Internet of Robotic Things (IoRT): An Intelligent Framework for Automated Manufacturing

Bethini Kavya[1], Dr. Kakarla Hari Kishore[2]
[1]Department of ECE, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur, Andhra Pradesh, India.
[2]Professor, Department of ECE, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur, Andhra Pradesh, India.

Article Info

Article history:

Received Jan 7, 2025
Revised Feb 8, 2025
Accepted Mar 6, 2025

Keywords:

Internet of Robotic Things (IoRT)
Smart Manufacturing
Industry 4.0
Edge Computing
Artificial Intelligence
Collaborative Robots
Cyber-Physical Systems
Digital Twin

ABSTRACT

IoRT is transforming manufacturing because it brings together robotics, the IoT and AI. IoRT serves as the backbone of Industry 4.0 by joining together intelligent robots, sensors, platforms at the edge and in the cloud and AI to allow for monitoring, thinking and acting all at real time. As a result, organizations become more efficient, adaptable and ready to respond in today's manufacturing world. This study investigates all major elements of IoRT systems, focusing on perception layers that use sensors and actuators, network protocols such as MQTT and 5G and processing layers relying on edge and cloud computing. Adaptive control, predictive maintenance and quality assurance are main areas where AI is used. New technologies in robotics allow equipment to identify faults, anticipate when machinery will fail and manage workload with nearly no requirement for people to intervene. Additionally, IoRT helps create cobots, so robots work safely together with people and boost productivity as well as ergonomic well-being. The paper further looks into important obstacles that stop IoRT adoption such as difficulties in making different robot platforms interoperate, slow responses in real-time communication, risks of losing privacy and computer attacks and how difficult it is to manage many intelligent robots at once. So, these recent research areas—edge AI, digital twins for live monitoring, 6G-based ultra-reliable networks and ethical approaches to AI—are being considered as answers to these issues. All in all, this review explains that IoRT is more than a technical union; it provides a plan for how manufacturing systems should operate, adjust and progress. Autonomous systems powered by data are helping IoRT redefine manufacturing as an intelligent, strong and user-friendly place which is an important move toward bringing Industry 4.0 to life.

Corresponding Author:

Bethini Kavya,
Department of ECE,
Koneru Lakshmaiah Education Foundation, Andhra Pradesh, India.
Email: bethinikavya123@gmail.com

1. INTRODUCTION

Industrial automation has advanced through many key periods, beginning with Industry 1.0's mechanization and ending with the age of mass production, controlled systems and early robots. Traditional robots were highly effective, but they were generally alone, fixed and not flexible, so they did the same thing over and over. Because they couldn't interact with either their environment or each other, these systems weren't useful for meeting changing production needs [1]. As basic networked devices were first introduced in early 2000s, the field of IoT started to influence industrial environments and open the way for smart manufacturing systems [2].

Currently in Industry 4.0, the Internet of Robotic Things (IoRT) is transforming the field by combining intelligent robots, sensor systems, edge/cloud computing and AI. Thanks to this connection, robotic systems can detect and analyze their environment, respond quickly in real time, adapt to what they experience and communicate between other machines and systems [3]. IoRT helps smart manufacturing by introducing collaborative robots (cobots), making assembly lines work more intelligently, detecting problems with AI and planning maintenance ahead. Because of more edge computing, more real-time analytics and better communication security, IoRT is being used more to achieve better efficiency, less downtime and better product quality [4,5].

In the years to come, IoRT is expected to become more independent, consider its surroundings and involve people in its operations. Recent research is emphasizing edge AI, federated learning, joining digital twins with other technologies and reducing latency through the launch of 6G networks. As a result of these updates, any changes made in the design will be immediately reflected in the physical robot, improving the adaptability and quick responses. Developments in explainability and security will play important roles as well. For this reason, IoRT may become the main technology that guides Industry 5.0, where people and intelligent machines combine to make manufacturing flexible, sustainable and highly suited to individuals.

