunication Core Network


ICS 33.060
M30
YD
中华人民共和国通信行业标准
YD/T XXXX—20xx
IMS 业务保护和容灾技术要求
Technical Requirements for IMS Service Protection and Restoration
（征求意见稿）


中国电信 CHINA TELECOM
_____同志：
您参与的 5G核心网容灾备份安全能力提升关键技术研究及应用 项目，被评为中国电信2023年度科技进步奖三等奖。
特颁此证
中国电信集团有限公司
二〇二四年二月


2022 International Communication Engineering and Cloud Computing Conference
Failure-Aware and Automated Disaster Backup in the 5G Core Network
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Abstract—To meet the operator-specified reliability target, operators spend more money augmenting the redundancy of the 5G core network. A key challenge is striking the balance between cost and reliability, as these are inherently at odds; the network lack of redundant deployment might not be able to obtain high reliability. We propose a novel method to this challenge that draws inspiration from 5G-advanced and 6G evolution. The Network Data Analytics Function (NWDAF) provides a means for intelligent control and scheduling based on the ability of data analysis. Our method enables Home Subscriber Server(HSS) as the backup of the Unified Data Management(UDM) by automated transferring in real time, when NWDAF detects all UDMs failing. The mechanism and procedures of automated disaster backup and recovery are described in detail. Finally, the effectiveness of the proposed method is analyzed by Fault Tree Analysis(FTA) and probability theory with qualitative and quantitative evaluation.
Procedures related to Service-Based Interfaces, Restoration Procedures related to Public Warning System (PWS), Restoration Procedures for MBS, and so on. What's more, operators and administrators often adopt engineering means to improve network reliability in practice. For example, NFs are deployed in geographically distributed data centers (DCs) despite more investment. Even so, there are still reports of large-scale network failures in 5G commercial use cases. It is the most possible reason that all Unified Data Management Functions (UDMs) fail. Because UDM stores 5G subscriber data and session contexts for authorization, registration, mobility management, and session management [5]. So UDMs are vulnerable to failure since they necessitate database synchronization. Generally, it takes three or more hours to repair. When UDM fails, users cannot access 4G and 5G networks, but when other NFs(e.g., AMF, SMF) fail, users can fall back to 4G

部分代表性成果与获奖
Part of representative achievements and awards



中国电信集团 IP SDN 智能控制系统与应用
China Telecom Group's IP SDN Intelligent Control System and Applications

基于 SRv6 技术的 IPSDN 骨干网控制器创新与规模化应用

Innovation and Large-Scale Application of an IPSDN Backbone Network Controller Based on SRv6 Technology

中国电信集团公司总部云网运营部
China Telecom Cloud Network Operating System R&D Center

中国电信 CHINA TELECOM

引言

中国电信首个基于 CN2-DCI 新平面的云网融合产品，实现 SRv6 与智能化管控技术规模化商用，通过 EVPN 统一承载专线、SDN 实现智能管控。首创多因子路由算法提升计算效率，构建跨厂家 SRv6 控制系统突破协议瓶颈，商业差异化切片服务。支撑 500+ 项目交付，降本超 3400 万元，获 25 项专利，推动行业生态升级。

Introduction

China Telecom's first cloud-network integration product based on the new CN2-DCI platform achieves large-scale commercialization of SRv6 and intelligent management. It utilizes EVPN for unified dedicated line carriage and SDN for intelligent control. Innovations include a multi-factor routing algorithm to boost computational efficiency and a cross-vendor SRv6 control system that overcomes protocol limitations, enabling differentiated network slicing services. It has supported 500+ project deliveries, reduced costs by over RMB 34 million, secured 25 patents, and driven industry ecosystem advancement.

实现多领域创新突破，提升网络效率、自动化水平及服务保障能力

Achieving breakthroughs across various domains to improve network efficiency, automation, and service assurance

中国电信基于 SRv6 与 SDN 技术实现六大创新与突破：

1. 网络切片：首创多因子路由算法，计算效率提升 40%-50%，支持低时延（时延降低 20%+）、弹性带宽、一跳直达等四大服务类型，构建差异化 SLA 保障体系。

2. 智能管控：通过 SDN 控制器实现端到端质量感知与路径调优，屏蔽多厂商设备协议差异，支持跨平面、多维度动态路由优化。

3. 复杂适配：对南向多厂商 YANG 抽象适配，实现运营级多域 SRv6 控制，设备交互效率提升 10 倍以上，配置时间缩短至分钟级。

4. 泛在接入：融合 EVPN+SRv6 技术，支持 IPRAN、5G、卫星等全接入方式，提供高保障与低成本服务，实现天地一体全覆盖。

5. 自动化运维：封装自动化场景，支撑业务分钟级开通，提供随选服务、灵活巡检等政企专线自动化功能。

6. 实时采集：基于 Telemetry 秒级流量采集与聚合，实现全天数据 0 丢失，完成流量计费在政企专线应用。

China Telecom has achieved six major innovations and breakthroughs based on SRv6 and SDN technologies:

1. Network Slicing: Pioneered a multi-factor routing algorithm, improving computational efficiency by 40%–50%. Supports four service types including low latency (reducing delay by over 20%), elastic bandwidth, and one-hop access, establishing a differentiated SLA assurance system.

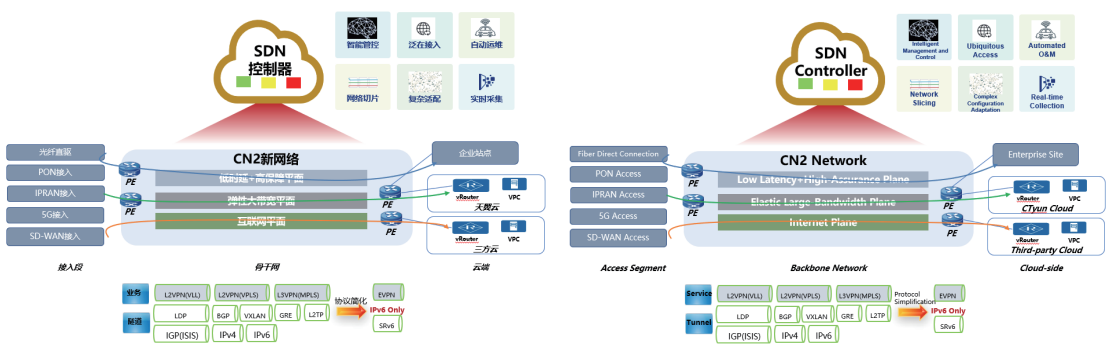
2.Intelligent Control: SDN controllers enable end-to-end quality perception and path optimization, overcoming multi-vendor protocol differences. Supports cross-platform, multi-dimensional dynamic routing optimization.

3.Complex Adaptation: Abstracted southbound multi-vendor YANG models to achieve carrier-grade multi-domain SRv6 control. Device interaction efficiency increased over 10 times, and configuration time shortened to minutes.

4.Ubiquitous Access: Integrated EVPN and SRv6 technologies to support all access methods including IPRAN, 5G, and satellite. Provides high-reliability, low-cost services, achieving seamless ground-space integration.

5.Automated O&M: Prepackaged automation scenarios enable minute-level service provisioning. Offers automated functions for enterprise dedicated lines such as on-demand services and flexible inspection.

6.Real-time Collection: Telemetry-based second-level traffic collection and aggregation ensure zero data loss. Enables traffic-based billing for enterprise dedicated lines.



中国电信基于 SRv6 与 SDN 技术实现六大创新与突破

China Telecom Delivers Six Key Innovations and Breakthroughs Leveraging SRv6 and SDN Technologies

升级骨干网络，提升网络智能化与服务效率，实现降本增收

Backbone Network Upgrade for Enhanced Intelligence, Service Efficiency, Cost Reduction, and Revenue Growth

中国电信 IP SDN 控制器基于 SRv6 技术实现骨干网新平面全面部署，覆盖 3600 万宽带用户及超 1 万政企专线，支持 EVPN+SRv6 融合承载。其创新应用覆盖教育、医疗、政务、金融及工业领域，累计支撑 9 万余条入云专线交付，落地 500 余个项目。

经济效益：通过跨厂商配置适配与效率提升，节省设备开局、中继开通等费用超 3400 万元，助力政企累计收入超 60 亿元，拉动组网专线及互联网专线业务收入超 500 亿元。

应用成效：实现 SRv6 低时延切片与 MPLS 互通；完成端到端开通监控及卡单自动派单；提供自助服务（流量监控、带宽随选等）。

社会效益：设备上线时间缩短 50%-60%，骨干中继开通效率从周级提升至分钟级（及时率 98%），并推动多厂商设备能力升级，开放骨干网 API 实现“软件定义”智能管控突破。

China Telecom's IP SDN controller, leveraging SRv6 technology, has achieved full deployment on a new backbone network plane. This network supports 36 million broadband users and over 10,000 enterprise dedicated lines, utilizing EVPN+SRv6 for converged carriage.

Its innovative applications span education, healthcare, government, finance, and industry, having supported the delivery of more than 90,000 cloud-access dedicated lines and the implementation of over 500 projects.

Economic Benefits: By enabling cross-vendor configuration adaptation and improving efficiency, the project saved over RMB 34 million in costs related to equipment commissioning and trunk line provisioning. It has helped generate cumulative enterprise revenue exceeding RMB 6 billion, and driven over RMB 50 billion in revenue from networking and internet dedicated line services.

Application Effectiveness: Key achievements include implementing SRv6 low-latency slicing with MPLS interoperability, establishing end-to-end provisioning monitoring and automatic ticket dispatch for stalled orders, and offering self-service capabilities like traffic monitoring and on-demand bandwidth adjustment.

Social Benefits: The project reduced equipment onboarding time by 50-60% and accelerated backbone trunk provisioning from weeks to minutes (with a 98% timeliness rate). It also promoted capability upgrades across multi-vendor equipment, and a breakthrough in software-defined intelligent control through open backbone network APIs.



推动骨干网络升级，实现降本增收，效益显著
Backbone Network Upgrade: Cost Reduction, Revenue Growth, and Significant Benefits

构建跨厂商统一控制器，实现网络智能化和自动化，促进产业生态

Development of a Cross-Vendor Unified Controller for Intelligent, Automated Networks and a Thriving Industry Ecosystem

本项目具备可持续迭代和在线部署能力，核心成果包括：构建跨厂家统一控制器，通过自定义北向接口和多厂商 YANG 适配，屏蔽设备差异，促进产业生态，节约采购与运维成本；实现 IP 网络智能控制，将传统人工 CLI 配置升级为图形化操作，提供原子能力调用与 SRv6 网络可编程能力，增强功能定制与自动化水平；推动产业联动，建立南向标准化与北向开放能力，支持随选服务、流量计费和 3D 化运维，助力云网升级与人员转型；应用前景广阔，可推广至大型企业自建 SRv6 网络及全国 IP 承载网，提升云网一体化运营与差异化服务能力，推动 SRv6 技术普及与下一代 IP 网络发展。系统目前已稳定运行于现网。

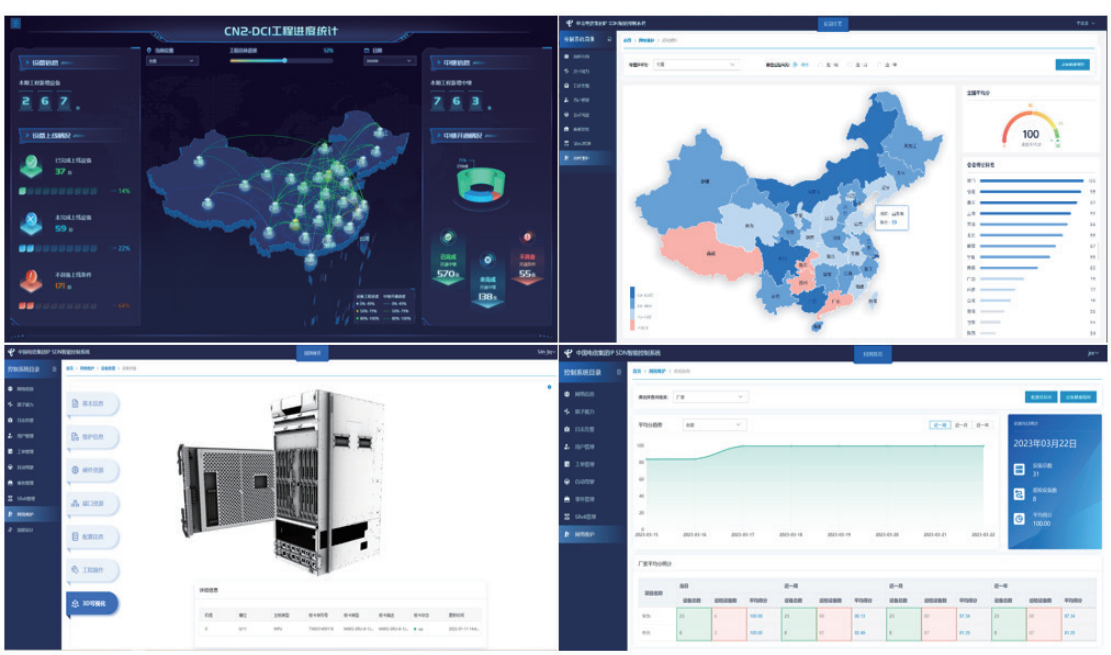
The project features sustainable iteration and online deployment capabilities. Its core achievements include:

Building a unified cross-vendor controller that masks device differences through customizable northbound interfaces and multi-vendor YANG adaptation. This promotes industrial ecosystem development and reduces procurement and O&M costs.

Enabling intelligent IP network control by replacing traditional manual CLI configuration with graphical operations. It provides atomic capability invocation and SRv6 network programmability, enhancing customization and automation.

Driving industry collaboration by establishing southbound standardization and northbound open capabilities. It supports on-demand services, traffic-based billing, and 3D O&M, facilitating cloud-network upgrades and workforce transformation.

With broad application prospects, the solution can be extended to large enterprises for building private SRv6 networks and nationwide IP carrier networks. It enhances integrated cloud-network operations and differentiated service capabilities, promoting SRv6 adoption and next-generation IP network development. The system currently operates stably in live networks.



