

The Application of Internet of Things Technology in the Field of Industrial Robots

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Abstract: This study aims to explore the application of Internet of Things technology in the field of industrial robots and the changes it brings. The system has sorted out the definition, characteristics, and key technologies of the Internet of Things, including sensor technology, cloud computing, and big data analysis. Subsequently, the development history of industrial robots and their current applications in intelligent manufacturing, warehousing, and logistics were reviewed. The application architecture of IoT technology in industrial robots was analyzed in detail, and the specific applications and effects of IoT technology were elaborated through three typical cases: intelligent manufacturing production lines, intelligent warehousing systems, and intelligent logistics systems. The significant advantages of IoT technology in improving production efficiency, optimizing resource allocation, and enhancing system intelligence were revealed. At the same time, the challenges faced in the application of technology, such as standardization, data security, system integration, and cost control, were pointed out, and corresponding countermeasures and suggestions were proposed, such as strengthening the formulation of technical standards and enhancing data security protection. This paper summarizes the application value of Internet of Things technology in the field of industrial robots, and looks forward to the future development trend, including artificial intelligence fusion, edge computing applications and other technological innovation directions, as well as the application prospects in emerging industries. This study provides theoretical support and practical guidance for the in-depth application of IoT technology in the field of industrial robots.

Keywords: Internet of Things technology; Application of industrial machine networking technology; Industrial robot; Internet of Things; Industrial Internet of Things.

1. Introduction

1.1. Research background and significance

With the advancement of the Fourth Industrial Revolution, the Internet of Things (IoT), as a core enabling technology of Industry 4.0, is deeply integrating with industrial robotics. As a key vehicle for intelligent manufacturing, industrial robots are facing increasingly prominent demands for intelligence, networking, and collaboration. Leveraging characteristics such as smart sensing and ubiquitous connectivity, IoT endows robots with innovative capabilities including real-time monitoring, fault diagnosis, multi-robot coordination, and remote maintenance. This not only enhances the operational precision and efficiency of robots but also provides critical support for the construction of "future factories."

From a PEST analysis perspective: Politically, various countries have introduced supportive policies (e.g., China's "Made in China 2025"); Economically, IoT applications reduce costs and improve efficiency, delivering significant benefits to enterprises; Socially, they drive industrial upgrading and improve employment quality; Technologically, the continuous progress of IoT provides solid support for robotic development.

Currently, major global industrial nations such as Germany, the United States, and Japan are actively innovating in this field (e.g., Germany's "Industry 4.0" and the U.S. Advanced Manufacturing Strategy). In China, the "14th Five-Year Plan for the Development of the Robotics Industry" explicitly promotes the IoT-enabled transformation and intelligent upgrading of industrial robots. Against this backdrop, reviewing the current application status of IoT in the field of

industrial robotics, and analyzing its technical pathways, application effects, and development trends, holds significant theoretical value and practical guiding significance.

1.2. Current research status at home and abroad

In the international research arena, European and American countries have achieved remarkable results in the integration of the Internet of Things (IoT) and industrial robotics. For instance, within Germany's "Industry 4.0" strategy, IoT technologies are widely applied to robotic control systems, enabling highly automated and intelligent production [1]. Research in the United States focuses more on utilizing IoT data for real-time monitoring and predictive maintenance of robots, significantly enhancing the stability and efficiency of production lines.

Regarding domestic research, with the advancement of the "Made in China 2025" initiative, the application of IoT technology in the field of industrial robotics has also made considerable progress [2]. For example, enterprises such as Huawei have implemented remote monitoring and intelligent scheduling of robots through IoT platforms, thereby improving production efficiency.

2. Development and Applications of Industrial Robots

Industrial robots originated in the 1950s, driven by the demand for industrial automation. In their initial phase, they primarily featured mechanical structures and basic electrical control, serving only simple, repetitive tasks such as welding and material handling, with single-function capabilities.

From the 1960s to the 1970s, the integration of computer

technology propelled them into the automation stage, enabling complex motion control through elementary programming. In the 1980s, sensor technology endowed robots with environmental perception and self-adaptive adjustment abilities; the application of robotic vision systems and force feedback control marked a core breakthrough [3]. By the 1990s, the advancement of microelectronics and embedded systems significantly elevated their intelligence level, allowing them to perform delicate and complex tasks, thus laying the foundation for subsequent integration with the IoT and Artificial Intelligence (AI).

