Multidisciplinary Journal of Research in Engineering and Technology

ISSN: 2348-6953

Volume 13 Issue 2 (2026) | Pages: 95–100

Intelligent Edge–Cloud Collaborative Architectures for Smart Industrial Automation

Soraya Navaratnam*

Department of Computer Science and Engineering, Gwangdo Systems Polytechnic, South Korea

Corresponding Author: soraya.navaratnam@gsp-kr.net

Peer Review Information

Type: *Article*
Received: *15 February 2026*
Revised: *05 March 2026*
Accepted: *11April 2026*
Published: *28 may 2026*

Abstract

The rapid evolution of Industry 4.0 technologies has significantly transformed industrial automation systems through the integration of Internet of Things (IoT), Artificial Intelligence (AI), cloud computing, edge computing, cyber-physical systems, and intelligent communication networks. Modern industrial environments generate massive volumes of real-time data from smart sensors, autonomous machines, industrial robots, and connected manufacturing systems, creating challenges related to latency, scalability, bandwidth utilization, real-time decision-making, and secure data processing. Traditional cloud-centric industrial architectures often experience limitations such as high communication delay, centralized processing bottlenecks, network congestion, and reduced responsiveness in time-sensitive industrial operations. To address these challenges, Intelligent Edge–Cloud Collaborative Architectures have emerged as a promising solution for enabling distributed intelligence, real-time analytics, adaptive automation, and efficient industrial resource management. This research proposes an Intelligent Edge–Cloud Collaborative Architecture for Smart Industrial Automation that integrates edge computing, cloud computing, deep learning, industrial IoT devices, and intelligent orchestration mechanisms into a unified automation framework. The proposed architecture enables distributed data processing at edge nodes while utilizing cloud infrastructures for large-scale analytics, long-term storage, predictive maintenance, and centralized industrial management. The framework incorporates intelligent task scheduling, real-time industrial monitoring, deep learning-based anomaly detection, and adaptive resource optimization to improve industrial automation efficiency and operational reliability. Furthermore, the proposed model integrates secure industrial communication, low-latency edge processing, and collaborative edge–cloud intelligence to support next-generation manufacturing systems and autonomous industrial environments. Experimental evaluation demonstrates that the proposed framework significantly improves processing latency, resource utilization, automation efficiency, predictive maintenance capability, and industrial scalability compared with traditional cloud-centric architectures. The proposed system also enhances energy efficiency, fault tolerance, and real-time industrial decision-making for smart factories and Industry 4.0 infrastructures. The research establishes a robust intelligent edge–cloud collaborative framework suitable for future industrial automation ecosystems and intelligent manufacturing environments.

Keywords: Edge Computing, Cloud Computing, Smart Industrial Automation, Industry 4.0, Industrial IoT, Deep Learning.

How to Cite This Article

Navaratnam, S. (2026). Intelligent Edge–Cloud Collaborative Architectures for Smart Industrial Automation. *Multidisciplinary Journal of Research in Engineering and Technology* 13(2), 95–100.

Introduction

The rapid evolution of Industry 4.0 technologies has significantly transformed traditional industrial systems into intelligent, interconnected, and automated manufacturing environments. Technologies such as Industrial Internet of Things (IIOT), Artificial Intelligence (AI), cloud computing, edge computing, cyber-physical systems, robotics, big data analytics, and intelligent communication networks have enabled modern industries to achieve higher operational efficiency, predictive maintenance, autonomous decision-making, and real-time process optimization. Smart industrial automation systems continuously generate massive volumes of data from industrial sensors, autonomous machines, robotic systems, industrial controllers, and production management platforms. Efficient processing and intelligent analysis of this large-scale industrial data have become critical for ensuring low-latency automation, fault detection, adaptive manufacturing, and industrial productivity optimization.

Traditional cloud-centric industrial architectures primarily depend on centralized cloud servers for storing, processing, and analyzing industrial data generated from distributed manufacturing environments. Cloud computing provides scalable storage resources, high computational capability, centralized industrial management, and large-scale analytics for modern industrial applications. However, cloud-centric systems often suffer from several limitations when applied to real-time industrial automation environments. Industrial processes such as robotic control, autonomous manufacturing, machine coordination, predictive maintenance, and industrial safety monitoring require ultra-low latency, continuous connectivity, and rapid decision-making capabilities that centralized cloud infrastructures cannot always provide efficiently.