构建跨厂商统一控制器，实现网络智能化和自动化

Building a Unified Multi-Vendor Controller for Intelligent and Automated Networks

成果丰富，屡获荣誉
Rich achievements and repeated honors

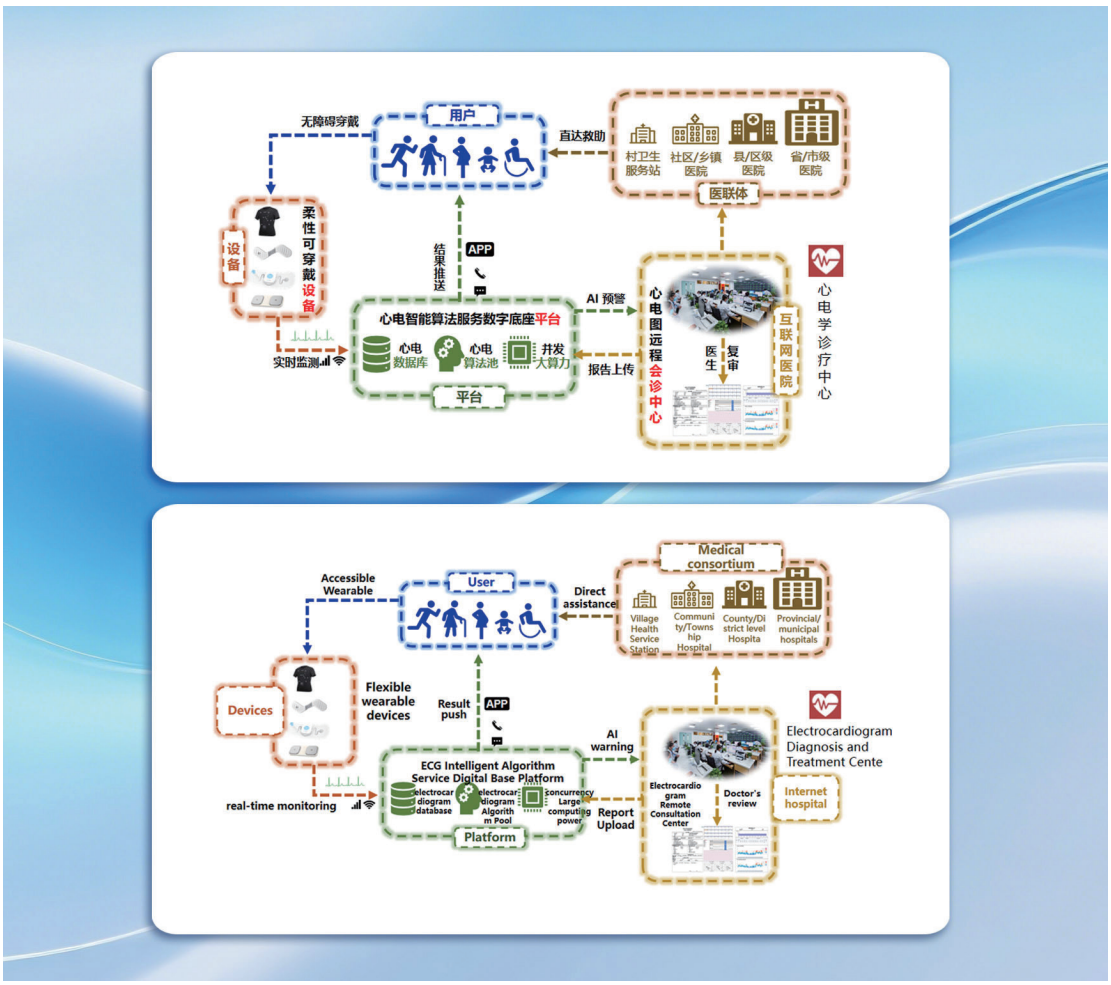
形成了一批具有行业影响力的成果，输出 25 项发明专利、1 项 PCT 专利、6 件软件著作权，论文 1 篇，获得“中国电信 2023 年度科技进步奖一等奖”、“第二届 IPv6 技术应用创新大赛行业专题赛 强基赛道 优秀奖”、“第三届“鼎新杯”数字化转型应用优秀案例三等奖”。为 SRv6 技术和 IPSDN 骨干网控制器的创新与规模化应用做出切实贡献。

The project has yielded a series of influential industry outcomes, including 25 invention patents, 1 PCT patent, 6 software copyrights, and 1 academic paper. It has been honored with several awards, such as the "China Telecom 2023 First Prize for Scientific and Technological Progress," the "Excellent Award in the Foundation Track of the 2nd IPv6 Technology Application Innovation Competition," and the "Third Prize for Excellent Digital Transformation Application Cases at the 3rd 'Dingxin Cup'."
These accomplishments represent a tangible contribution to the innovation and large-scale application of SRv6 technology and the IP SDN backbone network controller.



成果丰富，屡获荣誉
Rich achievements and repeated honors





心电智能监测与预警服务平台运行示意图
Schematic Diagram of the Operation of the ECG Intelligent Monitoring and Early Warning Service Platform

基于边缘计算 - 云端协同的心电数据监测平台的关键技术研究及应用

Key Technology Research and Application of ECG Data Monitoring Platform Based on Edge Computing-Cloud Collaboration

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引言

随着居民健康意识提升，老年、慢病患者人群等亟需专业心电监测方案。河南移动针对传统心电监测技术痛点问题，研发边缘计算—云端协同的心电监测技术，实现居家心电监测诊断与心脏疾病早发现早诊断早治疗。

Introduction

With the improvement of residents' health awareness, the elderly, chronic disease patients and other groups are in urgent need of professional ECG monitoring solutions. Addressing the pain points of traditional ECG monitoring technology, Henan Mobile has developed ECG monitoring technology based on edge computing-cloud collaboration. This technology enables home-based ECG monitoring and diagnosis, facilitating the early detection, early diagnosis and early treatment of heart diseases.

聚焦用户痛点，实现科创技术攻关
Focus on User Pain Points and Achieve Breakthroughs in Technological Innovation

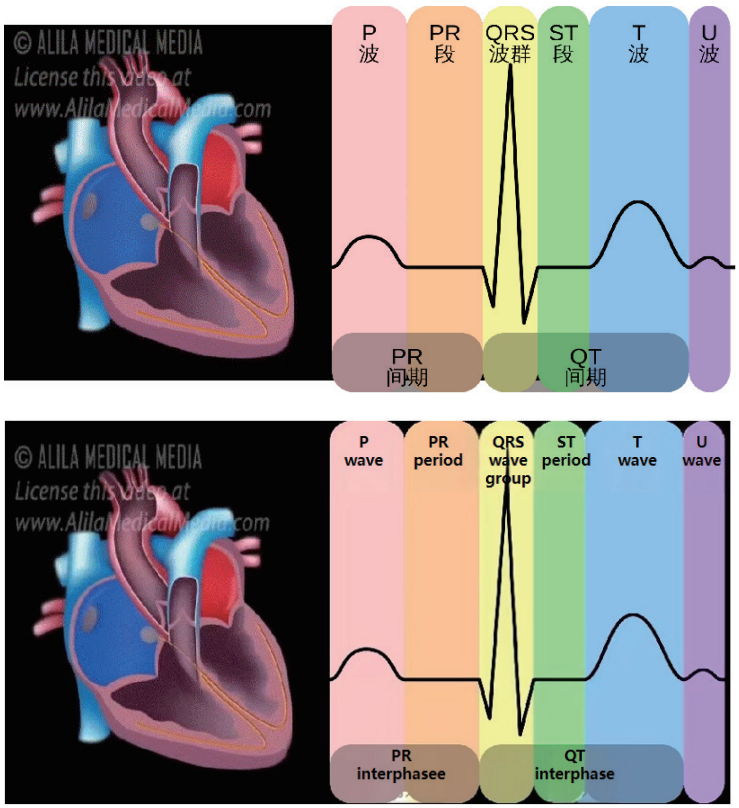
河南移动针对心电检测便捷性不足、报告可读性差等用户痛点，重点研发以下内容：1）打造心电智能算法数字服务底座平台，支持 10 万级设备并发接入，联动县域心电中心与医院，危急预警响应＜ 60 毫秒，助力急危病症快速干预；2）构建含儿童心电数据库及分人群成人数据库的 500 万例精标注心电数据库，借“四波四段”精标注技术将精准度提升 30%；3）研发心电健康医疗 AI 大模型算法，整合 12 类设备数据、识别 40 + 种疑难心电事件，诊断准确率超 90%，达中高级心电医师水平；4）推出 AI 智能心电卡与柔性心电衣双核心产品，以医疗级 AI 监测技术搭配无感穿戴体验，构建“精准筛查 - 风险预警”全周期心脏健康管理闭环；5）建设心电大模型专家系统与多模型任务协作能力，依据用户心电检测数据，生成专属心血管慢病管理方案。

Targeting user pain points in ECG testing—such as insufficient convenience and poor report readability—Henan Mobile has focused on the following key R&D initiatives:1) Build a digital service base platform for ECG intelligent algorithms, supporting concurrent access of 100,000-level devices. It connects county-level ECG centers and hospitals, with a critical warning response time of less than



AI 智能心电卡
AI Intelligent ECG Card

60 milliseconds to facilitate rapid intervention for acute and critical conditions.2) Establish a 5-million-case precisely annotated ECG database, which includes a pediatric ECG database and a population-specific adult database. The annotation accuracy is improved by 30% through the "four-wave and four-segment" precise annotation technology.3) Develop an AI large model algorithm for ECG healthcare, which integrates 12 types of device data, identifies more than 40 kinds of complex ECG events, and achieves a diagnostic accuracy rate of over 90%—reaching the level of intermediate and senior ECG physicians.4) Launch two core products: AI intelligent ECG cards and flexible ECG clothing. Combined with medical-grade AI monitoring technology and non-invasive wearable experience, they form a full-cycle heart health management loop of "precision screening - risk early warning".5) Build an ECG large model expert system and multi-model task collaboration capability, which generates customized cardiovascular chronic disease management plans based on users' ECG test data.



心搏级“四波四段”精标注技术
Beat-Level "Four-Waves and Four-Segments" Precise Annotation Technology

智慧康养，心电普惠，构建全民健康服务体系
Smart Health and Wellness, ECG for All, Building a National Health Service System

本成果推广后，能早期预警多种心血管疾病，为危重心电事件监测预警提供新思路与方案，可降低患者发病率和死亡率，减少患者家庭痛苦，节约医疗支出，减轻社会经济压力，且已广泛应用于基层医疗及个人、家庭健康管理领域，在居民健康监测、社区慢病管理中作用显著。

其 AI 诊断准确度达中高级心电图医生水平，已应用于全国 200 多个市县 500 多家医院，建成县级心电会诊中心 108 家，连接基层医院 352 家，服务到院用户近 3000 万人次，覆盖超 5.1 万个乡村、社区，发展康养用户超 635 万户，带动河南移动康养业务增收 2.5 亿元。

技术方面，研发的 AI 心电监测算法可识别 21 种高危心律，诊断准确率超 90%；构建的平台支持 10 万级设备并发接入，危急预警＜ 60 毫秒；智能心电卡仅 21 克，5 秒即可启动；柔性心电衣实现 7 天续航与 1000Hz 采集。

After the promotion of this outcome, it can provide early warning for a variety of cardiovascular diseases and offer new ideas and solutions for the monitoring and early warning of critical ECG events. It helps reduce the incidence and mortality of cardiovascular disease patients, alleviates the pain of patients' families, saves medical expenses, and eases the social economic pressure. Moreover, it has been widely applied in primary medical care, personal and family health management, playing a significant role in residents' health monitoring and community chronic disease management.

Its AI diagnostic accuracy has reached the level of intermediate and senior ECG doctors. It has been used in more than 500 hospitals across over 200 cities and counties in China, with 108 county-level ECG consultation centers established and 352 primary hospitals



洛阳“心电进社区”义诊活动
"ECG into Communities" Free Medical Consultation Activity in Luoyang

connected. It has served nearly 30 million in-hospital users, covered more than 51,000 villages and communities, developed over 6.35 million health and wellness users, and driven Henan Mobile's health and wellness business to increase revenue by 250 million yuan.

In terms of technology, the developed AI ECG monitoring algorithm can identify 21 types of high-risk heart rhythms with a diagnostic accuracy of over 90%; the built platform supports concurrent access of 100,000-level devices, with critical early warning response time of less than 60 milliseconds; the intelligent AI ECG card weighs only 21 grams and can be activated in 5 seconds; the flexible ECG clothing achieves 7-day battery life and 1000Hz data collection.



河南省人民医院心电会诊中心应用案例
Application Case of the ECG Consultation Center of Henan Provincial People's Hospital

技术领先，开启心电筛查与防护新模式
Leading Technology, Initiating a New Model for ECG Screening and Protection

本成果研发的专业心电设备已成功入驻中国 500 余家医疗机构，覆盖各级医院与基层医疗站点，累计服务患者近 3000 万人次，为不同地区人群提供便捷的心电监测服务。在此基础上，构建起“广覆盖、强闭环、全周期”的特色医疗模式，不仅有效提升基层医疗可及性，让偏远地区患者也能享受优质监测服务，还将跨区域会诊时间大幅缩短至 15 分钟，助力快速制定诊疗方案，截至目前已成功处置 15493 例危急患者，显著降低心脏疾病风险。

在科创层面，成果打造的智能监测与预警平台斩获多项权威荣誉，包括河南省科技进步奖、中国算力大会创新先锋称号，以及第七届下一代互联网技术创新大赛产业应用组一等奖，充分彰显技术创新性与行业认可度。同时，团队围绕该成果发表高水平论文 128 篇，深入分享技术原理与应用经验，还获得授权发明专利、实用新型专利、软件著作权共 63 项，形成完整的知识产权体系，为技术持续迭代与推广奠定坚实基础。

The professional ECG equipment developed under this outcome has been successfully adopted by over 500 medical institutions in China, covering hospitals at all levels and primary medical sites. It has served nearly 30 million patients cumulatively, providing convenient ECG monitoring services for people in different regions. On this basis, a distinctive medical model featuring "wide coverage, strong closed-loop, and full cycle" has been built. This model not only effectively improves the accessibility of primary medical care, enabling patients in remote areas to access high-quality monitoring services, but also significantly shortens the cross-regional consultation time to 15 minutes, facilitating the rapid formulation of diagnosis and treatment plans. Up to now, it has successfully handled 15,493 critical patients, significantly reducing the risk of heart diseases.

In terms of technological innovation, the intelligent monitoring and early warning platform built under the outcome has won a number of authoritative honors, including the Henan Provincial Science and Technology Progress Award, the title of "Innovation Pioneer" at the China Computing Power Conference, and the first prize in the Industrial Application Group of the 7th Next-Generation Internet Technology Innovation Competition. These honors fully demonstrate the technology's innovation and industry recognition. Meanwhile, the team has published 128 high-level papers focusing on this outcome, in-depth sharing technical principles and application experience. It has also obtained a total of 63 authorizations, including invention patents, utility model patents, and software copyrights, forming a complete intellectual property system and laying a solid foundation for the continuous iteration and promotion of the technology.

