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Integration of Emerging Technologies in the Industrial Internet of Things to Improve Efficiency

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The Industrial Internet of Things (IIoT) has emerged as a cornerstone of the Internet of Things, particularly with the advent of the fourth industrial revolution. This realm is characterized by the integration of emerging technologies such as blockchain, machine learning, and 5G networks into industrial systems, aiming to enhance their processes and increase efficiency. In this context, the present work focuses on conducting a systematic literature review to identify the most commonly used technologies in IIoT and those that provide the greatest benefits in terms of performance efficiency for IIoT systems. Through this comprehensive review, the aim is to better understand the current technological landscape in the field of IIoT and highlight the most relevant innovations driving continuous improvement in the industry. This study will not only contribute to advancing knowledge in this field but also provide valuable guidance for the effective implementation of technologies in constantly evolving industrial environments.

Keywords: Industrial Internet of Things, Emerging Technologies, Efficiency.

1. Introduction

The Internet of Things (IoT) is a concept that involves connecting various ordinary objects, such as smartphones, sensors, and actuators, to enable communication between people and things, as well as between things themselves (Nourildean et al., 2022). It aims to establish a network where physical devices can communicate with each other (Suram, 2022). One specific type of IoT is the Industrial Internet of Things (IIoT), which focuses on interconnected devices in the manufacturing industry to enhance automation, control, and energy efficiency in smart factories (Ziegler et al., 2019; Genge et al., 2019). The IIoT involves machine-to-machine (M2M) communication technologies used in smart factories and automation fields (Ungurean & Gaitan, 2020).

The integration of IoT in the manufacturing industry has led to the development of the Industrial Internet of Things (IIoT), which connects supply chains, data, and people, transforming traditional industries into smart environments (Butt, 2020). The IIoT facilitates fine-grained access control in industrial settings, enhancing security measures (Ziegler et al., 2019). Moreover, the IIoT has been designed to improve automation, control, and orchestration in industrial systems while enhancing energy efficiency (Genge et al., 2019).

As an essential component of the "Industry 4.0" initiative, IoT systems, production equipment, industrial software systems, and production control systems are interconnected through the IIoT (Yuan-guo et al., 2021). The IIoT plays a crucial role in securing manufacturing intelligence by collecting and managing data from IIoT devices for predictive analytics in industries like manufacturing (Al-Aqrabi et al., 2020). Additionally, the IIoT enables real-time monitoring and control in various industrial applications, such as wastewater management (Salem et al., 2022).

The Industrial Internet of Things (IIoT) integrates, in addition to sensors, intelligent devices, and automated processing machines, emerging technologies that provide greater capabilities and strengthen the objectives of IIoT systems.

Emerging technologies are playing a crucial role in integrating with the Industrial Internet of Things (IIoT) to enhance industrial operations. One significant technology that is being integrated with IIoT is blockchain. Blockchain technology is being utilized to secure data and transactions in IIoT settings, ensuring data protection and enabling secure communication within industrial systems Alladi et al. (2019)Yu et al., 2022). This integration of blockchain with IIoT is essential for realizing the potential of Industry 4.0 and ensuring the security and integrity of industrial processes.

Another emerging technology that is being integrated with IIoT is cloud computing. The combination of IIoT and cloud computing is enabling remote control, operational efficiency upgrades, and real-time big data monitoring in industrial control systems, leading to more efficient and intelligent industrial operations (Lee et al., 2022). Cloud computing provides the necessary infrastructure for storing and processing the vast amounts of data generated by IIoT devices, enabling real-time analytics and decision-making in industrial settings.

Moreover, the integration of machine learning with IIoT is another emerging trend. Machine learning algorithms are being used in IIoT systems to enhance security measures, specifically through the integration of intrusion detection systems (IDS) with machine learning for Industry 4.0 resilience (Idouglid, 2024). This integration allows for the detection of anomalies and potential threats in industrial systems, ensuring the continuous operation and security of IIoT networks.

Additionally, the convergence of wireless power transfer (WPT) and mobile edge computing (MEC) is fostering the rise of wireless powered MEC, which is crucial for the sustainability of IIoT systems (Wu et al., 2020). This integration ensures that IIoT devices have a continuous and reliable source of power, enabling seamless communication and operation in industrial environments.

The integration of blockchain, cloud computing, machine learning, and wireless powered MEC technologies with the Industrial Internet of Things (IIoT) is revolutionizing industrial operations by enhancing security, efficiency, and reliability in manufacturing processes.