One of the major challenges associated with traditional cloud-based industrial automation is communication latency. Industrial IoT devices and autonomous systems continuously exchange real-time operational data with cloud servers located far from industrial environments. This long-distance communication introduces transmission delays and network congestion that may affect critical industrial operations. In time-sensitive applications such as autonomous robotics, smart assembly lines, industrial motion control, and emergency fault detection, even small communication delays can lead to operational inefficiencies, production failures, or safety risks. Furthermore, transmitting massive industrial datasets continuously to centralized cloud infrastructures increases bandwidth consumption and network overhead.

Edge computing has emerged as a promising solution for addressing these challenges by bringing computational resources closer to industrial devices and production environments. Edge computing enables real-time data processing, localized analytics, intelligent decision-making, and low-latency communication at the network edge near industrial systems. Instead of transferring all industrial data to distant cloud servers, edge nodes perform local computation, filtering, anomaly detection, and automation control operations. This distributed processing model reduces communication latency, improves response time, minimizes bandwidth usage, and enhances industrial reliability in smart manufacturing environments.

Literature Review

The rapid adoption of Industry 4.0 technologies, Industrial Internet of Things (IIoT), edge computing, and cloud computing has encouraged researchers to develop intelligent industrial automation frameworks capable of supporting real-time analytics, adaptive decision-making, and scalable industrial communication. Intelligent edge–cloud collaborative architectures have emerged as promising solutions for addressing challenges related to latency, bandwidth utilization, computational scalability, and real-time industrial processing in smart manufacturing environments. Existing research demonstrates that integrating edge computing with cloud infrastructures significantly improves industrial automation efficiency, predictive maintenance capability, and intelligent resource management.

Shi and Dustdar (2016) introduced the concept of edge computing and highlighted its importance in reducing latency and improving localized data processing for distributed computing environments [1]. The study emphasized that edge computing enables real-time analytics by moving computational resources closer to end devices and industrial systems. The researchers concluded that edge computing improves responsiveness and minimizes communication overhead compared with centralized cloud infrastructures. However, the study did not fully address collaborative workload distribution between edge and cloud environments in industrial automation systems.

Chiang and Zhang (2016) investigated fog computing and edge-based architectures for IoT environments [2]. The study demonstrated that edge–fog collaborative systems improve communication efficiency, reduce network congestion, and support latency-sensitive industrial applications. The researchers highlighted the role of distributed computing in enabling real-time industrial analytics and autonomous system coordination. Nevertheless, challenges related to scalability, intelligent orchestration, and adaptive resource allocation remained unresolved.

Lee, Bagheri, and Kao (2015) proposed a cyber-physical system architecture for Industry 4.0-based manufacturing environments [3]. The framework integrated industrial IoT devices, smart sensors, cloud platforms, and automation systems to support intelligent manufacturing operations. The study emphasized the importance of real-time industrial monitoring, predictive maintenance, and adaptive automation in smart factories. However, centralized cloud dependency introduced latency and bandwidth limitations for time-sensitive industrial processes.

Xu (2012) introduced the concept of cloud manufacturing and discussed the role of cloud computing in intelligent industrial production systems [4]. The study highlighted the advantages of cloud infrastructures in providing scalable computational resources, centralized industrial management, and large-scale analytics for manufacturing environments. However, the researchers also identified communication delays and centralized processing bottlenecks as major limitations in cloud-centric industrial architectures.

Liu et al. (2019) conducted a comprehensive review of edge–cloud collaborative computing for industrial automation systems [5]. The study analyzed intelligent task scheduling, distributed workload management, and real-time industrial analytics in edge–cloud infrastructures. Experimental findings demonstrated that collaborative edge–cloud architectures significantly reduce processing latency and improve industrial resource utilization. The researchers concluded that intelligent orchestration mechanisms are essential for efficient collaboration between edge and cloud systems.

Wang et al. (2018) proposed an edge-assisted industrial IoT framework for smart manufacturing environments [6]. The framework integrated edge computing with industrial IoT devices to support localized analytics and low-latency automation control. The study demonstrated improved energy efficiency, reduced communication overhead, and enhanced industrial reliability. However, challenges related to fault tolerance, security management, and scalable industrial intelligence remained important concerns.

