

The Organic Integration of Autonomous Driving, Internet of Things and Intelligent Mechanical Equipment

Wang Mingpei

College of Engineering, China Agricultural University, Haidian District, Beijing, China, 100083

1984522272@qq.com

Abstract

Building a comprehensive collaborative system integrating autonomous driving, Internet of Things (IoT), and intelligent mechanical equipment to achieve a closed-loop interaction of "perception - decision-making - execution - feedback", this approach aims to overcome the limitations of individual technologies in complex scenarios and establish a reusable cross-domain collaboration model. This will provide efficient, safe, and green intelligent solutions for smart industries, agriculture, infrastructure, and other fields. This research focuses on the organic integration of autonomous driving, IoT, and intelligent mechanical equipment, discussing the integration of single, dual, and multiple directions. It reviews relevant literature from the past five years, summarizes the convergence points in autonomous driving and IoT, the compatibility between IoT and intelligent mechanical equipment, and the connection points between autonomous driving and intelligent mechanical equipment. It analyzes the current research status in these fields and proposes a comprehensive road map for better realization and completion of the perception-decision-execution process, as well as a vision for the future development of this area. The goal is to comprehensively summarize existing articles and build upon the achievements of previous researchers to think towards higher goals.

Keywords: Autonomous Driving; Internet of Things; Intelligent Mechanical Equipment; Perception-Decision-Execution; Dynamic Weight Allocation Algorithm

1. Introduction

1.1 Research Background:

The organic integration of autonomous driving, the Internet of Things (IoT), and intelligent mechanical equipment can achieve the reengineering of production processes to reshape industrial efficiency paradigms and enhance productivity in extreme environments. Moreover, it can drive technological paradigm shifts, implement embodied intelligent production lines, and enable multi-agent collaborative evolution, compressing traditional hours-long processes to minutes. Most importantly, it can reshape high-risk scenarios by replacing human labor with safety and sustainability in mind and precisely allocate resources.

1.1.1 Broad Context: The Convergence of Global Industrial Transformation and National Strategy Upgrades

The joint issuance of the "Digital Transformation Implementation Plan for the Machinery Industry" by eight departments including the Ministry of Industry and Information Technology ^[1] indicates that the global manufacturing industry is undergoing profound changes centered on digitalization, intelligence, and networking. Autonomous driving, IoT, and intelligent mechanical equipment, as core carriers of new-generation information technology, are driving profound changes in transportation, communication, and manufacturing. However, in complex scenarios such as smart mines, digital farms, and flexible factories, no single technology can effectively address the challenges of dynamic and unstructured environments. In recent years, both the academic and industrial communities have gradually recognized that the organic integration of these three technologies to form a "perception-decision-execution" closed-loop system is the inevitable path to achieving system-level intelligence. In this round of competition, autonomous driving technology is penetrating from the transportation sector into industrial scenarios, IoT is achieving interconnection of billions of devices, and intelligent mechanical equipment is becoming the execution terminal in the physical world - the integration of the three marks the leap from "single-point automation" to "system autonomy" in industrial production.

1.1.2 Narrow Context: Current Focus

Currently, a large number of studies focus on the combination of two technologies, such as autonomous driving and mechanical equipment, IoT and mechanical equipment, etc., but there is still a lack of systematic reviews on the intrinsic logic, technical paths, and core challenges of their synergy. This paper aims to review the research status of the two-by-two integration and system-level collaboration of autonomous driving, IoT, and intelligent mechanical equipment, deeply analyze the key scientific issues and technical bottlenecks, and look forward to the development direction of future integrated intelligent systems.

1.2 Review of Domestic and International Research Status:

With the inclusion of intelligent connected technology in China's "14th Five-Year Plan" for strategic emerging industries, and the establishment of artificial intelligence innovation experimental zones in Shanghai, Beijing, and other places, as well as the signing of the "Embodied Intelligent Equipment Operation Robot Platform" project between the Hongkou District Government and Dianze Intelligent, which focuses on breaking through the general-purpose barriers of equipment and adapting to various industrial, logistics, and agricultural machinery through algorithm switching, the importance and feasibility of organic integration have become more prominent. Research in the domestic field mainly focuses on three major directions: industrialization of embodied intelligent models, multi-agent collaborative control, and enhanced human-machine interaction safety. The application scenarios of these three major directions are slightly different, and they are continuously achieving industrial application from demonstration scenarios to large-scale promotion as development progresses.