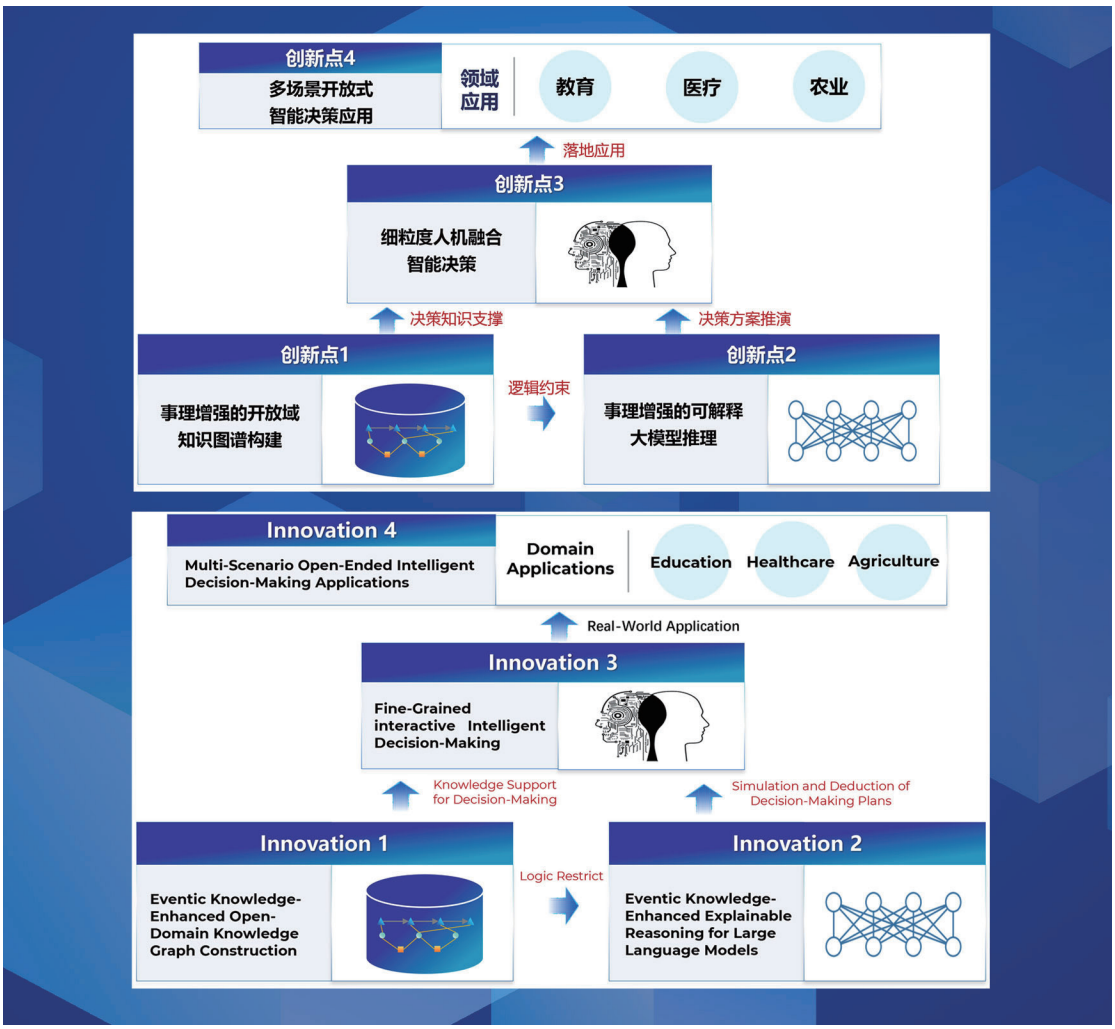


本成果获得河南省科学技术进步奖等奖项
This Outcome Has Won Awards Including the Henan Provincial Science and Technology Progress Award



本成果获得发明专利、实用新型专利、软件著作权 63 项
This outcome has obtained 63 authorizations, including invention patents, utility model patents, and software copyrights





事理增强的细粒度智能决策关键技术及多场景应用创新点
Innovations in the Technologies and Applications of Fine-grained Intelligent Decision-making Enhanced by Eventic Graphs

事理增强的细粒度智能决策关键技术及多场景应用

Technologies and Applications of Fine-grained Intelligent Decision-making Enhanced by Eventic Graphs

哈尔滨工业大学
Harbin Institute of Technology

科大讯飞股份有限公司
iFLYTEK Co.,Ltd.

复旦大学
Fudan University

引言

本项目首创“事理图谱”知识表达新范式，突破了事理增强的大模型可解释推理技术，同时创造性地提出事理驱动的细粒度人机辩论式决策技术，实现多场景开放式智能决策应用。项目产出成果取得良好社会效益和经济效益。

Introduction

This project pioneered “Eventic Graph”, a new knowledge representation paradigm, achieving breakthroughs in eventics-enhanced explainable reasoning in large language models. This project also creatively proposed an eventics-driven, fine-grained debate-style human-AI co-decision architecture, enabling open-ended intelligent decision-making applications across multiple scenarios. The outcomes have delivered significant social and economic benefits.

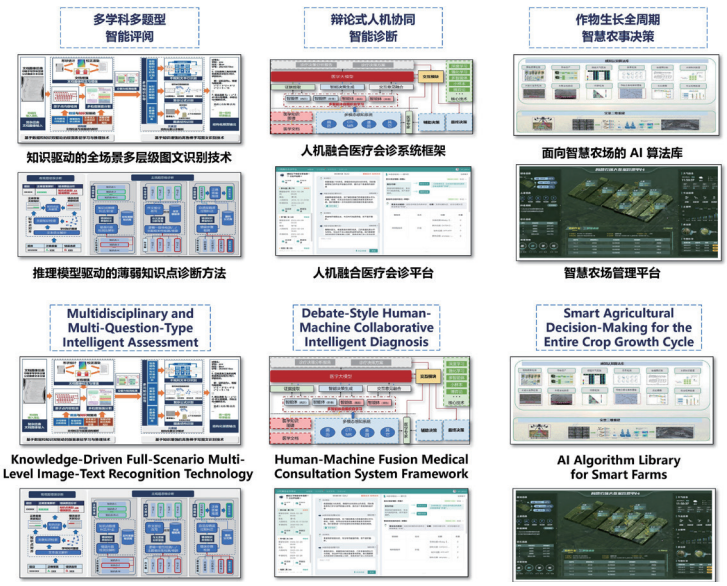
构建国际领先知识图谱与可解释推理新范式
New State-of-The-Art Paradigm for Knowledge Graph and Explainable Reasoning

本项目攻克了传统知识图谱重实体轻逻辑、大模型推理可解释性弱、智能决策可信性不足三大技术难题，实现了四项核心创新：首创“事理图谱”技术体系，突破静态与动态知识联合建模瓶颈，构建全球首个亿级节点事理增强开放式知识图谱；提出事理知识引导的大模型可解释推理框架，首次实现事理图谱与大模型的动态协同，推理准确率显著超越国际主流模型；创新事理驱动的细粒度人机辩论决策技术，构建具备批判性思维的人机融合智能体系，在复杂任务中实现超人类水平的高可信决策；研发多场景智能决策应用关键技术，在教育、医疗、农业等领域实现精准化推理与决策。成果获 53 项授权知识产权、127 篇高水平论文及 8 项国际冠军，被中国计算机学会科技成果鉴定会鉴定为“整体国际先进，事理图谱与人机辩论决策国际领先”。



事理增强的开放域知识图谱构建
Eventics-Enhanced Open Domain Knowledge Graph Construction

This project addressed three major technical challenges: lack of logical reasoning ability in traditional knowledge graphs, weak explainability in large language model (LLM) reasoning, and low trustworthiness in intelligent decision-making.
It has also achieved four core innovations: 1) pioneering the “Eventic Graph” technical framework, overcoming bottlenecks in joint modeling of static and dynamic knowledge, and constructing the world’s first eventics-enhanced open knowledge graph with hundreds of millions of nodes. 2) Proposing an eventics-guided framework for explainable LLM reasoning, enabling dynamic collaboration between Eventic Graphs and LLMs for the first time, significantly surpassing worldwide



多场景开放式智能决策应用
Applications of Multi-Scenario Open-Ended Intelligent Decision-Making

mainstream models in reasoning accuracy. 3) Innovating eventics-driven fine-grained debate-style human-AI co-decision architecture, establishing a critically thinking human-machine integrated intelligent system that achieves superhuman-level trustworthy decision-making in complex tasks. 4) Developing key technologies for multi-scenario intelligent decision-making applications, enabling precise reasoning and decision-making in education, healthcare, agriculture, and other fields.

This project has earned 53 intellectual property licenses, 127 high-impact publications, and 8 international awards. It was praised by the China Computer Federation as “a global frontrunner overall, achieving state-of-the-art status in the area of Eventic Graph and debate-style human-machine co-decision-making.”

技术系统广泛应用于教育、医疗、农业等场景，社会和经济效益显著
Widely applied in education, healthcare, agriculture, and other fields, achieving significant social and economic benefits

该成果技术成熟度高，自 2014 年起历经十年迭代与多场景验证，已在教育、医疗、农业、政务等领域实现大规模落地应用。经济效益显著，近三年累计创造直接经济效益 54.06 亿元，实现利润 7.01 亿元，在各行业形成持续盈利能力。社会效益尤为突出：在教育领域，作为中国唯一中高考规模化智能评阅系统，年服务考生超 4000 万，为教师日均减负 1 小时以上；在医疗领域，医生诊断效率提升 40%，复杂误诊率下降 55%，有效促进优质医疗资源下沉基层；在农业领域，“天工开悟”大模型覆盖“耕、种、管、收”全流程，推广面积 468.9 万亩，服务农户 3.5 万人次，增产节支效果明显。成果还拓展至政务、司法、新闻出版等行业，构建了从关键技术到产业生态的完整创新体系，社会影响深远，具有重大的市场价值与社会价值。

This project has achieved high technical readiness through a decade of iterations and multi-scenario validations since 2014. It has already been applied on a large scale in education, healthcare, agriculture, governance, and other fields. The economic benefits are remarkable, cumulatively generating direct economic revenue of 5.406 billion yuan, achieving a profit of 701 million yuan over the past three years, establishing sustainable profitability across various industries. Its social impacts are particularly outstanding: 1) in education, as China’s only large-scale intelligent grading system for national secondary school and college entrance exams, it serves over 40 million students annually, reduces teachers’ daily workload by more than one hour. 2) In healthcare, it improves doctors’ diagnostic efficiency by 40% and reduces misdiagnosis rates by 55%, effectively bringing high-quality medical resources closer to the lower class. 3) In agriculture, the “Kwoo” large language model covers the entire process from plowing, sowing, managing, to harvesting. It achieves a reach of 4.689 million mu, serving over 35,000 farmers, significantly increasing yield while reducing costs. The project has additional accomplishments in governance, judiciary, news and publishing, and other fields, establishing a comprehensive innovation system from key technologies to industrial ecosystems. Its profound social influence underscores substantial market value and societal significance.

全国高利害考试全面应用

- 智能评阅技术已在教育部教育考试院及20个省市区高考、全国大学英语四六级等考试中应用
- 2024年服务考生4000万+，累计服务考生2.4亿+，年均辅助修正教师评卷存疑样本超过1.2万份



教育部副部长王嘉毅在全球智慧教育大会观看讯飞智能评卷产品展示

日常教学场景广泛应用

- 通过 AI 学习机、智能批阅机等产品服务学校教学与自主学习场景
- 提供作文细粒度、个性化评价反馈，并能够推荐个性化学习资源
- 帮助教师提高批改效率40%，覆盖全国28个省市区学校，在50000+学校应用



蚌埠市智慧学校全覆盖，服务875所学校，6292个班级，2万名教师、40万余名学生

Full-Scale Implementation for National-Level High-Stakes Examinations

- Intelligent Grading Technology has been applied in the National College Entrance Examination as well as other examinations such as CET-4 and CET-6 which is administered by the National Education Examinations Authority of the Ministry of Education and covers 20 provinces, municipalities, and autonomous regions.
- In 2024, the number of candidates served exceeded 40 million, the total number of candidates served has surpassed 240 million, the average number of questionable samples in teachers' grading that it has assisted in correcting is over 12,000.



Vice Minister of the Ministry of Education Wang Jiayi watched the product demonstration of iFLYTEK's intelligent paper-marking at the Global Smart Education Conference.

Widely Applied in Daily Teaching Scenarios

- Products such as AI-powered learning machines, intelligent marking devices are applied to support the scenarios of school-based traching and self-directed learning.
- Provide fine-grained and personalized evaluative feedback on essays, and capable of recommending personalized learning resources.
- Assisting teachers in enhancing their grading efficiency by 40%, covering schools in 28 provinces, municipalities, and autonomous regions, applying in 50,000+ schools.



Bengbu City has achieved full coverage of smart schools, serving 875 schools, 6,292 classes, 20,000 teachers, and over 400,000 students.

项目在教育领域中的应用
Applications in Education

构建人机融合医疗会诊系统

- 通过全国首个医疗健康领域大模型应用技术标准测评，通过算法备案
- 在北京肝胆胰外科学术会议发布，系统覆盖22个省市100+家医疗机构
- 临床辅诊、患者随访等场景中，效率提升超 70%，为超百万患者提供个性化诊后管理服务，典型医院的计划复诊率提升 3 倍。



构建医学知识图谱增强的大模型

- 研发全国首个医学大模型“本草”，GitHub开源后获得4800+推荐
- 入选中国大模型TOP70榜单
- 助力301医院和讯飞医疗的医疗问答系统，日访问量达万人次



Construct a Human-Machine Integrated Medical Consultation System

- Passing China's first evaluation of application technical standards for large language models in the medical and healthcare field, and completed the algorithm filing.
- Released at the Beijing Hepatobiliary and Pancreatic Surgery Academic Conference, covering 22 provinces and municipalities as well as 100+ medical institutions.
- In scenarios such as clinical auxiliary diagnosis and patient follow-up, efficiency has increased by over 70%, providing personalized post-diagnostic management services for more than one million patients, and the scheduled follow-up consultation rate of typical hospitals has tripled.



Construct a large model enhanced by medical knowledge graph

- Developing China's first medical large language model "BenTsao", which gained 4,800+ stars after being open-sourced on GitHub.
- Being selected into China's Large Language Models TOP 70 List.
- Assissting the medical Q&A systems of the 301 Hospital and iFlytek Healthcare, which achieve a daily visit volume of 10,000.