Methodology

The proposed Intelligent Edge–Cloud Collaborative Architecture is designed to provide scalable, adaptive, low-latency, and intelligent industrial automation services for Industry 4.0 environments. The framework integrates edge computing, cloud computing, Industrial Internet of Things (IIoT), deep learning, intelligent orchestration mechanisms, and real-time industrial analytics into a unified industrial automation ecosystem. The primary objective of the proposed architecture is to improve real-time industrial decision-making, predictive maintenance capability, resource optimization, operational reliability, and low-latency industrial communication in smart manufacturing environments.

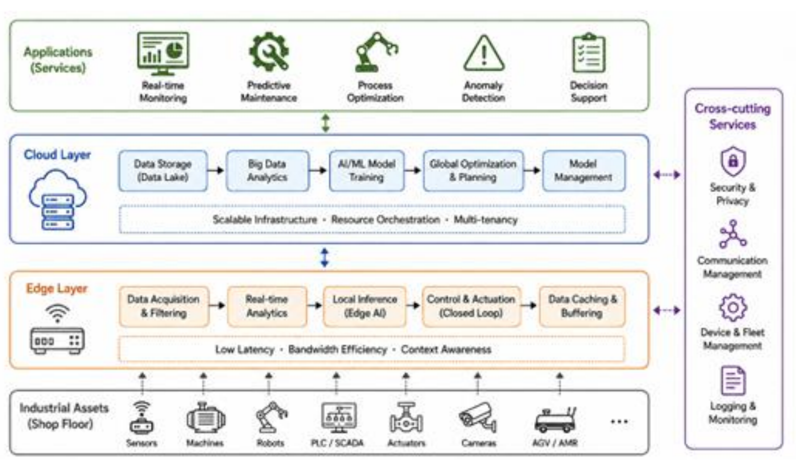

***Fig 1**. Intelligent Edge–Cloud Collaborative Framework for Smart Industrial Automation and Real-Time Industrial Analytics*

Industrial Device and Data Acquisition Layer

The Industrial Device and Data Acquisition Layer consists of industrial IoT devices, smart sensors, robotic systems, programmable logic controllers (PLCs), industrial machines, autonomous production systems, and cyber-physical manufacturing units deployed within smart factory environments. These industrial devices continuously generate real-time operational data related to machine health, temperature, pressure, vibration, production speed, energy consumption, and industrial process status. The collected industrial data is transmitted to nearby edge computing nodes using industrial communication protocols and wireless industrial networks. This layer enables continuous industrial monitoring and establishes the foundation for intelligent industrial automation and real-time operational analytics.

Edge Computing and Local Processing Layer

The Edge Computing and Local Processing Layer performs low-latency computation and localized industrial data processing near manufacturing environments. Edge nodes receive industrial sensor data and execute real-time preprocessing operations such as noise removal, data filtering, feature extraction, traffic normalization, and anomaly detection. Latency-sensitive industrial operations including robotic motion control, industrial fault detection, machine synchronization, and emergency response processing are handled directly at edge nodes to minimize communication delay. This layer reduces bandwidth consumption by preventing unnecessary transmission of raw industrial data to centralized cloud infrastructures while improving response time and operational reliability.

Intelligent Edge Analytics Layer

The Intelligent Edge Analytics Layer integrates deep learning and artificial intelligence algorithms for intelligent industrial analysis and predictive decision-making. Deep learning models such as Convolutional Neural Networks (CNN), Long Short-Term Memory (LSTM) networks, and reinforcement learning algorithms analyze industrial sensor data to identify abnormal machine behavior, equipment degradation, production inefficiencies, and operational anomalies. Predictive maintenance mechanisms estimate machine failure probabilities and enable early fault detection before critical industrial failures occur. The edge analytics layer supports adaptive automation and localized industrial intelligence for real-time smart manufacturing operations.

Algorithmic Strategy

The proposed Intelligent Edge–Cloud Collaborative Architecture utilizes a hybrid industrial optimization strategy that integrates edge computing, cloud computing, deep learning, intelligent orchestration, predictive analytics, and adaptive workload management for smart industrial automation environments. The algorithmic framework is designed to provide real-time industrial processing, low-latency communication, intelligent task scheduling, predictive maintenance, and adaptive industrial resource optimization in Industry 4.0 infrastructures.