2. IORT ARCHITECTURE AND CORE COMPONENTS

Its design layers the Internet of Robotic Things (IoRT), making it easier for robots and industrial equipment to communicate, process information and be controlled together. This style of architecture supports distributed intelligence, provides instant reactions and ensures all systems can talk to each other, all key aspects of advanced automated manufacturing. IoRT framework consists of the Perception Layer, Network Layer, Processing Layer and Application Layer, all of them with their own roles while being linked together [6].

2.1. Perception Layer

This layer takes in all the data from the surrounding world. It brings together several physical sensors and actuators inside robotics systems to sense both the outside world and robot performance. Such sensors include images or LiDAR through cameras, tactile sensors, distance detectors, temperature sensors and force detectors [7]. Collection of data at this layer provides the basis for additional analysis and choices. By using processed data, actuators take control actions that lead to interaction with physical systems. With this layer, operators can easily monitor events on the plant floor and get instant responses.

2.2. Network Layer

The network layer makes sure data is shared securely and effeciently among the many parts of the IoRT system. It connects to both wired and wireless networks using MQTT (Message Queuing Telemetry Transport), OPC-UA (Open Platform Communications – Unified Architecture) and 5G [8]. Following these protocols means that robots, sensors, edge devices and cloud systems exchange data securely and immediately. Device discovery, interoperability and secure transmission are all made possible by the network layer which is a key to the stability and response of large systems.

2.3. Processing Layer

The IoRT system's intelligence is focused in the processing layer. This technology mixes edge computing, fog computing and AI analytics to keep data processing local and faster, so it doesn't always have to rely on cloud connections. In this work, the team uses machine learning algorithms and advanced signal processing techniques to support activities like detecting anomalies, guessing how a robot will move, planning the best route and making adjustments on the fly [9]. By doing this, robots can make autonomous choices using sensory information and quick responses, helping to create closed-loop systems and avoid breaks in operation.

2.4. Application Layer

At the application layer, IoRT systems connect with major enterprise systems such as ERP, MES and SCADA software. Its main roles include planning jobs and processes, optimizing how they flow, sharing resources and keeping tabs on their performance. This layer allows for both human-machine interfaces (HMI) and dashboards which help plant operators and managers make the right decisions [10]. On this level, integration helps manage robotics to meet their role within company targets and the production process.

2.5. Cloud Integration and Analytics

Cloud computing supports other parts of the architecture from a side role, but it helps a lot. Cloud services offer plenty of computing and storage capacity for uses such as training neural networks, studying statistics from earlier times and making future predictions. Because of cloud integration, manufacturing companies can use cross-factory analytics, remote diagnostics and centralized system updates to keep improving, expand and transform into digital factories [11,12].

Therefore, the multi-layer structure of IoRT enables manufacturing to be automated in a structured, elastic and intelligent system. Thanks to strong links between sensing, communication, processing and the control system, IoRT supports the move from controlled by events to being ready for anything autonomously.

Table 1. IoRT Architecture Layers and Their Core Functions

Layer	Primary Components	Core Functions
Perception Layer	Sensors (vision, proximity, tactile, temperature, force), Actuators	Captures environmental and machine data; enables real-time feedback and actuation.
Network Layer	MQTT, OPC-UA, 5G, wired/wireless links	Provides secure, low-latency communication and interoperability among IoRT devices and systems.
Processing Layer	Edge computing devices, AI/ML models, fog nodes	Enables local data analysis, real-time decision-making, predictive control, and anomaly detection.
Application Layer	ERP, MES, SCADA systems, Human-Machine Interfaces (HMIs)	Handles task scheduling, workflow optimization, system monitoring, and enterprise integration.
Cloud Integration & Analytics	Cloud servers, storage systems, remote diagnostics, analytics platforms	Provides large-scale data storage, deep learning model training, historical analysis, and cross-factory insights.