The present study focuses on conducting a systematic literature review to determine the most utilized emerging technologies in the Industrial Internet of Things (IIoT) for enhancing the efficiency of these systems. The undertaking of this research holds significant importance within the context of the IIoT with the aim of improving the efficiency of these systems, it will contribute to advancing knowledge in this field, providing an updated guide for researchers and professionals, fostering the adoption of innovative technologies in industrial environments, and driving the development of more efficient and productive solutions for the industry. This study will offer a comprehensive view of technological trends in IIoT, allowing for process optimization, cost reduction, and enhancement of competitiveness for organizations in an increasingly digitized and automated environment.

2. Background

Emerging technologies in industrial areas are revolutionizing manufacturing processes and enhancing operational efficiency. Among these technologies, blockchain is playing a significant role in Industry 4.0 applications by ensuring secure data transactions and communication Bodkhe et al. (2020)Dwivedi et al., 2021). Cloud computing is another crucial technology integrated with the Industrial Internet of Things (IIoT) to enable remote control, real-time monitoring, and efficient data processing in industrial settings (Swamy & Raju, 2020; Rehman et al., 2021). Machine learning is increasingly utilized in industrial IoT systems to enhance security measures and enable predictive analytics (Wang et al., 2019; Dangana et al., 2021).

Wireless communication technologies are pivotal in industrial environments, with studies focusing on channel models and the suitability of technologies like Narrowband IoT (NB-IoT) for industrial applications (Salih et al., 2022; Yli-Ojanperä et al., 2019). The convergence of wireless power transfer and mobile edge computing is also gaining traction, ensuring reliable power supply for IoT devices in industrial settings (Zhou et al., 2023; Vijayakumaran et al., 2020). Additionally, artificial intelligence is being deployed to secure IoT in industrial environments, addressing cybersecurity challenges and ensuring the integrity of Industry 4.0 technologies (Λαμπρόπουλος et al., 2019; Meng, 2022).

The Internet of Things (IoT) is being leveraged in various industrial sectors such as oilfield development, construction, and the hospitality industry to drive innovation and enhance operational efficiency (Mahmood & Abdul-Jabbar, 2023; Satheesh, 2020; Fatima et al., 2019). The adoption of IoT technologies in sustainable construction and the maritime industry is also being modeled to improve processes and sustainability (Ahmad et al., 2019; Wang et al., 2021). Overall, these emerging technologies are reshaping industrial landscapes, driving digital transformation, and optimizing operational processes in various sectors.

The evolving technologies utilized in the Internet of Things (IoT) landscape encompass a variety of innovative solutions that are reshaping connected systems. Among these technologies, blockchain stands out as a prominent tool for enhancing security and data integrity in IoT applications Bodkhe et al. (2020)Al-Turjman et al., 2019). By leveraging blockchain technology, IoT systems can ensure secure data transactions and communication, thereby enhancing the trustworthiness of interconnected devices.

Cloud computing is another prevalent technology extensively integrated with IoT to enable remote control, real-time monitoring, and efficient data processing in IoT ecosystems

(Nižetić et al., 2020; Bellini et al., 2022). The synergy between cloud computing and IoT empowers industrial control systems with enhanced operational capabilities and scalability, facilitating advanced analytics and decision-making processes.

Machine learning is also a key technology increasingly utilized in IoT systems to enhance security measures and enable predictive analytics (Zhou et al., 2023; Khanam et al., 2020). By integrating machine learning algorithms, IoT applications can detect anomalies, predict potential threats, and enhance the resilience of Industry 4.0 environments.

The convergence of wireless power transfer (WPT) and mobile edge computing (MEC) is gaining traction in IoT deployments, particularly in industrial settings (Shi et al., 2019; Meng, 2022). This integration ensures continuous and reliable power supply to IoT devices, fostering seamless communication and operation in industrial IoT environments.

3. Systematic Literature Review

We followed B. Kitchenham's proposed methodology to conduct a Systematic Literature Review (SLR). An SLR is a rigorous process used by researchers to thoroughly examine and document the current state of knowledge on a specific topic. It involves analyzing and identifying relevant information to address research questions systematically within a defined area of interest. This SLR consisted of the following steps: (1) Establishing a review protocol and defining research questions (outlined in Section 3), (2) Conducting the review by identifying and evaluating primary studies (discussed in Section 3), (3) Extracting the findings (detailed in Section 4), and (4) Discussing and analyzing the results of the systematic literature review (elaborated on in Section 4).