项目在医疗领域中的应用
Applications in Healthcare

成果关键技术获多项国际顶级奖项，被全球顶尖机构引用
Received Multiple International Awards and Cited by Numerous Leading Global Institutions

本成果累计产出中国计算机学会推荐的高水平论文 127 篇（4 篇论文单篇被引超 1000 次），获国际自然语言处理顶会杰出论文奖 3 项，最佳论文提名奖 1 项，在 8 项国际比赛中获得冠军，2024 年度荣获全球四大国际发明展之一的英国国际发明展最高奖—钻石奖，获中国省部级一等奖 3 项。事理图谱概念及其技术体系的研究工作已在国际学术界产生广泛影响：首篇事理图谱论文单篇被引 1150 次，入选 Paper Digest 评选出的 IJCAI 最有影响力论文。2022 年，中国计算机学会计算机术语审定委员会将事理图谱作为专用术语发布；2024 年，事理图谱入选由中国科学技术名词审定委员会发布的计算机领域年度前沿十大热点词。事理图谱相关工作被 MIT、CMU、OpenAI、NVIDIA 等国际知名高校和企业引用，引用文献发表于 ACL、TKDE 等 10 余个中国计算机学会推荐的 A 类国际顶级期刊会议上。

This project has produced a total of 127 papers rated as “high-quality” by the China Computer Federation (CCF), including 4 papers that each achieved over 1,000 citations. It has received 3 outstanding paper awards at top-tier international conferences on natural language processing, 1 best paper nomination, and won the first place in 8 international competitions. In 2024, it was awarded the Diamond award, the highest award, in the British Invention Show, one of the world’s largest invention exhibitions. It also achieved 3 provincial and ministerial level first-class prizes in China.

The research on the concept and technical framework of “Eventic Graph” has deeply influenced the international academic community; the inaugural paper on “Eventic Graph” has been cited 1,150 times and was recognized by Paper Digest as one of the most influential papers at International Joint Conference on Artificial Intelligence (IJCAI). In 2022, CCF officially released “Eventic Graph” as an established technical term; in 2024, it was selected as one of the “Top Ten Hot Topics in Computer Science” by the China National Committee for Terminology in Science and Technology.

Research related to “Eventic Graph” has been cited by internationally renowned institutions and companies including MIT, CMU, OpenAI, and Nvidia, with citing papers being published in over 10 CCF-A top-tier international journals and conferences including Annual Meeting of the Association for Computational Linguistics (ACL), and IEEE Transactions on Knowledge and Data Engineering (TKDE).



ACL2024 杰出论文奖



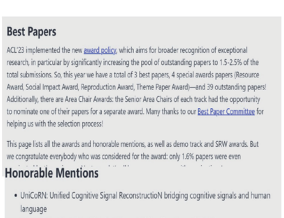
COLING 2024 杰出论文奖



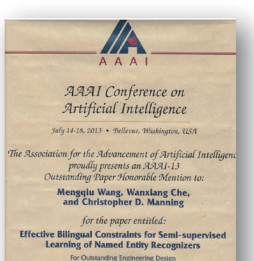
成果荣获2024年英国国际发明展最高奖—钻石奖



“天工开悟”农业大模型获《China Daily》报道



ACL 2023 最佳论文提名奖

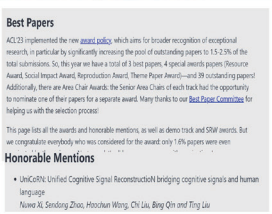


AAAI 2013
最佳论文提名奖

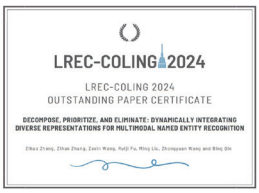




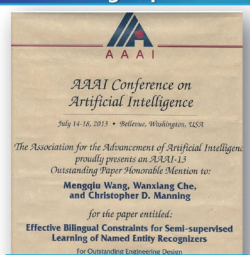
ACL2024 Outstanding Paper Award



ACL 2023 Best Paper Candidate Awards



COLING 2024 Outstanding Paper Award



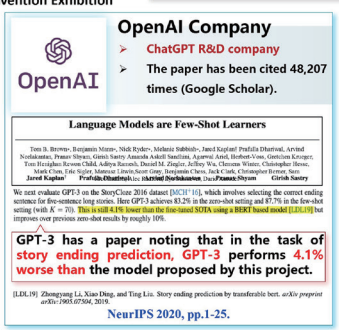
AAAI 2013 Best Paper Candidate Awards



This project won the highest award (Diamond Award) of the 2025 UK BIS International Invention Exhibition

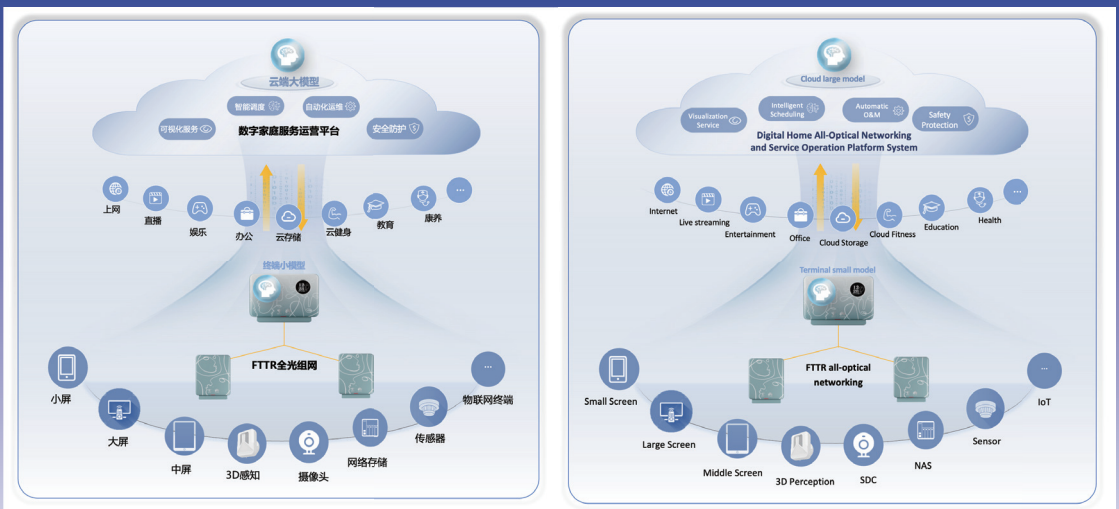


"Kwoo" Agricultural Large Model has been reported by *China Daily*



成果获多项国际顶级奖项被国际顶尖机构正面引用高度评价

Top-Tier International Awards Received, and Citations by World Renowned Institutions



AI 驱动一张全光网，迈入网络智能新纪元
AI-driven all-optical networks, a new age of intelligent networking

数字家庭全光组网技术创新与规模化应用

Digital home all-optical networking technology innovation and large-scale application

中国电信集团有限公司
China Telecom Corporation Limited

华为技术有限公司
Huawei Technologies Co., Ltd.

引言

面向家庭数字化应用新需求，中国电信持续深耕数字家庭领域，加速融合 AI 技术，创新升级“一张全光网”，助力“一个美好家”业务发展，以科技创新重塑数字生活方式，为亿万家庭打造畅连智享的新型全光网络。

Introduction

In response to new demands for home digital applications, China Telecom continues to deepen its presence in the digital home sector, accelerate the integration of AI technology, innovate and upgrade all-optical home network, support the development of the digital home service, reshape the digital lifestyle with technological innovation, and create a new all-optical network that provides seamless connectivity and intelligent enjoyment for hundreds of millions of families.

创新引领，实现家庭全光网络升级
Leading with Innovation, Upgrading Home All-Optical Network

光与 Wi-Fi 异构网络协同与 AI 抗干扰技术，实现光链路与无线网络的深度融合调度，频谱效率提升 50%，漫游切换时延降低至 20ms。

端网协同智能加速技术，实现统一的“光 + 无线”切片架构和应用识别控制，平均传输时延降低 40%，显著提升关键业务承载质量。

超大规模集约运营平台，实现亿级终端实时管理与大数据质量分析，具备交付精准、排障迅速、质态可控的运营能力，极大提升部署和运维效率。

智能感知与多模态识别技术，实现居家场景识别，联动设备提供全屋节能、安全告警等服务，让网络成为懂生活的智能管家。

数字家庭生态连接能力创新，通过 AI 辅助识别和通感技术，实现未联网设备识别、快速配网、终端协同，为家庭生态融合提供底层能力。

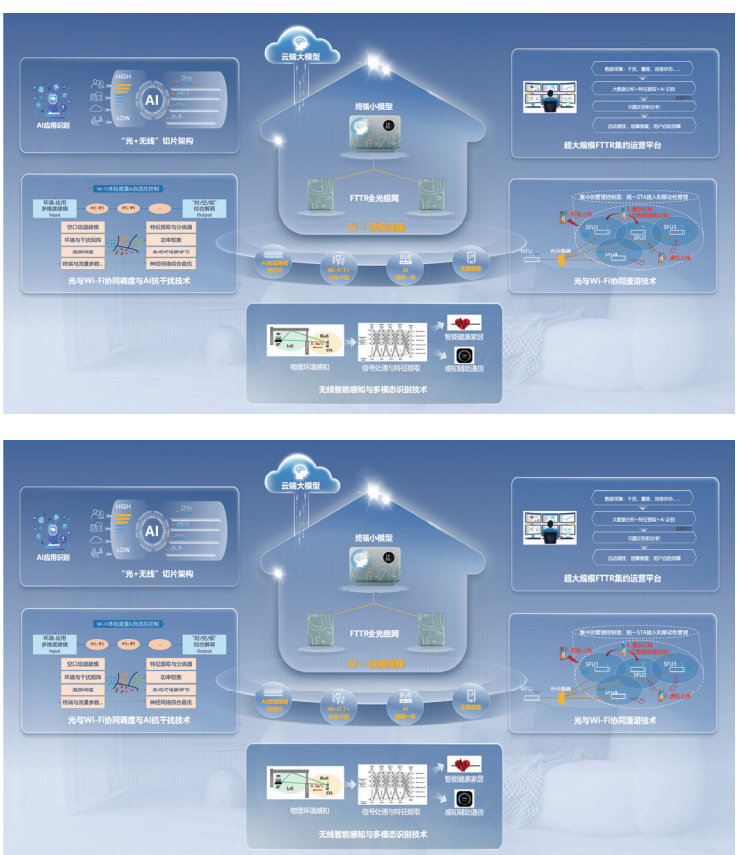
Collaboration between optical and Wi-Fi heterogeneous networks, along with AI anti-interference technology, enables deep integration and scheduling of optical links and wireless networks, increasing spectral efficiency by 50% and reducing roaming switch latency to 20ms.

End-network collaborative intelligent acceleration technology achieves a unified "optical + wireless" slicing architecture and application recognition control, reducing the average transmission delay by 40%, significantly enhancing the QoS of VIP services.

Ultra-large-scale intensive operation platform enables real-time management of hundreds of millions of terminals and big data quality analysis, featuring precise delivery, rapid troubleshooting, and controllable quality, significantly enhancing deployment and operation efficiency.

Intelligent sensing and multimodal recognition technologies enable smart identification of home scenarios, coordinating home devices to provide services such as whole-house energy saving and safety alerts, transforming the network into an intelligent butler that understands daily life.

Innovation in Digital Home Ecosystem Connectivity: AI-assisted recognition, and Integrated Sensing and Communication (ISAC) technologies, enable identification of unconnected devices, rapid network configuration, and terminal collaboration, providing underlying capabilities for home ecosystem integration.



端云融合的智能连接底座
Intelligent connection base for end-cloud integration

效益提升，推动数字家庭高质量发展
Enhancing Efficiency, Promoting High-Quality Development of Digital Homes

本成果推动了 FTTR 终端的标准化及产业成熟，实现“光纤全联接、千兆全覆盖、Wi-Fi 全漫游”，形成全面贯通技术研究、芯片设计、设备开发、安装部署、业务开通、运维排障、用户服务等的行业发展新范式。累计应用终端超 4200 万台，拉动经济收入超百亿元，有效带动产业链上下游企业协同发展，经济效益显著；实现家庭网络全光升级，突破传统网络瓶颈，大幅提高使用寿命，降低故障率，社会价值突出。

通过高质量网络基础设施建设，支撑构建数字生活体系，实现家庭终端的跨生态接入与场景联动，为用户提供智能家居、智能安防、全屋节能、智慧健康、智慧娱乐等多种服务，并与智慧社区、数字乡村融通协同，提升用户的数字生活体验和服务便利性。

This achievement has propelled the standardization and industrial maturity of FTTR terminals, realizing "full fiber connectivity, gigabit coverage, and Wi-Fi roaming," and has established a new industry development paradigm that comprehensively integrates technology research, chip design, equipment development, installation and deployment, service provisioning, operation and maintenance troubleshooting, and user services. Over 42 million terminals have been deployed, generating over 10 billion yuan in economic revenue and effectively driving the coordinated development of upstream and downstream enterprises in the industry chain, resulting in significant economic benefits. This achievement has enabled all-optical upgrades to home networks, breaking through traditional network bottlenecks, significantly extending service life, and reducing failure rates, creating significant social value.

By constructing high-quality network infrastructure, the digital life system is developed, enabling cross-ecosystem access and scenario integration for home terminals. This provides users with a variety of services including smart home, intelligent security, whole-house energy efficiency, smart health, and smart entertainment. Additionally, it integrates and collaborates with smart communities and digital villages to enhance users' digital living experiences and service convenience.



AI+ 数字生活体系，创造美好数字生活
AI+ Digital Life System, Creating A Better Digital Life

协力共筑，建设繁荣数字生态
Collaborate to Build Together, Build a Prosperous Digital Ecosystem

家庭全光组网技术创新实现了国际性标准化技术引领，不仅直接推动了芯片、设备、网络和应用等产业的发展，更为“万物智联”时代奠定坚实基础。构建数字家庭智能化互联能力，可视家庭终端超 20 亿，实现百余个品类终端的接入与联动，基于亿级用户入口进行全体系商业赋能，推动产业生态共同繁荣。

本成果完成 30 余项发明专利、软件著作权，形成 10 余项 ITU、CCSA、WAA 相关标准，获得世界宽带论坛“最佳数字家庭运营商”、中国电信科技进步一等奖、成果贡献银奖等奖项。通过技术创新，产业融通和融合开放，为用户提供更丰富、更智能、更便捷的数字生活产品和服务，共创“美好家”。

Innovations in home all-optical networking technology have achieved international standardization and leadership, not only directly driving the development of industries such as chips, equipment, networks, and applications, but also laying a solid foundation for the

era of "intelligent interconnection of all things." By building the intelligent interconnection capabilities of digital homes, this achievement has enabled the visualization of over 2 billion household terminals, supporting the access and collaboration of hundreds of types of terminals. Based on an entry point with hundreds of millions of users, it empowers the entire system and drives the collective prosperity of the industrial ecosystem.