Today, the applications of industrial robots have permeated various sectors extensively. In manufacturing, robots used for welding and assembly in the automotive industry enhance production efficiency and quality. For instance, Tesla's factories leverage the IoT to achieve intelligent scheduling and remote monitoring of robots, thereby increasing production line flexibility. In the logistics and warehousing sector, Amazon's Kiva system utilizes the IoT to enable robotic collaboration, elevating warehouse intelligence. In the medical field, surgical robots improve surgical safety through high-precision operations supported by IoT data. In agriculture, plant protection robots employ the IoT for precision fertilization and pest control, boosting agricultural efficiency.

3. Application of IoT Technology in The Field of Industrial Robotics

3.1. Architecture of industrial robot IoT systems

The architecture of Industrial Robot IoT systems serves as the critical technical foundation for realizing the vision of intelligent manufacturing and Industry 4.0 [4]. The system's overall architecture is divided into four layers: the Perception Layer, Network Layer, Platform Layer, and Application Layer.

The Perception Layer, primarily composed of various sensors, is responsible for collecting operational status data of industrial robots, such as temperature, pressure, and vibration. These sensors achieve comprehensive perception of the robot's working environment through smart sensing technology.

The Network Layer utilizes ubiquitous connectivity technologies, such as Wi-Fi and 5G, to transmit data from the Perception Layer to the Platform Layer [5]. This layer ensures efficient and stable data transmission, addressing the issue of poor communication in traditional industrial robots.

Acting as the core of data processing, the Platform Layer leverages cloud computing and big data analytics technologies to store, process, and analyze massive datasets, extracting valuable information [6].

3.2. Application cases of IoT technology in industrial robotics

3.2.1. Intelligent manufacturing production line

The application of IoT technology in intelligent manufacturing production lines has yielded remarkable results, primarily reflected in three aspects:

First, enhancing logistics efficiency. By leveraging the characteristics of smart sensing and ubiquitous connectivity, deploying sensors and RFID tags at various production nodes enables real-time material tracking and data collection. This reduces information latency and improves process coordination and response speed. For example, after

introducing this technology, a certain automotive manufacturer shortened its material delivery time by 30%, significantly boosting production efficiency.

Second, reducing transportation costs. Relying on data interoperability and cloud-based collaboration, real-time monitoring and route optimization of transport vehicles minimize empty running rates and transportation time, thereby reducing fuel and labor costs. Data indicates that IoT-enabled intelligent logistics systems, on average, lower transportation costs by 20%, with even more pronounced effects in complex logistics scenarios involving multi-batch and small-batch operations.

Third, optimizing real-time monitoring and scheduling, ensuring the efficient operation of production processes.

3.2.2. Intelligent warehousing system

The intelligent warehousing system represents a typical application of IoT technology in the field of industrial robotics, characterized by the integration of diverse technologies and intelligent management capabilities.

On the hardware side, the system encompasses sensors, actuators, RFID tags, industrial robot bodies, and communication modules. These components are responsible for collecting environmental and cargo status data, executing commands, tracking and identifying goods, transporting and sorting materials, as well as ensuring seamless data transmission between nodes. On the software side, it integrates a Warehouse Management System (WMS), a Robot Control System (RCS), and a data analytics platform: the WMS handles inventory and orders while optimizing paths; the RCS schedules and controls robots in real-time; and the data analytics platform leverages big data and machine learning to provide decision support and fault prediction. The collaboration of these three elements ensures efficient and precise operations.

The application has demonstrated significant effectiveness. Regarding logistics efficiency, by collecting real-time data on cargo location, temperature, and humidity via smart sensors and RFID tags, performing preliminary processing through edge computing, and subsequently transmitting it to the cloud for in-depth analysis, one system achieved a 30% increase in goods picking efficiency with a sorting accuracy rate reaching 99.5% [7]. In terms of cost control, integrating GPS and in-vehicle sensors to monitor vehicle status and routes allows for path optimization to reduce energy consumption. This has led to an average 15% reduction in transportation costs and a 20% improvement in vehicle utilization [8]. Additionally, predictive maintenance reduces vehicle downtime, further lowering operational costs.

3.2.3. Intelligent Logistics System

The intelligent logistics system is a typical application of IoT technology in the field of industrial robotics, characterized by high integration and intelligence [9]. In terms of hardware, core components include RFID tags, sensor nodes, smart shelves, Automated Guided Vehicles (AGVs), robotic arms, and central control servers, which are responsible for item tracking and monitoring, identification and positioning, automated transportation and sorting, as well as system coordination and scheduling, respectively. On the software side, the system integrates an IoT platform, data analytics engines, machine learning algorithms, and visualization interfaces, enabling functions such as data acquisition and transmission, logistics optimization and scheduling, demand forecasting, and operational monitoring and decision-making.