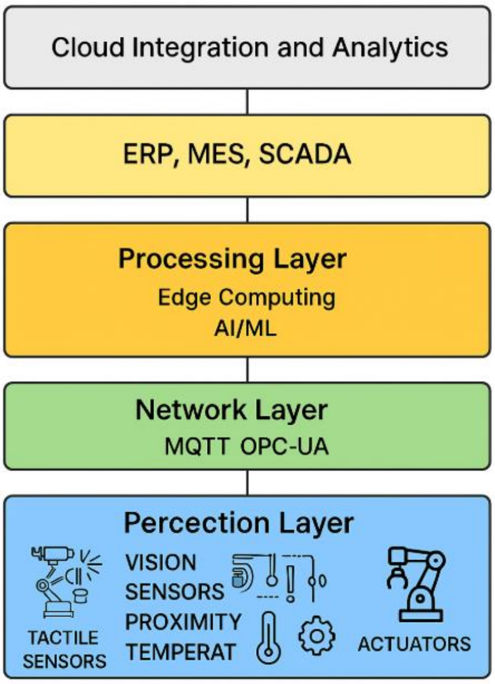

Figure 1. Layered Architecture of the Internet of Robotic Things (IoRT) for Automated Manufacturing

3. APPLICATIONS IN AUTOMATED MANUFACTURING

The Internet of Robotic Things (IoRT) is changing the way manufacturing works by introducing robots that cooperate, change with new challenges and update the process in real-time. Adopting AI, sensor networks and powerful communication protocols allows IoRT to improve both productivity, flexibility and dependability. This section looks at the main uses of IoRT in making manufacturing automated.

3.1. Collaborative Robotics (Cobots)

Cobots, as collaborative robots are known, are created to assist human workers in close contact situations, providing a safer and more efficient way to work. Unlike conventional industrial robots, IoRT-implemented cobots support advanced AI functions for recognizing what a human is intending, planning movements and adjusting the way they work. By receiving real-time sensor data and using cloud computing, cobots can recognize human gestures, keep track of how a job is going and adjust themselves as needed during complex assembly or handling jobs. With proximity sensors and force-limiting actuators, robot actions are safe and comply with all safety standards. With IoRT, workplaces move away from fixed automation to spaces that are better for people.

3.2. Smart Assembly Lines

Traditional assembly lines become smarter and capable of changing as needed because of IoRT. AI-powered analysis and ongoing sensor information help adjust how a system operates in response to new orders, changes in equipment or the availability of materials. Edge devices make decisions locally to ensure timing, sequencing and resources are correct and central systems keep the whole operation flowing smoothly. Thanks to this capability, equipment doesn’t lay idle, product quality improves and each product created meets high quality standards. Should the alignment on a workstation be detected to be off, the system will adjust server activities or sound the alarm for a fix. Being responsive in real time increases how well an operation runs and how prepared it is for difficult conditions.

3.3. AI-Based Quality Inspection

In manufacturing, monitoring and controlling product quality is essential and IoRT does this by connecting AI-powered cameras. Photos and dimensions of products are collected by cameras, infrared sensors and 3D scanners continuously during the production process. In real time, these models look at the inputs and detect flaws such as cracks, other kinds of surface issues, differences in size or assembly mistakes by working on datasets with correctly labeled defects. Because of this, manual inspection is not needed which decreases mistakes and quickly ensures all products are inspected properly. Also, using inspection results, managers can see which defects happen often and make changes to production processes before they become an issue again.

3.4. Predictive Maintenance

By fitting sensors into robotic systems and machinery, IoRT helps predict when machines may need maintenance. Using machine learning models, the sensor data is reviewed to predict when something might break before it happens. Bearing trouble may be found by the system when motor vibration increases, trigging an auto-alert. Using predictive maintenance helps reduce the risk of unexpected machine downtime, saves on costs and makes equipment last longer. Now, by taking into account how and where equipment is being used, it is possible to create maintenance schedules that respond to current conditions rather than only following a fixed dates rules.