This achievement has completed over 30 invention patents and software copyrights, established more than 10 ITU-T, CCSA, and WAA related standards, and has been honored with awards such as the "Best Digital Home Operator" at the World Broadband Forum, the First Prize for Technological Progress from China Telecom, and the Silver Award for Contribution to Achievements. Through technological innovation, industrial integration, and open collaboration, it provides users with richer, smarter, and more convenient products and services, jointly creating a better digital life.



部分标准、专利、软著、荣誉
Some standards, patents, software copyrights and honor



构建跨域智能弹性调度能力，打造确定性网络服务 2.0，助力算力网业务发展
Develop Intelligent and Elastic Cross-Domain Scheduling Capabilities, Establish Deterministic Networking Service 2.0, and Support the Growth of Computing Power Network Services

算力网确定性网络服务
Deterministic Networking Service for Computing Power Network

中国移动通信集团有限公司
China Mobile Communications Group Co., Ltd.

TIME 公司（马来西亚）
TIME dotCom Berhad

华为技术有限公司
Huawei Technologies Co., Ltd.

中盈优创资讯科技有限公司
China Unitechs Co., Ltd.

引言

项目攻克算力网确定性时延、带宽、路径及质量等关键技术，拓展应用场景，获 320 余项国际和中国专利，形成 73 项国际标准，研制出技术领先 AI 集群路由器，建成超 600T 带宽的 SRv6 算力网实体，覆盖近 40 国，服务 200 万企业客户，惠及 13 亿用户。

Introduction

This project has conquered key technologies such as deterministic latency, bandwidth, path, and quality in computing power networks, expanded application scenarios, obtained over 320 international and Chinese patents, established 73 international standards, developed advanced AI cluster routers, built an SRv6 computing power network with over 600T bandwidth, covering nearly 40 countries, serving 2 million enterprise customers, and benefiting 1.3 billion users.

突破关键技术，构建确定性算力网技术体系
Breakthroughs in Key Technologies to Construct the Technical System for Deterministic Computing Power Network

项目产出国际标准 73 项，获国际专利 45 项、中国专利 283 项，发表顶会顶刊论文 14 篇，取得软件著作权 10 项。

一、构建确定性算力网技术体系

1、微秒级智能感知体系：研发 Micro TWAMP 技术，时延测量精度提升 1000 倍，部分局向时延优化超 75%。

2、T 比特级动态带宽引擎：实现分钟级 T 比特带宽调整和毫秒级故障检测，为算网业务提供弹性带宽保障。

3、多模态路径编程体系：创新增强蚁群算法，支持 50 + 因子 SRv6 网络编程控制，实现跨域路径管控和超低时延连接。

4、内生安全质量体系：将 DDOS 攻击处置提至秒级，高敏业务可用性达 99.999%。

二、突破 AI 集群路由器关键技术

1、突破容量瓶颈：首创 Cable 背板技术，突破 PCB 容量限制，单模块实现 600G 集群互联能力。

2、开创 AI 新范式：创新融合 NP 转发芯片与 AI 协处理器，实现“高速转发”与“智能计算”的双重突破。

The project produced 73 international standards, obtained 45 international patents and 283 Chinese patents, published 14 top-tier conference and journal papers,



T 比特级动态带宽引擎
T-Bit-Level Dynamic Bandwidth Engine

and acquired 10 software copyrights.

I. Construct the Technical System for Deterministic Computing Power Network

1. Microsecond-Level Intelligent Sensing System: Developed Micro TWAMP technology, improving latency measurement accuracy by 1,000 times and optimizing latency in certain directions by over 75%.

2. T-Bit-Level Dynamic Bandwidth Engine: Achieved minute-level T-bit bandwidth adjustment and millisecond-level fault detection, providing elastic bandwidth guarantees for computing power network services.

3. Multi-Modal Path Programming System: Innovatively enhanced ant colony algorithm, supporting SRv6 network programming control with 50+ factors, enabling cross-domain path management and ultra-low latency connectivity.

4. Intrinsic Security Quality System: Elevated DDoS attack handling to second level, achieving 99.999% availability for sensitive services.

II. Break through Key Technologies of AI Cluster Routers

1. Breaking Capacity Bottlenecks: Pioneered Cable backplane technology, overcoming PCB capacity limitations, and achieving 600G cluster interconnection capability per module.

2. Create a New AI Paradigm: Innovatively integrated NP forwarding chips with AI coprocessors, achieving dual breakthroughs in "high-speed forwarding" and "intelligent computing".



多模态路径编程体系
Multi-Modal Path Programming System

600T 带宽覆盖 40 国，服务 200 万企业、13 亿用户
600T Bandwidth Covering 40 Countries, Serving 2 Million Enterprises and 1.3 Billion Users

项目构建了超 600T 带宽的确定性网络服务算力网实体，覆盖中国、马来西亚、欧美非等近 40 个国家，服务 200 万企业客户，惠及 13 亿用户，助力中国网络强国建设与国际网络空间命运共同体的构建。

1、经济效益可观：助力中国移动视联网产品服务近 1 亿政企及家庭客户，总创收约 30 亿元人民币，支撑云网业务销售收入共计 7.14 亿元。

2、社会效益明显：发布《“九州”算力互联网（MATRIXES）“AI+”时代目标架构白皮书》，推动网络与 AI 双向赋能，面向客户提供更加灵活、可靠、安全、绿色的新产品、新服务，为互联网应用创新提供更为广阔的可能性。

3、生态效益突出：构建超 600T 带宽 "IPv6+" 骨干网（“九州”算力互联网），IPv6 联接超 10 亿，实现 SRv6 确定性网络服务能力延伸至北美、欧洲、东南亚方向，为远程教育、企业办公、直播等体验敏感业务进行应用加速，跨境访问时延优化 32% 以上。

The project has built a deterministic network service computing power network with 600T bandwidth, covering nearly 40 countries including China, Malaysia, Europe, America, and Africa, serving 2 million enterprise customers, benefiting 1.3 billion users, and contributing to China’s goal of becoming a cyber powerhouse and the global community with a shared future in cyberspace.

1. Significant Economic Benefits: Supported China Mobile’s video networking products in serving nearly 100 million government, enterprise, and household customers, generating total revenue of approximately RMB 3 billion, and underpinning cloud network service sales revenue of RMB 714 million.

2. Notable Social Benefits: Released the "Jiuzhou Computing Power Internet (MATRIXES) Target Architecture White Paper for the AI+ Era," promoting mutual empowerment between networks and AI, providing customers with more flexible, reliable, secure, and green new products and services, and offering broader possibilities for internet application innovation.

3. Outstanding Ecological Benefits: Con-

structed an "IPv6+" backbone network ("Jiuzhou" Computing Power Internet) with over 600T bandwidth, supporting over 1 billion IPv6 connections. Extended SRv6 deterministic network service capabilities to North America, Europe, and Southeast Asia, enabling application acceleration for experience-sensitive services such as remote education, enterprise office work, and live streaming, while reducing cross-border access latency by over 32%.



Fig 3-2 "MATRIXES Technology System New Technology in the AI+ Era



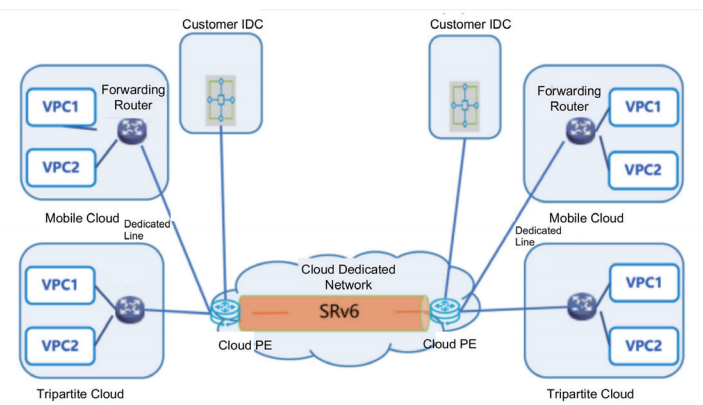


Fig 4-9 Deployment plan for Computing Power Network

发布《“九州”算力互联网（MATRIXES）“AI+” 时代目标架构白皮书》
Released the "Jiuzhou Computing Power Internet (MATRIXES) Target Architecture White Paper for the AI+ Era"

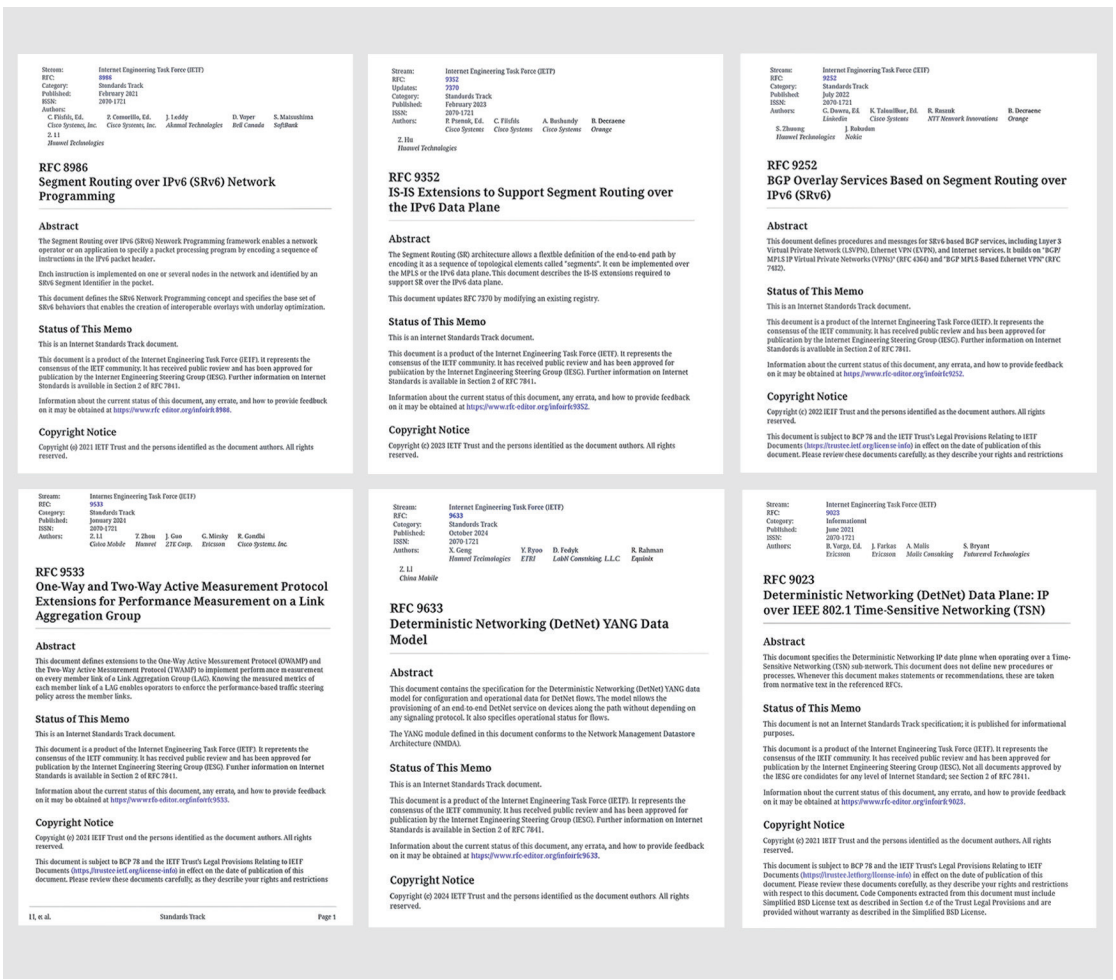


推动互联网技术标准发展，获全球高度评价
Promoted the Development of Internet Technology Standards and Received Global Acclaim

1. 推动互联网技术标准发展，促进算力网演进：中国移动联合华为、Time 等积极推进 SRv6 标准体系构建，近五年在 IETF 发布 RFC 171 篇、新文稿 402 篇，推动成立 srv6ops、nmop、cats 等工作组，并担任 IESG、IAB 等高级管理职位。中国移动和华为在 IETF 标准贡献度分居全球企业 TOP5 和 TOP2。

2. 打造高品质算力网，提升社会影响力：项目整合产业链各方力量，打造网络时延、带宽、路径、质量等四个维度的确定性算力互联网。在东南亚，TIME 率先部署 SRv6 解决差异化服务和业务开通效率问题，为“一带一路”国家的人民提供高品质联接服务。

3. 项目获全球高度评价：获得 2024 年信息社会世界峰会（WSIS）最高项目奖、世界宽带论坛 infoVision 大奖、日本 Interop 金奖、中国科技进步奖、中国通信学会科学技术奖、江苏省科学技术进步奖、北京市科技进步奖等。



RFC 8986
Segment Routing over IPv6 (SRv6) Network Programming

RFC 9352
IS-IS Extensions to Support Segment Routing over the IPv6 Data Plane

RFC 9252
BGP Overlay Services Based on Segment Routing over IPv6 (SRv6)

RFC 9533
One-Way and Two-Way Active Measurement Protocol Extensions for Performance Measurement on a Link Aggregation Group

RFC 9633
Deterministic Networking (DetNet) YANG Data Model

RFC 9023
Deterministic Networking (DetNet) Data Plane: IP over IEEE 802.1 Time-Sensitive Networking (TSN)