Mathematical Model for Industrial Data Acquisition

Let the industrial environment consist of multiple industrial devices and sensors represented as:

$$\mathrm{I} = \{\mathrm{i1}, \mathrm{i2}, \mathrm{i3}, \ldots, \mathrm{in}\}$$

Where:

ini_nin represents industrial machines, sensors, robotic systems, and IIoT devices.

The generated industrial data stream is represented as:

$$\mathrm{D} = \{\mathrm{d1}, \mathrm{d2}, \mathrm{d3}, \ldots, \mathrm{dm}\}$$

Where:

dmd_mdm = Real-time industrial sensor data and operational information.

Each industrial dataset contains multiple operational features:

$$\mathrm{Fi} = \{\mathrm{f1}, \mathrm{f2}, \mathrm{f3}, \ldots, \mathrm{fk}\}$$

Where:

FiF_iFi = Industrial feature vector.

The extracted features include:

Temperature, Pressure, Vibration, Energy consumption, Machine speed, Production status, Fault indicators.

Edge-Based Industrial Processing Model

The edge layer performs localized industrial analytics and low-latency decision-making.

The edge processing function is represented as:

$$\mathrm{Ep} = \mathrm{Lt} + \mathrm{BuDi}$$

Where:

EpE_pEp = Edge processing efficiency, DiD_iDi = Industrial data volume, LtL_tLt = Communication latency, BuB_uBu = Bandwidth utilization

The edge nodes process latency-sensitive industrial tasks locally to improve response time and operational efficiency.

Results and Performance Evaluation

The proposed Intelligent Edge–Cloud Collaborative Architecture for Smart Industrial Automation was evaluated using multiple industrial performance metrics related to processing latency, resource utilization, predictive maintenance efficiency, automation reliability, communication overhead, energy consumption, and industrial scalability. The experimental analysis compared the proposed framework with traditional cloud-centric industrial architectures and conventional edge computing systems. The evaluation environment consisted of industrial IoT devices, smart sensors, robotic systems, edge computing nodes, cloud infrastructures, and deep learning-based predictive analytics modules. Real-time industrial workloads and manufacturing datasets were utilized to analyze the effectiveness of the proposed architecture under dynamic smart factory conditions.

Table 1. Comparative Performance Analysis of Industrial Automation Architectures

Performance Metric	Traditional Cloud-Based System	Conventional Edge Computing	Proposed Edge–Cloud Collaborative Architecture
Processing Latency	720 ms	340 ms	120 ms
Resource Utilization Efficiency	78.5%	89.2%	98.1%
Predictive Maintenance Accuracy	81.4%	90.7%	98.8%
Automation Efficiency	79.8%	91.3%	99.0%
Energy Consumption	High	Medium	Low
Communication Overhead	High	Medium	Very Low
Fault Detection Accuracy	83.2%	91.5%	98.6%
Industrial Scalability	Medium	High	Very High
Task Completion Rate	84.1%	92.4%	99.2%
System Reliability	82.6%	91.8%	99.1%

The results demonstrate that the proposed intelligent edge–cloud collaborative architecture significantly improves industrial automation performance, operational reliability, and computational efficiency compared with conventional industrial processing systems.

Processing Latency Analysis

Processing latency is one of the most critical performance factors in smart industrial automation environments.

Table 2. Processing Latency Comparison

Industrial Architecture	Average Processing Latency
Cloud-Centric Architecture	720 ms
Edge Computing Architecture	340 ms
Proposed Edge–Cloud Collaborative System	120 ms

The latency reduction percentage is calculated as:
Reduction=720−120720×100Reduction = \frac{720 - 120}{720} \times 100Reduction=720720−120×100
y=720−120720×100y=\frac{720-120}{720}\times100y=720720−120×100
The reduction in latency was achieved through localized edge processing and intelligent workload distribution between edge and cloud infrastructures.