The application of IoT technology has yielded significant results: First, by leveraging real-time data collection, edge computing, and cloud collaboration capabilities, logistics efficiency is greatly enhanced. For instance, in a certain large logistics center, sorting speed increased by 30% and turnover time was shortened by 20%. Second, through refined management and energy optimization, transportation costs are reduced. Relevant systems have seen a 15% reduction in

energy consumption and a 10% decrease in maintenance costs. Furthermore, predictive maintenance extends equipment lifespan and reduces long-term operational expenditures.

4. Challenges and Countermeasures of IoT Technology in Industrial Robot Applications

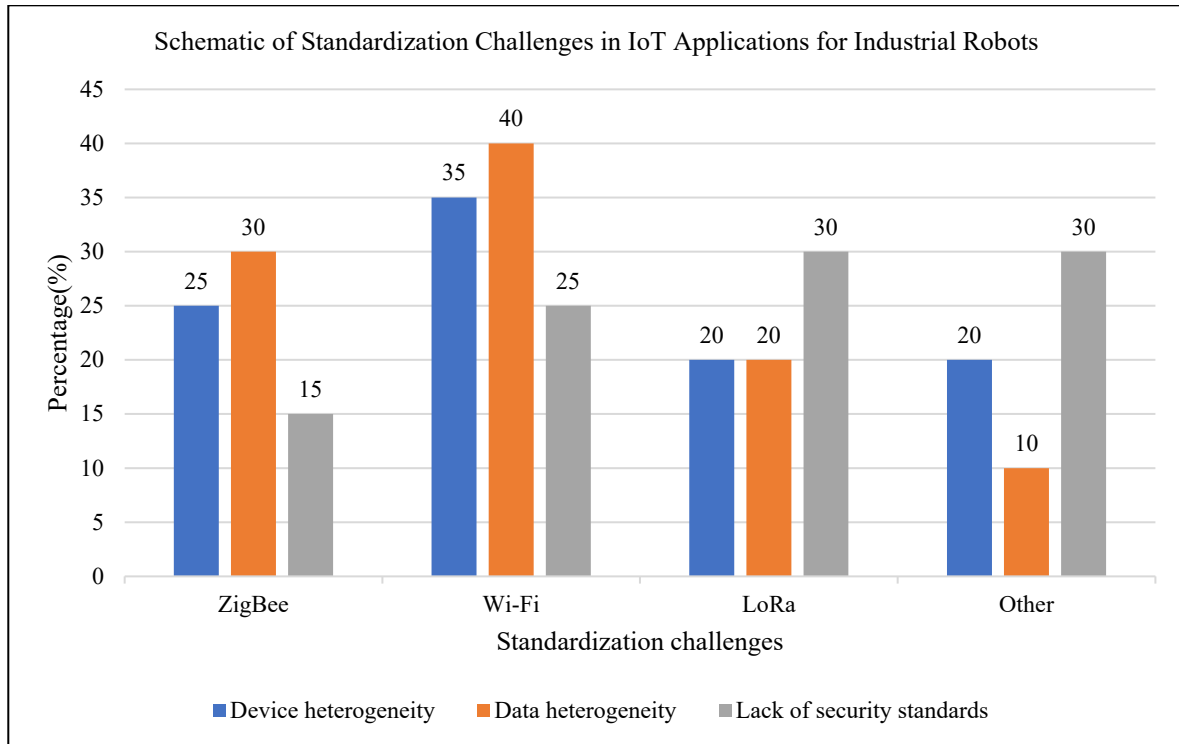


Figure 1. Schematic of Standardization Challenges in IoT Applications for Industrial Robots

(1). Challenges in Technical Standardization

Core Issues: As shown in Figure 1: fragmentation of communication protocols (e.g., ZigBee, Wi-Fi, LoRa), heterogeneity in data formats and precision, and the absence of security standards [10]. This lack of uniformity hinders deep integration, as evidenced by past incidents where manufacturers suffered production halts due to cyberattacks stemming from protocol inconsistencies.

Countermeasures: Establish a unified standard system covering communications, data, and security through deepened cross-industry and international cooperation [11]. Introducing tools such as Model-Driven Architecture (MDA) can shorten project cycles by 20% and reduce failure rates by 15% [12].