项目产出的部分 IETF 国际标准
Some IETF International Standards Produced by the Project

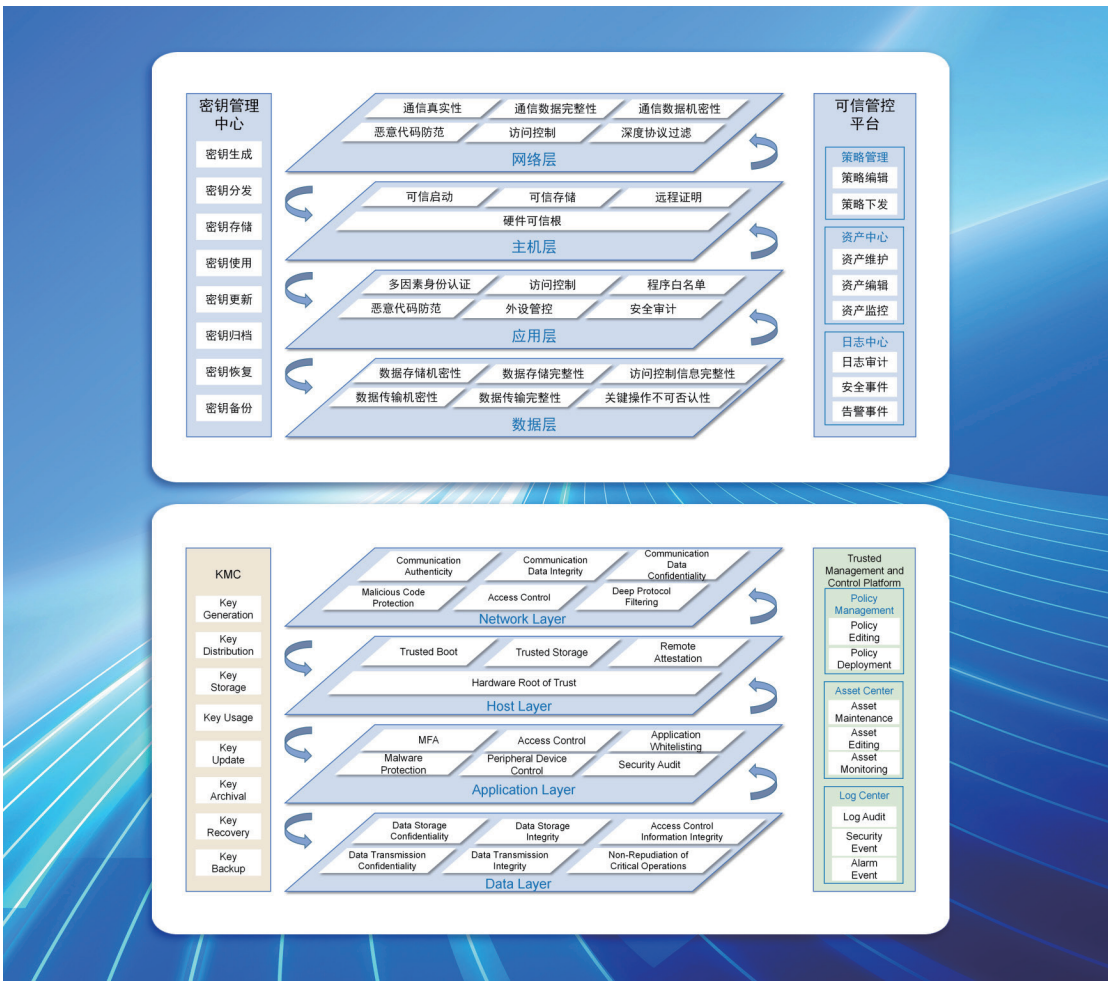
1. Promoted the development of internet technology standards and advanced the evolution of computing power networks: China Mobile, in collaboration with Huawei and TIME, actively advanced the construction of the SRv6 standard system. Over the past five years, they published 171 RFCs and 402 new drafts in the IETF, promoted the establishment of working groups such as srv6ops, nmop, and cats, and held senior management positions in the IESG and IAB. China Mobile and Huawei ranked among the top 5 and top 2 global enterprises, respectively, in IETF standard contributions.
2. Built a high-quality computing power network and enhanced social influence: The project integrated efforts from across the industry chain to create a deterministic computing power internet with four dimensions: network latency, bandwidth, path, and quality. In Southeast Asia, TIME takes the lead in deploying SRv6 to solve the problems of differentiated services and service opening efficiency, providing high-quality connectivity services for the people of the 'Belt and Road' countries.
3. The project received global acclaim: It won the top project award at the 2024 World Summit on the Information Society (WSIS), the World Broadband Forum infoVision Award, the Japan Interop Gold Award, the China Science and Technology Progress Award, the China Institute of Communications Science and Technology Award, the Jiangsu Provincial Science and Technology Progress Award, and the Beijing Science and Technology Progress Award.







项目获得的部分奖项
Some Awards Received by the Project



纵深防御体系
Defense-in-Depth System

铁路列控系统网络安全技术研究与应用

Research and Application of Cybersecurity Technologies for Railway Train Control Systems

北京全路通信信号研究设计院集团有限公司
CRSC Research & Design Institute Group Co., Ltd.

北京量子信息科学研究院
Beijing Academy of Quantum Information Sciences

北京工业大学
Beijing University of Technology

引言

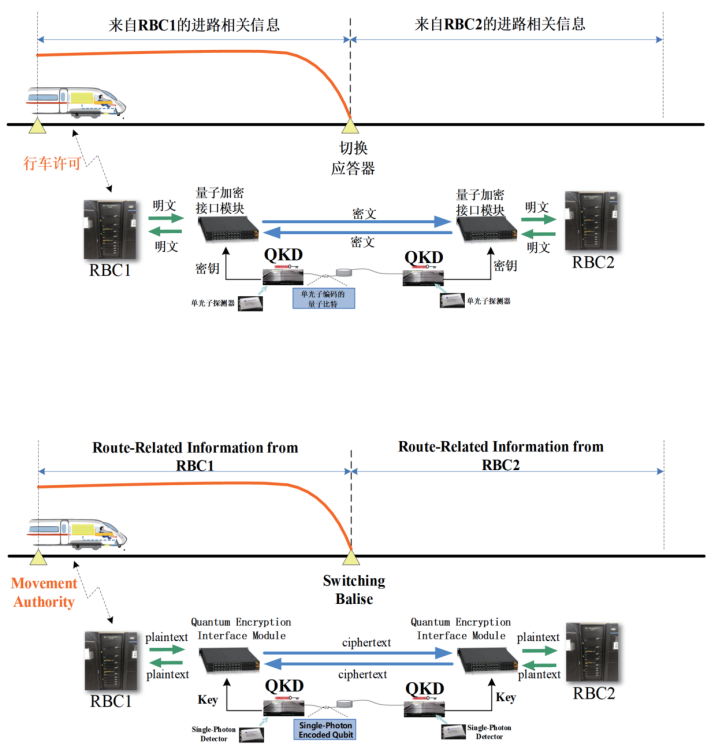
在数智化转型浪潮中，铁路网络安全成为保障运输安全与效率的关键。本项目基于主动安全和自主防御等安全设计方法，构建涵盖数据、应用、主机、网络等多维一体的纵深防御体系，确保铁路列车的安全稳定运行。

Introduction

Amid the wave of digital and intelligent transformation, railway cybersecurity has become a key factor in ensuring transportation safety and efficiency. This project adopts security design approaches such as proactive defense and autonomous protection to build a multi-layered, integrated defense system that spans data, applications, hosts, and networks, ensuring the safe and stable operation of railway trains.

多维一体，打造铁路纵深防御体系
Building a Multi-Dimensional Integrated Defense-in-Depth System for Railways

本项目通过创新融合密码算法、可信度量与密钥全生命周期管理技术，构建了多维一体化防护框架，解决了铁路列控系统终端设备可信能力不足、边界防护策略宽泛以及通信数据加密体系薄弱等核心问题，满足铁路列控系统高安全、高可靠、低延时的行业需求。



量子密钥加密通信机制
Quantum Key-Based Encrypted Communication Mechanism

具体而言，本项目通过以下三方面措施实现上述目标：一是通过安全度量与主机加固等技术协同应用，实现了内核级防护、细粒度访问控制和可信恢复机制，突破传统被动防护模式；二是构建铁路密钥管理中心，率先实现了 SM2/SM3/SM4 密码算法在列控系统通信 GSM-R 及 4G/5G 异构网络下的深度适配，同时引入量子密钥分发机制，实现更高安全等级的加密体系升级；三是打造基于列控网络业务逻辑的铁路专用安全协议（RSSP）过滤防护策略，有效隔离列控系统子网间横向渗透，弥补了列控系统传统物理隔离的不足。

This project integrates innovative cryptographic algorithms, trusted measurement, and full-lifecycle key management technologies to build a multi-dimensional integrated protection framework, addressing core issues such as insufficient trustworthiness of railway train control system terminal devices, broad and ineffective boundary defense strategies, and weaknesses in communication data encryption. It meets the railway train control system requirements for high security, high reliability, and low latency.

Specifically, the project achieves these objectives through three key measures. First, by collaboratively applying trusted measurement and host hardening technologies, it implements kernel-level pro-

tection, fine-grained access control, and trusted recovery mechanisms, thereby breaking through the limitations of traditional passive defense models. Second, the project establishes a Railway Key Management Center, achieving deep adaptation of the SM2/SM3/SM4 cryptographic algorithms for train control system communications over heterogeneous networks such as GSM-R and 4G/5G, while introducing quantum key distribution to upgrade the encryption system to a higher security level. Third, a Railway-Specific Security Protocol (RSSP) filtering and protection strategy is developed based on the business logic of the train control network, effectively preventing lateral movement between train control system subnets and compensating for the limitations of traditional physical isolation.

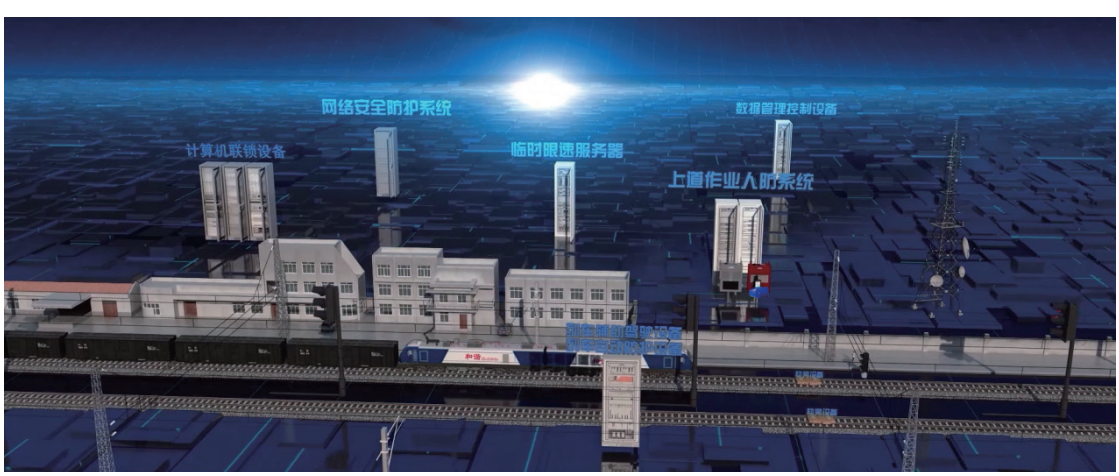
安全赋能，为多制式铁路运输保驾护航
Empowering Security to Safeguard Multi-Modal Railway Operations

本项目成果覆盖高速铁路、重载铁路、磁浮铁路以及海外铁路等多制式铁路线路。项目有效保障人员安全出行年客运量达数亿人次，保障货物安全运输货运量逾数千万吨。通过增强列控系统安全性，有效减少了因网络攻击导致的信号系统故障，从而减少列车晚点、误点和运营安全事故，极大地提升了铁路运输的安全性，以及社会公众出行体验和安全指数。

The outcomes of this project extend across various types of railway systems, including high-speed railways, heavy-haul railways, maglev railways, and international railway lines. The project ensures the safe travel of hundreds of millions of passengers annually and securely transports tens of millions of tons of cargo each year. By enhancing the security of train control systems, it effectively reduces signal system failures caused by cyberattacks, thereby minimizing train delays, schedule disruptions, and operational safety incidents. This has significantly improved the overall safety of railway transportation, while also enhancing the public travel experience and increasing the overall safety index of the railway network.

项目打通了从实验室走向工程化、产业化的关键路径，形成了良好的应用成效和可推广示范。项目成果充分体现出成熟度高、经济效益显著、社会价值突出的特点，为轨道交通网络安全体系建设提供了坚实支撑。该成果可持续支持中国 16 万公里的铁路和 4.8 万公里高速铁路的安全改造。

The project has paved a critical pathway from laboratory research to engineering implementation and industrialization, delivering significant application results and creating demonstrable models for broader adoption. Its achievements highlight a high level of maturity, remarkable economic benefits, and outstanding social value, providing a solid foundation for building a robust cybersecurity framework for the rail transit sector. These outcomes can continuously support the security enhancement and transformation of China's 160,000 kilometers of railway lines, including 48,000 kilometers of high-speed railways.



铁路网络安全应用场景
Railway Cybersecurity Application Scenarios

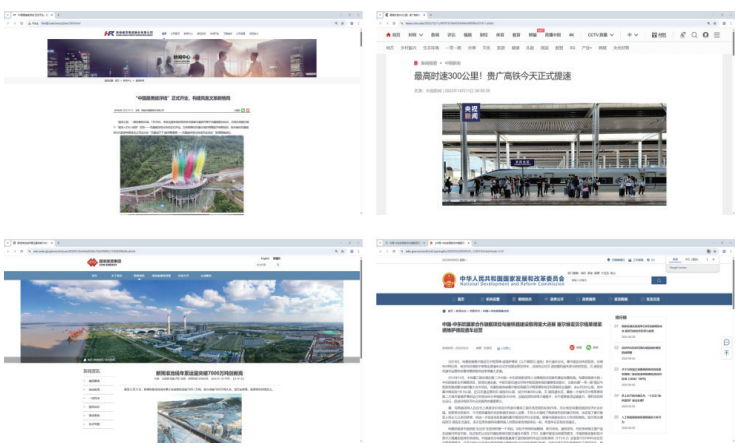
创新融合，构建网络安全协同发展生态
Innovative Integration to Build a Collaborative Cybersecurity Ecosystem

项目依托研发的网络安全防护装备和整体解决方案，已在凤凰磁浮、准池铁路、匈塞铁路、湖杭铁路、贵广铁路等多个实际工程中落地应用，累计带动直接经济效益达数千万元，并有效推动铁路网络安全技术的国际标准化，提升轨道交通行业的全球技术影响力。

The project, leveraging its self-developed cybersecurity protection equipment and integrated solutions, has been successfully implemented in multiple real-world railway projects, including the Fenghuang Maglev Express, Zhunchi Railway, Hungary-Serbia Railway, Huzhou-Hangzhou Railway, and Guiyang-Guangzhou High-speed Railway. It has generated direct economic benefits amounting to tens of millions of RMB and has effectively advanced the international standardization of railway cybersecurity technologies, thereby enhancing the global technological influence of the rail transit industry.

项目成功入选中国工业和信息化部“2024 年网络安全技术应用典型案例名单”，有效推动商用密码、可信计算以及量子通信等新技术在铁路信号领域的深度融合，带动密码芯片、网络安全以及量子科技等上下游产业链协同发展，形成良好产业集群效应。

The project was successfully selected for the Ministry of Industry and Information Technology (China)’s “2024 Typical Cases of Cybersecurity Technology Applications” list. It has effectively promoted the deep integration of emerging technologies—such as commercial cryptography, trusted computing, and quantum communication—into the railway signaling sector. Moreover, it has driven the collaborative development of upstream and downstream industries, including cryptographic chips, cybersecurity, and quantum technology, fostering a robust industrial cluster development.