Table 2. Comparative Overview of IoRT Applications in Manufacturing

Application	Technologies Involved	Primary Benefit	Example Use Case
Collaborative Robotics	AI, Proximity Sensors, Cloud Analytics	Enhanced safety & productivity	Cobots in mixed human-robot assembly tasks
Smart Assembly Lines	Edge Computing, AI Analytics, Sensors	Real-time responsiveness, reduced downtime	Reconfigurable production scheduling
AI-Based Quality Inspection	Computer Vision, Deep Learning, Cameras/Scanners	Faster, more accurate defect detection	Inline visual inspection of final products
Predictive Maintenance	Vibration/Temperature Sensors, ML Models	Reduced maintenance cost and downtime	Early detection of motor failure

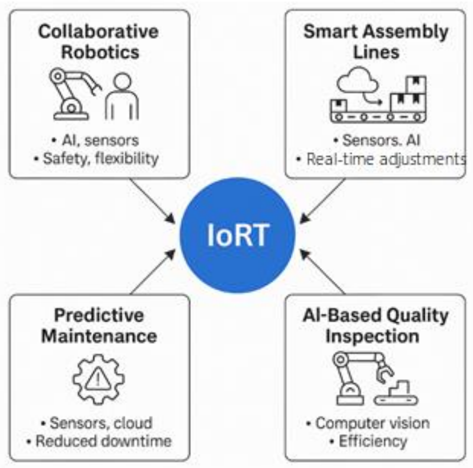

Figure 2. Key Applications of IoRT in Automated Manufacturing Environments

4. CHALLENGES AND RESEARCH GAPS

IoRT could revolutionize the way factories work, but getting it to work efficiently is met with a range of technical, operational and strategic issues. These problems hold back the large-scale introduction of IoRT systems and make important topics for further study. Resolving these issues supports the growth, safety, interconnectivity and rapidness of IoRT-powered manufacturing systems. Below, I discuss the important challenges along with any research gaps they involve.

4.1. Interoperability

A major problem with adopting IoRT is that heterogeneous devices, platforms and communication protocols cannot work together smoothly. Manufacturing processes often blend old machines, robots designed for one purpose and IoT devices produced by different sources. Because there are no standard ways of formatting data, communicating with devices or issuing commands, this complicates putting everything together. Because of this, information is passed and systems work together in a way that is both inefficient and error-prone. We need to have standard middleware and open frameworks that allow different hardware to be used together with little or no modification. Work on interoperability protocols should concentrate on creating versions that are lightweight and flexible enough to handle different and changing system setups.

4.2. Latency Sensitivity

Industrial automation depends heavily on real-time control, mainly for movements, avoiding collisions and controlling loops. Despite efforts, extremely low-delay communication across parts of a distributed IoRT is hard to accomplish. When there are delays in a network, disturbing signals or a congested channel, it becomes harder for robotic systems to perform well and safely. Even though 5G has great benefits, it is currently used in industrial areas only sparingly. Further research is required to find the best edge-native systems, TSN techniques and hybrid forms of edge-cloud computing to ensure low latency and still maintain efficient and reliable processing.

4.3. Security and Privacy

Since IoRT systems are connected to a vast network, they are especially at risk for cyber threats including unapproved entry, data modification and websites being down for a period. As robots can move and make physical steps, an attack on their systems could interfere with their work or cause danger to people. Moreover, production parameters, user details and exclusive algorithms pass over different devices and online services, making some people worry about their privacy. Today’s approaches for encryption and access control do not completely cover the needs of decentralized and real-time applications. Researchers should first create cybersecurity structures, anomaly detectors and privacy-preserving ML algorithms suitable for Internet of Resource-Things devices.

4.4. Scalability

With manufacturing changes toward larger, linked networks, the management of an expansive group of robots becomes more difficult. It can be difficult to scale systems due to limited bandwidth, a lack of processing power and the management of spread-out intelligence. If there are no useful resource management processes in place, the system may deal with delays and ineffectiveness. Besides, the ability to add or remove robotic elements quickly demands flexible architecture that lets the system handle these tasks on its own. Gaps are increasing in the study of control algorithms for decentralized systems, coordinated frameworks between edge and cloud and platforms that can adjust to changing demands.