(2). Challenges in System Integration

Core Issues: Industrial robots involve heterogeneous platforms such as PLC, SCADA, and MES, which are often incompatible with IoT devices in terms of protocols and formats, making data interoperability difficult [13]. Conflicts arise between the two regarding data transmission needs versus real-time stability requirements, often leading to insufficient bandwidth, delays, and packet loss. Additionally, integrating security mechanisms to safeguard data confidentiality and integrity remains a challenge.

Countermeasures: Adopt modular designs with standardized interfaces. Enhance system compatibility through universal hardware interfaces, unified software platforms, and protocols such as OPC UA.

(3). Challenges in High Costs

Core Issues: The procurement and maintenance of high-precision sensors and edge computing devices are expensive. System integration and debugging are labor-intensive and time-consuming, causing hesitation in corporate decision-making and straining cash flow, thereby restricting adoption by Small and Medium-sized Enterprises (SMEs).

Countermeasures: Utilize cost-benefit analysis models to evaluate Return on Investment (ROI). Optimize operations, energy consumption, and maintenance strategies using big data and AI. Introduce cost-reducing technologies such as edge computing, lightweight protocols (MQTT/CoAP), and blockchain.

Despite the significant effectiveness of IoT technology in fields such as smart manufacturing (30% efficiency increase, 20% failure rate reduction) and intelligent warehousing (99% picking accuracy, 15% inventory cost reduction), addressing the aforementioned challenges is essential to drive large-scale applications [14].

5. Conclusion and Future Perspectives

5.1. Research conclusion

The primary value of IoT technology in the field of industrial robotics lies in enhancing operational precision and efficiency. By collecting operational data such as position and velocity through smart sensors, and leveraging edge computing combined with cloud-based big data analytics for precise control optimization, robots can adjust parameters in real-time. For instance, in automotive manufacturing, robots

can fine-tune welding parameters based on real-time data to ensure weld quality; multi-robot collaboration further optimizes production processes, reducing resource waste.

This technology also promotes intelligent management of industrial robots. Through ubiquitous connectivity and data interoperability, IoT platforms can monitor robot status in real-time and predict failures using machine learning algorithms. An electronics manufacturer successfully implemented predictive maintenance, thereby reducing maintenance costs and improving equipment reliability.

Research indicates that the deep integration of IoT and industrial robots has significantly elevated the intelligence level of robots, enabling innovative applications in condition monitoring, fault diagnosis, and remote operation & maintenance. Data collected by sensors, after computation and processing, effectively reduces downtime.

However, existing applications still face several shortcomings: The application of IoT technology in this domain is still in its infancy. Inconsistent data formats between devices and platforms necessitate improvements in technical standardization and interoperability. The widespread connectivity of IoT devices increases the risk of cyberattacks, and current security measures struggle to adapt to industrial environments. Moreover, as existing research mostly focuses on single scenarios, multi-robot collaboration in complex environments faces challenges regarding algorithm optimization and real-time performance assurance, demanding further theoretical and technological breakthroughs.

5.2. Future development trends

Against the backdrop of deep integration between IoT and industrial robotics, AI convergence and edge computing stand out as the core frontier of innovation. Meanwhile, demand for applications in emerging industries is surging, and international cooperation & promotion holds tremendous potential [15].

(1). AI Convergence as the Core Innovation

Leveraging edge computing for real-time sensor data processing enables robot condition monitoring and fault prediction. This bidirectional empowerment between AI and IoT optimizes operations, drives algorithm iteration, and facilitates multi-robot collaboration and intelligent management.

(2). Edge Computing for Enhanced Support

By pushing computational tasks to the network edge, data can be processed locally in real-time. This approach reduces latency, ensures operational precision and responsiveness, alleviates cloud server load, decreases bandwidth consumption, and ultimately enhances system security [16].

(3). Expansion into Emerging Industries

Capitalizing on the strengths of smart sensing and ubiquitous connectivity, the technology is penetrating sectors such as smart manufacturing, smart healthcare, and smart agriculture to meet core demands and boost efficiency. It is further expanding into domains like smart cities and aerospace, covering equipment monitoring and early warning in extreme environments.

(4). Deepened International Cooperation and Promotion

Multinational research collaborations will accelerate technological convergence and standard unification. Relying on diverse channels such as international technology alliances

and the Hannover Messe, the industry can expand technological influence and achieve greater market penetration [17].

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