铁路网络安全应用工程
Railway Cybersecurity Application Project



2024 年网络安全技术应用典型案例
2024 Typical Cases of Cybersecurity Technology Applications



西碳迹 SiTANJI 破局碳管理，多技术建碳足迹视图，数据驱动企业绿色转型

SiTANJI breaks through carbon management bottlenecks, builds carbon footprint visualization with multiple technologies, and drives enterprises' green transformation

西门子西碳迹 - SiTANJI 碳足迹生态解决方案

SiTANJI, AI-Powered Carbon Footprint ECO Portfolios

西门子（中国）有限公司
Siemens Ltd., China

SIEMENS

引言

在全球绿色贸易新格局下，AI 技术正在重塑碳管理模式。西碳迹 SiTANJI 通过融合生成式 AI、数字孪生、区块链等前沿技术，打造智能化碳足迹解决方案，实现从 " 人工核算 " 到 " 智能精算 " 的技术跃迁。依托西门子 Xcelerator 开放式数字商业平台生态，助力企业突破碳数据壁垒，构建全球化绿色竞争新优势。

Introduction

Under the new pattern of global green trade, AI technology is reshaping carbon management models. By integrating cutting-edge technologies such as generative AI, digital twins, and blockchain, SiTANJI has created an intelligent carbon footprint solution, realizing a technological leap from "manual accounting" to "intelligent actuarial calculation". Relying on the Siemens Xcelerator platform ecosystem, it helps enterprises break through carbon data barriers and build new advantages in global green competition.

西碳迹 SiTANJI，AI 赋能的智能碳足迹解决方案
SiTANJI, AI-Powered Carbon Footprint ECO Portfolios

西碳迹 SiTANJI 依托西门子 Xcelerator 开放式数字商业平台，通过 AI 技术与工业领域专业知识的深度融合，实现碳管理智能化重大突破：

基于生成式 AI 技术，创新打造 "AI 碳管家 " 智能服务模块，将碳因子匹配效率跃升至秒级响应；

运用数字孪生技术，构建产品全生命周期碳足迹实时监测系统，助力企业清晰掌握每一个环节的碳排放细节；

依托边缘计算技术，对生产线程碳排放数据进行实时的采集、边缘侧数据预处理，实现碳排放数据的精准量化；

创新应用区块链技术，为供应链各环节的碳数据搭建可信与安全共享的通道，从技术层面解决了碳数据流转中的信任难题；

西碳迹作为首个加入 Catena-X（全球汽车行业可信数据空间）的中国解决方案提供商，其技术示例与行业适配性已在全球标杆项目中验证，获得欧盟工业绿色创新典范认可。

Relying on the Siemens Xcelerator digital business platform, SiTANJI has achieved a major breakthrough in intelligent carbon management through the in-depth integration of AI technology and industrial expertise:

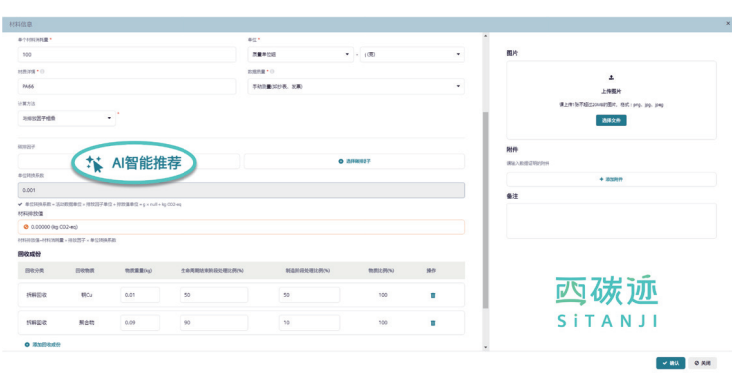
Based on generative AI technology, it has innovatively built the "AI Carbon Steward" intelligent service module, increasing the carbon factor matching efficiency to a second-level response;

Using digital twin technology, it has constructed a real-time monitoring system for the carbon footprint of the entire product life cycle, helping enterprises clearly grasp the carbon emission details of each link;

Relying on edge computing technology, it conducts real-time collection of carbon emission data in production processes and preprocesses data on the edge side, realizing accurate quantification of carbon emission data;

Through the innovative application of blockchain technology, it has built a credible and secure sharing channel for carbon data in all links of the supply chain, solving the trust problem in carbon data circulation from a technical perspective;

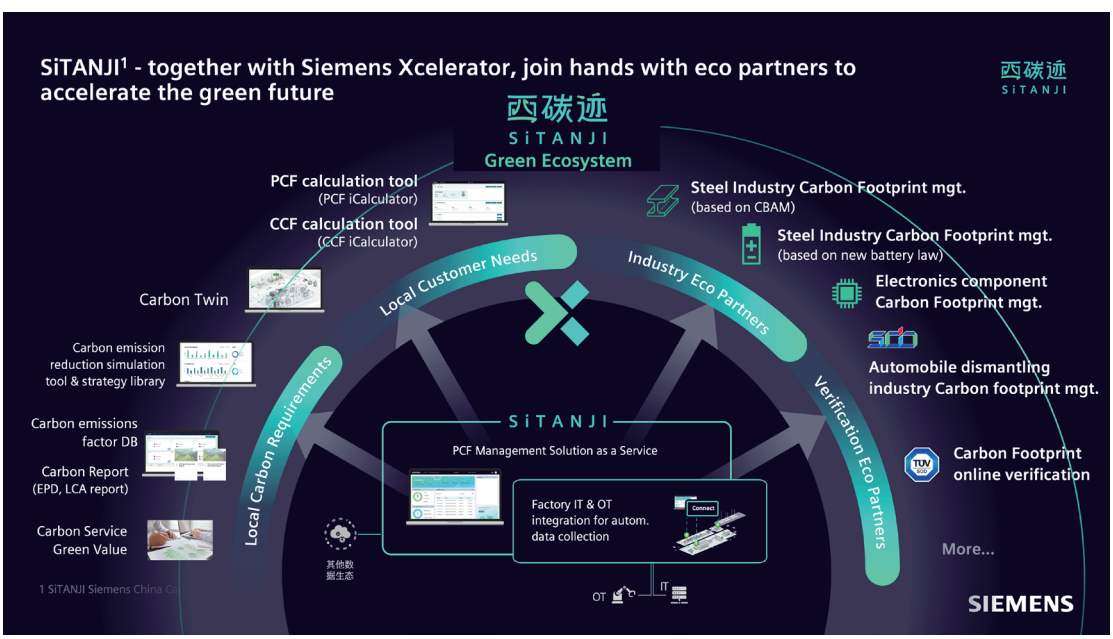
As the first Chinese solution provider to join Catena-X (the European Automotive Industry Data Sharing Alliance), SiTANJI's technical examples and industry adaptability have been verified in global benchmark projects and recognized as a model of EU industrial green innovation.



基于生成式 AI 技术的智能碳管理平台，实时展示产品碳足迹数据分析、碳因子智能匹配、减排路径优化等核心功能，将碳核算效率从小时级降低到分钟级

Based on generative AI technology, the intelligent carbon management platform dynamically displays core functions such as product carbon footprint data analysis, intelligent carbon factor matching, and emission reduction path optimization, reducing carbon accounting efficiency from the hour-level to the minute-level





西碳迹 SiTANJI 基于西门子 Xcelerator 的解决方案架构，依托 AI、数字孪生、区块链等核心技术模块的协同运作，支撑全链条碳足迹管理，并携手与行业合作伙伴、认证机构合作伙伴，全面助力中国企业绿色出海

Based on the solution architecture of the Xcelerator platform, SiTANJI supports end-to-end carbon footprint management by virtue of the collaborative operation of core technology modules such as AI, digital twins, and blockchain. It also joins hands with industry partners and certification institution partners to fully assist Chinese enterprises in their green global expansion

以 AI 驱动数字化创新，构建面向全球的绿色竞争新优势
Drive digital innovation with AI and build new global advantages in green competition

西碳迹 SiTANJI 以 “双轮驱动” 战略融合 AI 与低碳技术，助力和钢集团碳管理效率 40%，帮助宝马供应链碳数据透明度提升。依托西门子 Xcelerator，推进中小企业智能化 SaaS 服务，与海智在线合作助 70 万家工厂数字化转型，携手亚马逊云科技联合发布气候友好承诺认证碳中和绿标直通车服务，一站式助力企业绿色出海。

SiTANJI integrates AI and low-carbon technologies through its "dual-drive" strategy, serving over 1,000 enterprises in sectors such as iron and steel, and automotive. It has helped HBIS Group increase carbon management efficiency by 40% and significantly enhanced the transparency of carbon data in BMW's supply chain. Based on the Xcelerator platform, SiTANJI provides intelligent SaaS services for small and medium-sized enterprises; in collaboration with Haizhi Online, it assists 700,000 Chinese factories in their digital transformation. Meanwhile, it has jointly developed climate-friendly certification services with Amazon to empower enterprises in their green global expansion.

西碳迹依托在西门子 Xcelerator 上构建的全球合作生态，包括 Catena-X、TfS 等国际组织，以及覆盖认证、咨询、技术等领域的生态伙伴。目前已在汽车、电池、钢铁、化工、电子元器件、通信、轮胎、家居、药材、食品饮料等众多行业千余家客户中落地实践。

SiTANJI relies on the global cooperation ecosystem built on the Xcelerator platform, which includes international organizations such as Catena-X and TfS, as well as ecosystem partners covering fields like certification, consulting, and technology. Currently, its solutions have been implemented in over 1,000 client enterprises across numerous industries, including automotive, batteries, iron and steel, chemicals, electronic components, communications, tires, home furnishings, medicinal materials, and food and beverages.





西碳迹依托西门子 Xcelerator 构建全球合作生态，落地包括千余家多行业客户

SiTANJI leverages Xcelerator to build a global cooperative ecosystem, with its solutions implemented by over 1,000 clients across multiple industries

西门子 2024 年与赛迪研究院联合发布《“碳” 索之路》系列，深度剖析全球绿色监管对企业国际化的影响；同时携手信通院，基于西碳迹构建可信碳数据计算与交换基石，加速中国企业绿色出海。

In 2024, Siemens jointly released the "Path of Carbon Exploration" series with the China Center for Information Industry Development (CCID), deeply analyzing the impact of global green regulations on enterprises' internationalization. At the same time, Siemens has joined hands with the China Academy of Information and Communications Technology (CAICT) to build a credible foundation for carbon data calculation and exchange based on SiTANJI, accelerating the green global expansion of Chinese enterprises.



2024 年工博会企业绿色出海深度洞察报告 2.0 版本发布，2025 年工博会本报告 3.0 版本即将发布

The 2.0 version of the In - depth Insights Report on Enterprises' Green Overseas Expansion was released at the 2024 China International Industry Expo, and the 3.0 version of this report will be released at the 2025 China International Industry Expo

打造数智化绿色生态，链接中国产能与全球市场
Build a digital and intelligent green ecosystem, and connect China's production capacity with global markets

西碳迹 SiTANJI 依托西门子 Xcelerator 强大生态，构建跨境碳数据交换网络，通过 AI 技术创新，推动 Catena-X 全球汽车产业链绿色转型；符合 TfS 化工行业标准，实现数据智能采集，帮助国际客户降低 40% 运营成本。携手生态伙伴打造智能化碳足迹认证新模式，获评上海气候周的 China ESG Alliance024 十大最值得关注的气候技术名单。

Relying on the robust ecosystem of the Xcelerator platform, SiTANJI has built a cross-border carbon data exchange network. Through AI technology innovation, it promotes the green transformation of the global automotive industry chain under Catena-X. By connecting to the TfS chemical industry standards, it enables intelligent data collection, helping international clients reduce operating costs by 40%. SiTANJI has also joined hands with ecosystem partners to create a new model of intelligent carbon footprint certification, and was awarded as one of the "Top 10 Most Notable Climate Technologies in 2024".

基于西碳迹的碳管理与追溯功能，西门子在 2024 年进博会期间分别与四方维公司、欣旺达电子股份有限公司联合发布共创解决方案，推出针对电子元器件及电池行业的算碳模版，助其客户快速实现产品碳足迹的计算、溯源、透明化以及碳足迹的国际认证。其中，西碳迹 — 欣旺达联合解决方案将支持欣旺达电池护照平台电池产品碳数据的全生命周期核算。此外，西门子还将与上海海智在线网络科技有限公司发布绿色出海联合解决方案，关注非标零部件领域，助力中小企业实现高效生产与绿色发展。

Leveraging the carbon management and traceability functions of SiTANJI, Siemens jointly released co-created solutions with Supply-

frame Co., Ltd. and Sunwoda Electronic Co., Ltd. respectively during the 2024 China International Import Expo (CIIE). These solutions include carbon calculation templates tailored for the electronic components and battery industries, helping their customers quickly realize the calculation, traceability, transparency of product carbon footprints as well as international carbon footprint certification. Among them, the SiTANJI-Sunwoda joint solution will support the full-life-cycle accounting of carbon data for battery products on Sunwoda's Battery Passport Platform. In addition, Siemens will also release a joint green global expansion solution with Shanghai Haizhi Online Network Technology Co., Ltd., focusing on the non-standard parts sector to assist small and medium-sized enterprises (SMEs) in achieving efficient production and green development.



西门子在 2024 年进博会期间分别与四方维、欣旺达联合发布共创解决方案

During the 2024 China International Import Expo, Siemens jointly released co - creation solutions with Supplyframe Co., Ltd. and Sunwoda Electronic Co., Ltd. respectively



在第二届中国国际供应链促进博览会上，西门子携手亚马逊云科技发布“西门子西碳迹 - 亚马逊电商气候友好承诺认证 SCS 碳中和绿标直通车”，赋能中国制造业绿色出海

At the 2nd China International Supply Chain Promotion Expo, Siemens, in collaboration with Amazon Web Services (AWS), launched the "Siemens SiTANJI - Amazon E-commerce Climate Pledge Friendly Certification SCS Carbon Neutrality Green Label Direct Access" initiative, empowering China's manufacturing industry in its green global expansion

深耕本土创新生态，引领智能低碳产业新未来
Deeply cultivate the local innovation ecosystem and lead the new future of the intelligent and low-carbon industry

西碳迹持续深化 AI 技术创新，基于西门子 Xcelerator 打造本土化绿色解决方案。与亚马逊、TÜV 南德等国际伙伴共建智能认证体系；携手用友等伙伴开发 AI 驱动的绿色制造方案，优化企业能效投入；创新实践入选联合国气候大会 COP29 展示案例，并获得全球多项奖项。

SiTANJI continues to deepen AI technology innovation and build localized green solutions based on the Xcelerator platform. It has jointly established an intelligent certification system with international partners such as Amazon and TÜV SÜD; collaborated with partners including UFIDA to develop AI-driven green manufacturing solutions, optimizing enterprises' energy efficiency input; its innovative practices have been selected as a showcase case at the UN Climate Change Conference COP29 and won multiple global awards.