Table 3. Key Challenges and Research Gaps in IoRT-Based Automated Manufacturing

Challenge	Description	Key Research Needs
Interoperability	Lack of standardization across diverse robotic platforms and IoT devices.	Development of standardized middleware, open protocols, and plug-and-play frameworks.
Latency Sensitivity	Difficulty in ensuring real-time responsiveness due to communication delays.	Exploration of edge-native designs, TSN, and hybrid edge-cloud architectures.
Security and Privacy	Risk of cyberattacks and data breaches due to extensive connectivity.	Lightweight cybersecurity models, real-time anomaly detection, and privacy-preserving AI techniques.
Scalability	Complexity in managing a large number of interconnected robotic systems.	Decentralized control systems, scalable orchestration platforms, and dynamic resource management.

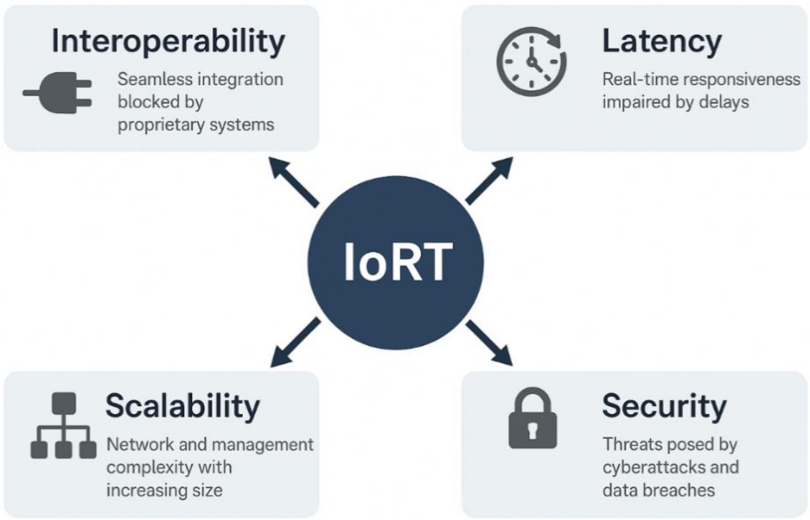

Figure 3. Core Challenges in Deploying IoRT for Intelligent Manufacturing

Figure 3 was designed by the authors using original vector illustrations for academic and educational purposes.

5. FUTURE RESEARCH DIRECTIONS

Important research areas are set to greatly improve system intelligence, response time and make the IoRT process more stable in automated manufacturing. Edge AI and TinyML are exciting fields because they help run compact machine learning models on the edges, make decisions immediately and allow devices to operate independently without relying on constant internet access. It makes a difference in manufacturing situations where speed and energy use matter a lot. We are also seeing Digital Twins which act as live virtual copies of physical robot systems. Having these digital partners in place lets us constantly check, predict possible issues and test solutions using models which supports reliability and improves advanced error prediction abilities. With expected 6G communication, ultra-reliable low-latency communication (URLLC) will support precise and rapid haptic feedback and remote work in challenging factory setups. As a result, robotic systems will react faster and we'll have more options for controlling and interacting with robots from afar in dangerous areas. As robots become increasingly autonomous, making Ethical AI central becomes extremely important. If we want users to trust AI systems and be safe around robots, the robots should be easy to understand and explain their decisions. Studies in this area must discuss fairness, minimize bias, ensure decisions can be understood and stay within the bounds of relevant regulations to allow safe usage of autonomous systems. All of these future directions are intended to bring IoRT from a passive control system to an adaptable, dependable and ethical foundation for next-generation manufacturing.