The current research status and frontier exploration in the international field are related to ecological competition and cooperation, but the research areas in different countries vary. Most studies focus on bionic robots and humanoid robots in service scenarios. There are also studies on generating AI to build intelligent agent systems and optimization models for the entire chain of planning, production, and operation, as well as swarm control algorithms. Currently, the frontier research of enterprises and teams focuses on three aspects: world models and simulation platforms, open-source operating systems, swarm intelligence and brain-like computing. The organic integration of autonomous driving, IoT, and intelligent mechanical equipment can be extended to multiple application scenarios such as special operations, precision agriculture, and medical collaboration.

1.2.1 Recent Key Technology Synergies Have Spawned Solutions:

- (1) Autonomous Driving + Mechanical Equipment: By fusing multi-source heterogeneous perception (LIDAR/IMU/cameras), full-time and all-domain positioning capabilities are constructed. 1. The DC-200 domain control terminal ensures continuous operation of intelligent snow removal vehicles in an environment ranging from -40°C to 85°C and achieves offline path planning through 100TOPS computing power. The EACON InterlliDrive mining truck realizes 24-hour unmanned transportation, increasing the daily operation time to 11 hours.
- (2) Internet of Things + Cluster Collaboration: Based on the cloud-edge-device computing power collaborative architecture, 30 unmanned mining trucks were deployed in the Xinjiang Er Mine project, and the transportation efficiency was increased by 30% through cloud scheduling. The Web/APP dual-end control system of Chengxin Zhilian realizes the "one person controlling multiple devices" Red Alert-style command mode.
- (3) AI Large Models + Equipment Intelligence: Industrial large models are embedded in equipment terminals. For example, through small sample learning to optimize inspection algorithms, the defect recognition accuracy in the power scene is increased to 99.2%.

1.3 Research Methods

This paper intends to adopt the literature analysis method to sort out the research status of three types of technologies (Internet of Things, mechanical intelligent equipment, and autonomous driving), summarize the theoretical gaps and technical bottlenecks in cross-domain collaboration (such as communication protocol compatibility, differences in data semantic understanding, real-time collaborative decision-making mechanisms, etc.), and provide theoretical basis and technical references for subsequent architecture design.

2. Research Content

This project intends to start with several sub-arguments of the organic unity of autonomous driving, the Internet of Things (IoT), and mechanical intelligent equipment, and conduct an analysis and review around their organic unity. It has sorted out the cutting-edge papers and materials in recent years and proposed the formation of an independent and

controllable technology system to break away from the dependence on foreign technologies in a single field and provide a "Chinese solution" for global intelligent equipment collaboration.

2.1 The Combination of Autonomous Driving and Mechanical Intelligent Equipment

Intelligent mechanical automation technology is a key technology covering multiple disciplines and plays a significant role in numerous application fields such as autonomous driving vehicles. With the continuous advancement of science and technology, intelligent mechanical automation technology will continue to achieve new developments. In the future, more advanced sensor technologies, more powerful computer hardware, and smarter algorithms will drive the application scope of intelligent mechanical automation technology to expand continuously, enabling it to achieve autonomous operation through perception, data processing, decision-making, and control capabilities. [2] Essentially, the relationship between the two is not distant. In other words, research in a single aspect may lead to technological inventions and discoveries, but the combination of the two can achieve a qualitative leap. Machines themselves cannot communicate and interact, but the interaction between machines becomes particularly important. It helps avoid collisions and promotes efficient workflow of equipment. Automated machines can enhance operational safety in dangerous environments and eliminate accidents caused by human errors. Secondly, compared to human operators, automated machines can perform repetitive tasks more efficiently and accurately. [3]

2.2 The Combination of IoT and Mechanical Intelligent Equipment

Compared to the relationship between autonomous driving and mechanical intelligent equipment, the connection between IoT and mechanical intelligent manufacturing has some gaps. The former has a more direct correlation, while the latter requires crossing the decision-making layer to directly enter the execution stage, and the technologies and engineering required to complete this step are even more complex, with frequent information reading and output. IoT, through various sensors (light-sensitive, heat-sensitive, etc.), wireless communication technologies, big data analysis, and artificial intelligence algorithms, mainly play an auxiliary role or the role of intelligent monitoring, remote control, and autonomous decision-making in mechanical intelligent equipment. The remote monitoring system based on IoT technology can use wireless communication networks to achieve real-time location tracking, operation status monitoring, and fault warning of agricultural machinery, ensuring that agricultural machinery can work collaboratively efficiently. [4]

2.3 The Combination of Autonomous Driving and IoT

Compared to the above two combinations, the relationship between autonomous driving and IoT is particularly important, as it involves information collection and analysis processing. Through means such as artificial intelligence algorithms, important information from sensors (such as images) is extracted, and clear information is obtained through big data processing and then input into the execution components for execution. The application of intelligent communication technology in electric vehicles has significantly improved driving safety and traffic efficiency. Take the Internet of Vehicles technology as an example. The vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) systems based on short-range wireless communication can achieve real-time interaction of dynamic information. Specifically, the dedicated short-range communication (DSRC) system based on the IEEE 802.11p protocol has the characteristics of low latency and high reliability, and can effectively transmit core data such as the real-time position, speed, and heading of vehicles; while the LTE-V2X solution based on cellular networks achieves wider network coverage and higher data transmission rates through the existing mobile communication architecture, making it possible to issue danger warnings under non-line-of-sight conditions.