西门子西碳迹作为行业领先的双碳践行者，始终致力于为出海企业提供最优的碳足迹解决方案，助力企业加速实现数字化、低碳化转型。在可持续发展领域，西碳迹 SiTANJI 已持续获得行业和媒体的高度认可

As an industry-leading practitioner in the dual-carbon goal, Siemens SiTANJI has always been committed to providing the optimal carbon footprint solutions for enterprises going global, helping them accelerate digital and low-carbon transformation. In the field of sustainable development, SiTANJI has continuously received high recognition from the industry and media





2024 年世界互联网大会乌镇峰会“互联网之光”博览会上发布“智算琢光”GSE-DPU 芯片
The "Zhi Suan Zhuo Guang" GSE-DPU chip was unveiled at the "Light of the Internet" Expo during the 2024 World Internet Conference

新一代 AI 驱动的基础电信网络 APT 监测防护的关键技术研究及应用

Research and Application of Key Technologies for Next-Generation AI-Driven APT Detection and Protection in Fundamental Telecommunications Networks

中国移动通信集团有限公司
China Mobile Communications Group Co., Ltd.

中移（杭州）信息技术有限公司
China Mobile (Hangzhou) Information Technology Co., Ltd.

浙江大学
Zhejiang University

北京神州绿盟科技有限公司
NSFOCUS Information Technology Co. Ltd.

引言

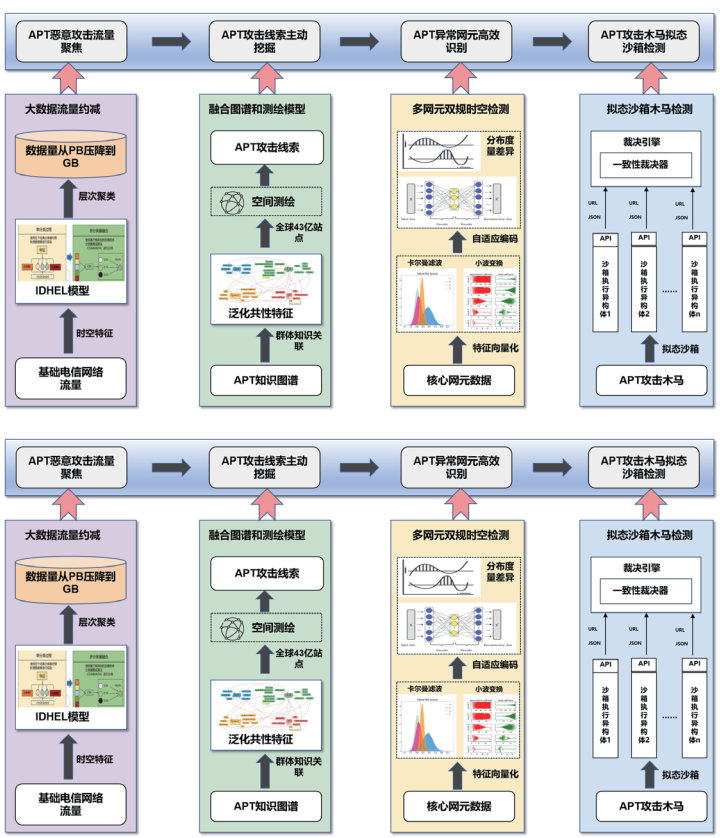
高级持续性威胁（APT）攻击以窃取高价值核心机密、破坏关基设施等为目标，严重危害全球网络空间安全。本成果历时 7 年，构建了全球领先的智能基础电信网络 APT 监测防护体系，有效助力全球网络空间安全治理。

Introduction

Advanced Persistent Threat (APT) attacks aim to steal high-value secrets and disrupt critical infrastructure, posing a grave threat to global cyberspace. After seven years of dedicated research, this achievementhas successfully established a world-leading intelligent APT detection and protection system for foundational telecommunications networks, significantly enhancing global cyberspace governance.

AI 驱动 APT 攻击精准感知，加速全球防护体系升级
AI-Driven Precision Detection of APT Attacks, Accelerating the Upgrade of Global Defense Systems

本成果突破单节点防护无法应对多向量组合攻击的局限，成功构建全球领先的智能基础电信网络 APT 监测防护体系，100% 覆盖核心网、信令网等多层网络，实现从单点防御到体系作战质的升级。在此基础上，创新提出面向超大规模复杂流量的高级威胁智能检测技术，实现对 APT 威胁从生成到扩散的全链路预测与主动干预，具备毫秒级响应能力。该技术依托运营商级流量层次聚类约减，在 PB 级流量中对微弱 APT 攻击特征进行逐级聚焦与提纯，并结合多网元双规时空检测机制强化异常刻画，识别准确率达 95%。同时构建具备持续学习与自演化能力的拟态多模裁决技术，有效识别非预设木马攻击模式，溯源准确率提升至 96%，总体技术达到国际领先水平，对全球 APT 监测防护技术演进具有借鉴意义。



面向超大规模复杂流量的高级威胁智能检测技术
Intelligent detection technology for advanced threats in massive-scale and complex traffic

This achievement transcends the limitations of single-node defense against multi-vector attacks by successfully establishing a world-leading intelligent APT detection and protection system for fundamental telecommunications networks. It provides 100% coverage across multi-layer networks, including core and signaling networks, realizing a qualitative leap from isolated defense to coordinated, system-wide operations. Building on this, the project pioneers an intelligent detection technology for advanced threats within massive-scale, complex traffic, enabling full-lifecycle prediction and proactive intervention against APT threats from generation to proliferation, with millisecond-level response capabilities. This technology leverages carrier-grade, hierarchical clustering for traffic reduction to progressively focus on and purify faint

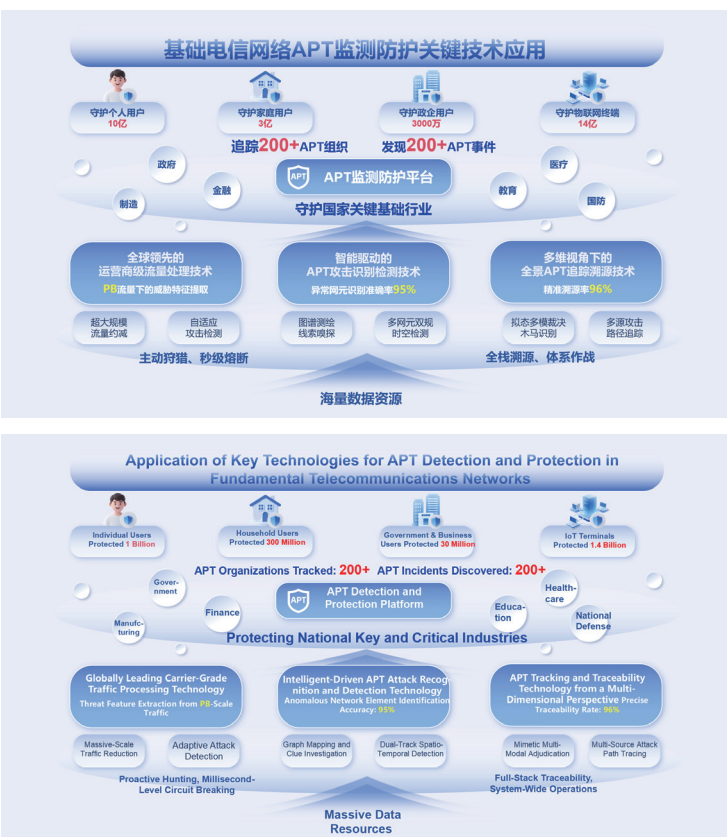
APT attack signatures within petabyte-scale traffic. Combined with a dual-track, spatio-temporal detection mechanism across multiple network elements to enhance anomaly characterization, it achieves a 95% identification accuracy rate. Furthermore, the project developed a mimetic multi-modal adjudication technology with continuous learning and self-evolution capabilities, which effectively recognizes non-predefined Trojan attack patterns and boosts traceability accuracy to 96%. The overall technology is rated as "internationally leading," offering significant reference value for the evolution of global APT detection and protection technologies.

助力全球网络空间安全治理，促进数字经济健康发展
Contributing to Global Cyberspace Governance, Fostering the Healthy Development of the Digital Economy

本成果充分发挥运营商网络在规模、技术与安全能力上的综合优势，面向全球开放 APT 监测与防护能力，积极践行“共享 + 共治”协同模式，形成高效联动、优势互补的国际合作格局，建立可复制、可推广的行业示范模式，已在巴基斯坦、巴西、阿联酋等全球 9 个国家和地区应用，为超 10 亿个人用户、3 亿家庭用户、3000 多万政企用户提供智能、高效的网络安全防护，发现并处置数百起重大 APT 攻击事件，有效避免经济损失上亿元。

同时，本成果积极落实全球“双碳”战略，联合全球合作伙伴共同构建绿色、低碳、可持续的网络安全新生态，发现并清除 11 万台被控主机上的“挖矿”木马，累计减少碳排放 3.64 亿吨，切实推动全球网络安全与生态文明建设深度融合。

This achievement fully leverages the comprehensive advantages of carrier-grade networks in scale, technology, and security. Making its APT detection and protection capabilities available globally, it actively practices a "share + co-govern" collaborative pattern, forming an international cooperation framework of efficient coordination and complementary strengths. It has established a replicable and transferable industry demonstration model that has been deployed in 9 countries and regions, including Pakistan, Brazil, and the UAE. The system provides intelligent and efficient cybersecurity protection for over 1 billion individual users, 300 million household users and more than 30 million government & business users, having detected and neutralized hundreds of major APT attacks and prevented economic losses in the hundreds of millions of RMB. Concurrently, this project actively implements the global "dual-carbon" strategy. In collaboration with global partners, it contributes to building a green, low-carbon and sustainable new cybersecurity ecosystem. It has detected and removed crypto-mining malware from 110,000 infected hosts, culminating in a reduction of 364 million tons of carbon emissions, tangibly advancing the deep integration of global cybersecurity with ecological civilization.



基础电信网络 APT 监测防护关键技术应用
Application of key technologies for APT detection and protection in fundamental telecommunications networks

引领全球治理格局，树立网络安全防护新典范
Leading the Global Governance Landscape, Setting a New Benchmark for Cybersecurity Defense

本成果在国际标准化、学术研究和产业应用等多维度均取得了显著突破。牵头主导国际标准 1 项，发表 10 余篇国际高水平论文，并应邀作为主讲嘉宾在 ACM SIGCOMM、IEEE INFOCOM 等全球顶级学术会议上进行现场汇报，获得国际同行高度认可，推动了网络安全前沿研究的发展。

在产业合作与国际交流方面，团队受邀参加“中巴信息技术产业联合工作组网络安全小组”工作会议，分享通信网络中基于 AI+ 的安全创新实践经验，为全球网络安全治理提供了可落地的技术方案和示范案例。

此外，本成果连续多年入选全球权威IT研究与分析机构Gartner发布的《全球威胁情报产品与服务市场指南》，并被评为威胁情报产品与服务标杆供应商，充分体现了技术实力与市场影响力的双重认可。



部分标准、获奖、论文、专利及软著情况
A selection of standards, awards, papers, patents and software copyrights



受邀多次参加国际会议，分享网络安全创新实践
Invited to multiple international conferences to share innovative cybersecurity practices

This achievement has made significant breakthroughs across multiple dimensions, including international standardization, academic research, and industrial application. It has spearheaded one international standard and published over ten high-impact international papers. The team was invited as keynote speakers to present at top-tier global academic conferences such as ACM SIGCOMM and IEEE INFOCOM, receiving high recognition from international peers and advancing the frontiers of cybersecurity research.

In terms of industrial cooperation and international exchange, the team was invited to the "China-Pakistan Information Technology Industry Joint Working Group on Cybersecurity" meeting to share innovative practices in AI-powered security for telecommunication networks, providing implementable technical solutions and demonstration cases for global cybersecurity governance.

Furthermore, this achievement has been featured for consecutive years in Gartner's "Market Guide for Threat Intelligence Products and Services," where it was recognized as a benchmark supplier. This reflects a dual endorsement of its technical strength and market influence.





提出全调度以太网（GSE）技术，首创基于报文容器（PKTC）的负载均衡技术，引入动态全局调度队列（DGSQ）和“Pull”模式信令机制

Proposing Fully-Scheduled Ethernet (GSE) technology, it pioneers a load balancing technique based on Packet Container (PKTC) and introduces a Dynamic Global Scheduling Queue (DGSQ) along with a "Pull"-mode signaling mechanism

通过全栈技术突破引领国际标准并推动产业结构重构
Through full-stack technological breakthroughs, leading international standards and driving industrial restructuring

技术制高点：首创 OISA/GSE 技术体系，攻克超大规模集群通信瓶颈，卡间带宽提升 14 倍；异构混训技术实现千卡训练效率达理论极限 95%，推动 15 个大模型落地；主导成立 IETF 近 20 年唯二中国工作组（CATS），制定 169 项国际标准。

产业链重构：纵向整合芯片 / 光模块等 100 余家企业，激活千亿级产业链；组建 40 余家“政产学研用”联合体，中国三大运营商联合发布行动计划；算网资源利用率提升 37.5%，年节电超 500 万度，驱动绿色集约转型。

Technological High Ground: Pioneered the OISA and GSE technology framework, overcoming communication bottlenecks in hyper-scale clusters and boosting inter-card bandwidth by 14 times, achieved 95% theoretical limit in training efficiency for thousand-card heterogeneous mixed training, enabling 15 large models to go live, spearheaded the establishment of CATS—one of only two Chinese IETF working groups in nearly 20 years—and formulated 169 international standards.

Industrial Chain Reconstruction: Vertically integrated over 100 enterprises including chip and optical module manufacturers, activating a hundred-billion-level industrial chain; formed over 40 “government-industry-academia-research-application” consortiums, with China's three major telecom operators jointly releasing action plans, increased computing and networking resource utilization by 37.5%, saving over 5 million kWh annually, driving green and intensive transformation.



启动智算开放互联 OISA 生态共建战略合作，发布 OISA 2.0 协议

Initiating the strategic collaboration for the co-construction of the Open Intelligent Computing Interconnection Architecture (OISA) ecosystem, the OISA 2.0 protocol was officially released