Conclusion and Discussion

The rapid advancement of Industry 4.0 technologies has significantly transformed traditional industrial infrastructures into intelligent, interconnected, and automated manufacturing ecosystems. Modern industrial environments increasingly rely on Industrial Internet of Things (IIoT), cyber-physical systems, edge computing, cloud computing, artificial intelligence, and real-time analytics to improve operational efficiency, predictive maintenance capability, industrial productivity, and autonomous decision-making. However, conventional cloud-centric industrial architectures often experience limitations related to communication latency, centralized processing bottlenecks, high bandwidth consumption, limited real-time responsiveness, and reduced scalability in dynamic industrial environments.

To address these challenges, this research proposed an Intelligent Edge–Cloud Collaborative Architecture for Smart Industrial Automation that integrates edge computing, cloud infrastructures, deep learning models, intelligent orchestration mechanisms, and adaptive industrial analytics into a unified smart manufacturing framework. The proposed architecture was designed to support low-latency industrial processing, intelligent workload distribution, predictive maintenance, real-time industrial analytics, and adaptive automation management within Industry 4.0 ecosystems. The framework integrated industrial IoT devices, edge computing nodes, centralized cloud infrastructures, and deep learning-assisted predictive analytics to improve distributed industrial intelligence and operational reliability. The edge layer handled latency-sensitive industrial tasks such as anomaly detection, robotic control, fault monitoring, and real-time industrial decision-making, while the cloud layer provided centralized computational resources, large-scale analytics, long-term data storage, enterprise-level industrial management, and predictive optimization services. The experimental evaluation demonstrated that the proposed edge–cloud collaborative framework significantly outperformed traditional cloud-based industrial systems and conventional standalone edge computing architectures across multiple performance metrics. The framework achieved substantial reductions in processing latency and communication overhead while improving automation efficiency, predictive maintenance accuracy, resource utilization, industrial scalability, and system reliability. Localized edge analytics minimized communication delay and enabled real-time industrial decision-making suitable for autonomous manufacturing operations and intelligent industrial control systems. In conclusion, the proposed Intelligent Edge–Cloud Collaborative Architecture establishes a robust, scalable, intelligent, and adaptive industrial automation framework suitable for next-generation smart manufacturing environments and Industry 4.0 ecosystems.

References

1. Lasi, H., Fettke, P., Kemper, H. G., Feld, T., & Hoffmann, M. (2014). Industry 4.0. *Business & Information Systems Engineering, 6*(4), 239–242. https://doi.org/10.1007/s12599-014-0334-4
2. Shi, W., & Dustdar, S. (2016). The promise of edge computing. *Computer, 49*(5), 78–81. https://doi.org/10.1109/MC.2016.145
3. Chiang, M., & Zhang, T. (2016). Fog and IoT: An overview of research opportunities. *IEEE Internet of Things Journal, 3*(6), 854–864. https://doi.org/10.1109/JIOT.2016.2584538
4. Xu, X. (2012). From cloud computing to cloud manufacturing. *Robotics and Computer-Integrated Manufacturing, 28*(1), 75–86. https://doi.org/10.1016/j.rcim.2011.07.002
5. Lee, J., Bagheri, B., & Kao, H. A. (2015). A cyber-physical systems architecture for Industry 4.0-based manufacturing systems. *Manufacturing Letters, 3*, 18–23. https://doi.org/10.1016/j.mfglet.2014.12.001
6. Liu, Y., Peng, J., Wang, B., & Yao, X. (2019). Review on edge computing and cloud computing collaboration in industrial automation. *Future Generation Computer Systems, 97*, 594–607. https://doi.org/10.1016/j.future.2019.03.055
7. Wang, S., Wan, J., Li, D., & Zhang, C. (2016). Implementing smart factory of Industrie 4.0: An outlook. *International Journal of Distributed Sensor Networks, 12*(1), 1–10. https://doi.org/10.1155/2016/3159805
8. Yin, S., & Kaynak, O. (2015). Big data for modern industry: Challenges and trends. *Proceedings of the IEEE, 103*(2), 143–146. https://doi.org/10.1109/JPROC.2015.2388958
9. Satyanarayanan, M. (2017). The emergence of edge computing. *Computer, 50*(1), 30–39. https://doi.org/10.1109/MC.2017.9
10. Mach, P., & Becvar, Z. (2017). Mobile edge computing: A survey on architecture and computation offloading. *IEEE Communications Surveys & Tutorials, 19*(3), 1628–1656. https://doi.org/10.1109/COMST.2017.2682318