In terms of road infrastructure, intelligent transportation systems can push important information such as traffic signal status, road abnormal conditions, and congestion warnings in real time through two-way communication with on-board terminals. Typical application scenarios include adaptive signal control systems that can dynamically adjust timing schemes based on traffic density, and emergency rescue vehicles can obtain priority passage rights through dedicated communication channels. The collaborative application of these technologies not only expands the driver's perception range, eliminating safety hazards caused by visual blind spots, but also provides drivers with longer emergency response time through early warnings, thereby effectively reducing the accident rate and improving road traffic conditions. Empirical studies have shown that the promotion and application of such technologies have a significant effect on alleviating traffic congestion and enhancing the operational efficiency of the road network.

3. System-level Synergy

3.1 Industrial Upgrading: Promoting the Deep Integration of Manufacturing and Transportation

The unification of the three has broken down the industry barriers between traditional manufacturing (mechanical equipment) and intelligent transportation (autonomous driving), giving rise to a new industrial ecosystem of "mobile operation units + IoT-enabled real-time monitoring system + specialized equipment". For instance, in smart factories, the synergy between autonomous driving AGVs, robotic arms, and IoT monitoring systems has driven the transformation of the production model from "fixed production lines" to "flexible full-domain production", accelerating the implementation of Industry 4.0.

3.2 Technological Breakthroughs: Solving Common Challenges in Cross-domain Synergy

Breaking through the bottleneck of "heterogeneous data fusion", providing a reusable federated learning framework for cross-industry data sharing; constructing "dynamic weighting algorithms" and "synergy intelligence evaluation systems", providing quantitative standards for the performance assessment of multi-agent systems, and promoting the evolution of artificial intelligence from "single-machine intelligence" to "collective intelligence".

3.3 Social Value: Supporting Extreme Scenarios and Sustainable Development

In dangerous scenarios such as mines and polar regions, unmanned collaboration can replace high-risk manual operations, ensuring life safety; precise operations in agriculture and construction (such as on-demand irrigation and material transportation) reduce resource waste, contributing to the realization of the "dual carbon" goals and promoting the transformation of society towards a "highly efficient, green, and safe" intelligent form.

The organic unification of the three is the core indicator of future intelligent equipment competitiveness. Its technological breakthroughs can support China in forming an independent and controllable technology system in fields such as smart manufacturing and intelligent transportation, reducing reliance on foreign technologies in a single domain, and providing a "Chinese solution" for global intelligent equipment collaboration.

4. Suggestions

Under the background of global supply chain restructuring, China's manufacturing industry faces dual challenges: the decline of the demographic dividend has pushed up labor costs, while the "double squeeze" of high-end manufacturing returning to Europe and America and low- and medium-end manufacturing shifting to Southeast Asia has intensified.

Currently, mechanical intelligence faces three core contradictions:

- (1) Perception and decision-making separation: The positioning of equipment is ambiguous (e.g., no GPS in underground pipelines), and decision-making is sluggish (response delay > 500ms), resulting in insufficient adaptability of intelligent equipment such as intelligent road rollers in complex scenarios.
- (2) Data silos: The communication protocols of equipment within factories are heterogeneous, with 30% of CNC machines unable to directly connect to MES systems, and the data intercommunication rate of the supply chain is less than 15%.
- (3) Cost constraints: The cost of digital transformation for small and medium-sized enterprises accounts for 8% to 10% of revenue, far exceeding the threshold of 3% to 5%.

To address the problems of information delay, ambiguous positioning, and weak adaptability caused by the separation of perception and decision-making, it is necessary to enhance the transmission and perception of information interconnection from the following aspects. Firstly, dynamic weighting algorithms should be developed to effectively allocate the weights of various sensors used in each sub-process in terms of usage frequency and times, enabling important steps to respond more quickly. Secondly, AI large models should be utilized for assessment and prediction and to organize relevant data, providing a better theoretical support basis for better resource weight allocation and more intuitively demonstrating the importance of solving information delay.