6. CONCLUSION

IoRT represents a major progress in manufacturing by combining robotics, artificial intelligence and connected sensing. With IoRT, it is possible to rapidly acquire data, make intelligent choices and easily link robotic devices, building extremely responsive, efficient and independent production environments. Thanks to this, it boosts both company productivity and adaptability while also supporting partnerships between employees and technology, predictive servicing and error-free production. All aspects of industrial workflows can be improved by the way cyber-physical systems, together with IoRT, establish a solid architecture: perception, networking, processing and application. Additionally, its use in collaborative robotics, smart assembly, AI-aided quality inspections and condition-based maintenance demonstrates its ability to change factory processes. Yet, even with the improvements, important issues such as interoperability, low-latency demands, cybersecurity and scaling remain important. More research is needed to develop standard methods, AI models that run at the network's edge, digital twin platforms and systems governed by ethics. Addressing these issues will play a key role in achieving all that IoRT can offer. All in all, IoRT is a leading part of Industry 4.0 and what comes after, providing a reliable, intelligent and fair route to smart manufacturing in the future.

REFERENCES

[1] I. Afanasyev, M. Mazzara, S. Chakraborty, N. Zhuchkov, A. Maksatbek, M. Kassab, and S. Distefano, "Towards the Internet of Robotic Things: Analysis, architecture, components and challenges," *arXiv preprint arXiv:1907.03817*, 2019.
[2] S. J. Khalid, "Internet of Robotic Things: A review," *Journal of Applied Science and Technology Trends*, vol. 2, no. 3, pp. 78–90, 2021, doi: 10.38094/jastt203104.
[3] G. Samara, A. Hussein, I. A. Matarneh, M. Alrefai, and M. Y. Al-Safarini, "Internet of Robotic Things: Current technologies and applications," *arXiv preprint arXiv:2204.04190*, 2022.
[4] O. Vermesan, R. Bahr, M. Ottella, M. Serrano, T. Karlsen, T. Wahlstrøm, and M. T. Gamba, "Internet of robotic things intelligent connectivity and platforms," *Frontiers in Robotics and AI*, vol. 7, p. 509753, 2020, doi: 10.3389/frobt.2020.509753.
[5] M. Serror, S. Hack, M. Henze, M. Schuba, and K. Wehrle, "Challenges and opportunities in securing the industrial Internet of Things," *arXiv preprint arXiv:2111.11714*, 2021.
[6] S. E. Arefin, T. A. Heya, and J. Uddin, "Real-life implementation of Internet of Robotic Things using 5 DoF heterogeneous robotic arm," *arXiv preprint arXiv:2305.13207*, 2023.
[7] K. J. Sibar, "Internet of Robotic Things: A review," *Journal of Applied Science and Technology Trends*, vol. 2, no. 3, pp. 78–90, 2021.
[8] S. Ghassan, H. Abla, A. M. Israa, A. Mohammed, and Y. A. Maram, "Internet of Robotic Things: Current technologies and applications," *arXiv preprint arXiv:2204.04190*, 2022.
[9] P. Raja, "The rise of the Internet of Robotic Things (IoRT)," *LinkedIn Article*, 2023. [Online]. Available: https://www.linkedin.com
[10] Appventurez, "Internet of Robotic Things (IoRT): Future of manufacturing," *Appventurez Blog*, 2025. [Online]. Available: https://www.appventurez.com
[11] S. Kesana, N. N. Prem Sai, O. Yallaiah, S. Saikrishna, and S. Khadarvali, "Circularly polarized fractal patch antenna with probe feed technique for Wi-Max applications," *National Journal of Antennas and Propagation*, vol. 3, no. 2, pp. 15–20, 2021.
[12] K. G. Devi, K. Tejasree, M. K. S. Sri, and M. Pravallika, "Energy reduction of D-flipflop using 130nm CMOS technology," *Journal of VLSI Circuits and Systems*, vol. 3, no. 2, pp. 34–41, 2021, doi: 10.31838/jvcs/03.02.04.