

# Industrial Internet of Things (IIoT): Trends and Technologies

Zhihao Liu <sup>1,\*</sup> , Franco Davoli <sup>2,3</sup>  and Davide Borsatti <sup>4</sup>

<sup>1</sup> Department of Production Engineering, KTH Royal Institute of Technology, 114 28 Stockholm, Sweden

<sup>2</sup> Department of Electrical, Electronic, and Telecommunications Engineering and Naval Architecture (DITEN), University of Genoa, 16145 Genova, Italy; franco.davoli@cnit.it

<sup>3</sup> CNIT National Laboratory of Smart and Secure Networks (S2N), 16145 Genova, Italy

<sup>4</sup> Department of Electrical, Electronic, and Information Engineering “Guglielmo Marconi”, University of Bologna, 40136 Bologna, Italy; davide.borsatti@unibo.it

\* Correspondence: zhihaol@kth.se

## 1. Introduction

The Industrial Internet of Things (IIoT) integrates sensors, machines, and data processing in industrial facilities to enable real-time monitoring, predictive insights, and autonomous control of equipment. Unlike the consumer Internet of Things (IoT), which focuses more on smart homes, wearables, and personal devices, the IIoT is designed to handle large volumes of high-speed data streams from critical equipment, often under harsh environmental conditions and strict safety or regulatory requirements.

Key technologies of the IIoT include advanced sensing and connectivity, edge computing, 5G and 6G communication, artificial intelligence, machine learning, digital twins, cybersecurity, interoperability, and application schemes considering specific scenarios. Specifically, high-precision sensors, low-power wide-area networks (e.g., LoRaWAN, NB-IoT), and deterministic MAC protocols ensure robust data acquisition and timely delivery. Processing data near its source reduces latency, lowers bandwidth costs, and supports real-time control loops critical for applications such as robotics and autonomous guided vehicles. Deep neural models trained on historical and streaming data drive anomaly detection, remaining-useful-life estimation, and adaptive control are significant to enhance the capabilities of IIoT applications. With growing connectivity in the IIoT, emerging standards (e.g., OPC UA, MQTT with TLS) and blockchain-backed identity management help safeguard IIoT ecosystems and simplify integration across diverse vendors.

Current trends in IIoT research include, but are not limited to, uncertainty-aware analytics that are used to distinguish true equipment faults from innocuous noise or missing readings, scalable communication strategies from optimized cache policies in CDNs to adaptive polling in LPWANs to handle ever-increasing device counts, smart IIoT frameworks, blending traditional preventive schedules with data-driven prognostics to minimize downtime and costs, and sustainable applications, such as precision agriculture and resource-efficient greenhouses, leveraging modular IIoT platforms to optimize yields while reducing the environmental impact.

## 2. Contributions

This Special Issue comprises seven contributions on the theoretical and practical research of the IIoT, including anomaly detection, learning-based content delivery performance enhancement, dynamic preventive intervals adjustment, an energy-efficient beaconing scheme, and an adaptive polling protocol, as well as case studies using the IIoT in small- and medium-sized enterprises and greenhouses.



Received: 8 May 2025

Accepted: 8 May 2025

Published: 13 May 2025

**Citation:** Liu, Z.; Davoli, F.; Borsatti, D. Industrial Internet of Things (IIoT): Trends and Technologies. *Future Internet* **2025**, *17*, 213. <https://doi.org/10.3390/fi17050213>

**Copyright:** © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

The first contribution [1], which is also a feature paper, surveys and evaluates efficient polling strategies for large-scale IIoT deployments on LoRaWANs. The paper proposes various polling mechanisms for industrial IoT applications in LoRaWANs and presents specific considerations for designing efficient polling mechanisms in the context of IIoT applications leveraging LoRaWAN technology.

In the second paper [2], the authors tackle the slow association phase in TSCH (Time-Slotted Channel Hopping) networks by proposing a dynamic beacon transmission schedule. A theoretical model is derived for the proposed mechanism to estimate the expected time for a node to get associated with the network. Simulation results obtained with different network topologies and channel conditions show that the proposed mechanism reduces the average association time and average power consumption during the network formation compared to the default minimal 6TiSCH configuration.