Experimental path: Based on the above-mentioned practical difficulties, it can be analyzed that to solve the problem of perception separation, non-specific situations should be handled first, and then structural adjustments should be made to the adaptability to different scenarios. Secondly, regarding the problem of data silos in information transmission, which has long been a concern, the proposal of blockchain and various attempts have established interconnections. Nowadays, cloud transmission and various secure, stable, efficient, and convenient transmission methods can nearly adapt to and solve the problem of data silos. Finally, regarding the issue of cost constraints, this has always been the most difficult problem for small and medium-sized enterprises to solve. Fundamentally, it can be said to be deeply rooted. Because

small and medium-sized enterprises are not large in scale, they will not choose to replace expensive production lines in pursuit of profits. Instead, they tend to prefer cost-effective, inexpensive, and time-saving methods. Small and medium-sized enterprises mostly survive by selling in large quantities or having high individual order prices. However, investing in a machine that can change all the funds, with a low return cycle and high price, and the inability to effectively ensure the integrity of the capital chain, etc., for this reason, we should focus on cost-effective and labor-saving aspects. Because in the future, as people's consumption levels and capabilities increase, basic wages and workers' wages will rise. Updating equipment is undoubtedly the best way to hedge against the increase in workers' wages.

5. Conclusion

This paper systematically reviews the research status of the two-way integration of autonomous driving, the Internet of Things, and mechanical intelligent equipment, as well as their system collaboration. The analysis shows that bilateral integration has made significant progress in specific scenarios, but moving towards the organic unity of the three still faces fundamental challenges such as system architecture, collaborative decision-making, and data communication.

Future research can be deepened in the following directions: First, explore intelligent collaborative algorithms, such as dynamic weight allocation mechanisms, to achieve adaptive collaboration among multiple intelligent agents in complex scenarios; second, establish unified performance measurement standards to guide system optimization; third, develop cross-domain privacy protection technologies, such as federated learning frameworks, to release data value while ensuring data security. Ultimately, by addressing these challenges, it is expected to achieve a paradigm shift from "tool intelligence" to "system intelligence", providing truly efficient, safe, and green solutions for smart industries, agriculture, and other fields.

REFERENCES

- [1] "Implementation Plan for Digital Transformation of the Machinery Industry" Ministry of Industry and Information Technology, China Unicom Notice [2025] No. 152
- [2] Wang Yue. Research on the Impact of Experiential Interaction Interface for Autonomous Driving Vehicles on Unprotected Left Turns on Driving Behavior [D]. Beijing University of Civil Engineering and Architecture, 2023.
- [3] Chen Nengsong. How Far Are Construction Machinery from Autonomous Driving Operations? - Insights from the Volvo Construction Equipment Sweden Headquarters Exploration Forum [J]. Construction Machinery Technology and Management, 2016, 29(09): 30-31.
- [4] Qin Shifan, Lan Wenjun, Chang Mengge. Design of an Intelligent Control System for Agricultural Machinery Based on the Internet of Things [J]. China Agricultural Machinery & Equipment, 2025, (06): 1-3.
- [5] Wang Chendong, Liu Chang. Research on the Deployment Plan for End-to-End Autonomous Driving Large Models [J]. Automotive & Safety, 2025, (06): 60-65.
- [6] Chen Zexin. Application and Development of AI Large Models in the Field of Intelligent Connected Vehicles from a Patent Perspective [J]. Automotive Manufacturing, 2025, (03): 12-16.
- [7] Zhang Guangqian. Research on Multi-modal Fusion Detection under BEV for Autonomous Driving [D]. Chongqing Jiaotong University, 2024.
- [8] Shen Zixiang, Sun Xunhong, Cong Yongzheng, et al. Research on Multi-AMR Scheduling Algorithm Based on Spatiotemporal Conflict and Nonholonomic Constraints [J]. Control and Decision, 2025, 40(03): 981-986.
- [9] LIAO T, CHEN F, WU Y, et al. Research on Path Planning with the Integration of Adaptive A-Star Algorithm and Improved Dynamic Window Approach[J]. Electronics, 2024, 13(2): 455.
- [10] LIU L, LIN J, YAO J, et al. Path planning for smart car based on Dijkstra algorithm and dynamic window approach[J]. Wireless Communications and Mobile Computing, 2021, 2021(1): 8881684.
- [11] Abhishesh Silwal; Joseph R. Davidson; Manoj Karkee; Changki Mo; Qin Zhang; Xie Huaibei. Research on Key Technologies of Cherry Tomato Picking Robot for Plant Factory [D]. University of Science and Technology of China, 2023.