The next study [3] proposes GreenLab, a modular, low-cost IIoT platform for precise climate control in small greenhouses. It integrates soil moisture, temperature, humidity, and light sensors with an automated irrigation and ventilation system, all managed via a cloud-based dashboard. Field trials demonstrate consistent crop yields across variable weather, showcasing its potential for resource-efficient urban and peri-urban agriculture.

The authors of [4] propose a dual-mode framework: when no sensor data are available, a dynamic preventive policy adjusts maintenance intervals using recent failure statistics; when sensor data exist, their enhanced k-LSTM-GFT model forecasts the remaining useful life (RUL), incorporating uncertainty margins. In case studies, their dynamic preventive scheme cuts costs by up to 51.8%, while the predictive approach attains near-optimal cost savings (within 3–5%) and prevents all critical failures.

In the fifth contribution [5], the authors model CDN cache replacement as a Markov decision process and extend it to a multi-agent setting, where each edge server runs a deep Q network. Their cooperative multi-agent deep Q network (MADQN) algorithm learns to evict content in concert, adapting to shifting request patterns and network loads. The performed simulations show it consistently achieves higher cache-hit ratios and lower user-perceived latency than traditional caching policies and single-agent reinforcement learning approaches.

The sixth paper [6] uses semi-structured interviews and a thematic analysis with small- and medium-sized enterprise (SME) stakeholders to uncover the human- (management support, requisite skills) and machine-related (device compatibility, lifecycle management, data storage) factors shaping IIoT adoption. The study highlights that strong leadership buy-in and targeted skill development are just as critical as resolving technical integration risks for successful deployment in resource-constrained SMEs.

Finally, the authors of [7] introduce LSTMAE-UQ (Long Short-Term Memory Autoencoder with Aleatoric and Epistemic Uncertainty Quantification), a long short-term memory autoencoder that jointly quantifies aleatoric (data) and epistemic (model) uncertainties via Monte Carlo (MC) Dropout. By embedding noise-awareness directly into the reconstruction process, LSTMAE-UQ more reliably distinguishes genuine anomalies from noisy fluctuations or missing values. Evaluated on multiple real-world IIoT datasets, it demonstrates substantially improved robustness and lower false-alarm rates for long-periodic sensor streams.

**Conflicts of Interest:** The authors declare no conflicts of interest.

## References

1. Todoli-Ferrandis, D.; Silvestre-Blanes, J.; Sempere-Payá, V.; Santonja-Climent, S. Polling Mechanisms for Industrial IoT Applications in Long-Range Wide-Area Networks. *Future Internet* **2024**, *16*, 130. [[CrossRef](#)]

2. Ortiz Guerra, E.; Martínez Morfa, M.; García Algora, C.M.; Cruz-Enriquez, H.; Steenhaut, K.; Montejo-Sánchez, S. Enhanced Beacons Dynamic Transmission over TSCH. *Future Internet* **2024**, *16*, 187. [[CrossRef](#)]
3. Volosciuc, C.; Bogdan, R.; Blajovan, B.; Stângaciu, C.; Marcu, M. GreenLab, an IoT-Based Small-Scale Smart Greenhouse. *Future Internet* **2024**, *16*, 195. [[CrossRef](#)]
4. Nunes, P.; Rocha, E.; Santos, J. Adaptive Framework for Maintenance Scheduling Based on Dynamic Preventive Intervals and Remaining Useful Life Estimation. *Future Internet* **2024**, *16*, 214. [[CrossRef](#)]
5. Dassanayake, J.K.; Wang, M.; Hameed, M.Z.; Yang, N. Multi-Agent Deep-Q Network-Based Cache Replacement Policy for Content Delivery Networks. *Future Internet* **2024**, *16*, 292. [[CrossRef](#)]
6. Khanfor, A. Determinants to Adopt Industrial Internet of Things in Small and Medium-Sized Enterprises. *Future Internet* **2024**, *16*, 340. [[CrossRef](#)]
7. Wiessner, P.; Bezirganyan, G.; Sellami, S.; Chbeir, R.; Bungartz, H.-J. Uncertainty-Aware Time Series Anomaly Detection. *Future Internet* **2024**, *16*, 403. [[CrossRef](#)]

**Disclaimer/Publisher's Note:** The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.