Research Questions

To address the objectives outlined in the introduction, two research questions were defined. As such, the following inquiries were formulated:

Research Question 1 (RQ1): What are the emerging technologies that integrate with IoT for the Industrial Internet of Things (IIoT)?

This question is essential to identify the technologies that are being integrated within the IIoT framework, providing an understanding of the tools and resources available to enhance industrial systems.

Research Question 2 (RQ2): Which of these emerging technologies contribute most to the efficiency of IIoT systems?

This question aims to determine which specific technologies have the greatest impact on the efficiency of IIoT systems. Identifying these technologies is crucial for prioritizing the implementation of solutions that maximize performance and productivity in industrial environments.

PICO Review protocol.

This research utilized the B. Kitchenham model in conjunction with the PICO (Population, Intervention, Comparison, and Outcome) protocol, a validated and widely acknowledged framework for conducting systematic literature reviews. This selection was made due to the protocol's established reliability, ensuring a robust methodological approach to the study.

- Population: This encompasses pertinent literature focusing on the prevalent methodologies and architectures employed in the deployment of IoRT systems.
- Intervention: This involves analyzing research papers that explore the various methodologies and architectures commonly utilized in IoRT systems.
- Comparison: This entails identifying and correlating the methodologies and architectures applied in IoRT systems, and their adaptations to diverse use cases and environments.
- Outcome: This aims to identify the frequently utilized methodologies and architectures in IoRT system deployment and assess their adaptability and efficacy.

Research and string generation

Selecting keywords that represent the research topic enabled us to obtain relevant and comprehensive results from studies that delve into the application of methodologies in IIoT. Furthermore, including synonyms for the keywords enhances the precision and effectiveness of constructing the search string, as demonstrated in Table 1.

Table 1. Keywords and synonyms used

Keyword	**Synonyms**
Industrial Internet of Things	IIoT
emerging technologies	New technologies
system efficiency	efficiency improvement

The choice of keywords in this search string is crucial for precisely defining the scope of research in the IIoT. By including terms such as "IIoT" and "emerging technologies," the latest advancements in the technological field are encompassed. Additionally, terms like "system efficiency" highlight the central objective of the research: enhancing efficiency in industrial systems. By combining these keywords with "AND," a focused and comprehensive search is ensured.

Criteria

We referred to the selection criteria for information sources, considering the methods used by Dyba et al. and Petersen et al. Key criteria encompassed open access to information from publications identified using the search string and the publication timeframe. The chosen scientific databases are 1) ACM Digital Library, 2) IEEE Digital Library, 3) ScienceDirect, 4) Scopus, and 5) Springer Link. The search string described in the following section was applied across these scientific databases.

Inclusion Criteria:

Open Access Studies: Only studies that offer unrestricted access to their content were incorporated.

Full Text Studies: All chosen studies were scrutinized to ascertain they presented comprehensive information, with preference given to those with complete availability.

Studies Within the Period: Studies were vetted to confirm they were published within the designated timeframe from 2015 to 2024, ensuring the currency and relevance of information for this SLR.

Consistency of the Study: Only studies pertinent to the IIoT field were incorporated, focusing on technologies and performance of IioT systems.

Content of the Study: The primary content of the studies was verified to confirm alignment with research questions RQ1 and RQ2. This assessment entailed reviewing the title, abstract, and keywords of the respective studies.

Accurate Digital Libraries: The confidence, quality, and quantity of studies available in the five mentioned digital libraries were evaluated.

Exclusion Criteria:

Studies Influenced by a Single Point of View: Studies presenting a singular viewpoint without addressing applied methodologies or architectures for IIoT were omitted from consideration.

Studies Not Related to the Topic: Studies not directly related to research questions RQ1 and RQ2, focusing on emerging technologies and the efficiency of IIoT.

Studies Addressing IoRT in Other Contexts: Studies that did not specifically focus on methodologies, architectures, guidelines, strategies, best practices, or techniques related to IoRT were excluded.

Studies Published Before 2019: To ensure relevance and up-to-date information, studies published before 2019 were omitted, considering the rapid advancements in IoRT.

Studies from Non-Traditional Publishers: To ensure currency and relevance of information, studies published before 2019 were excluded, acknowledging the rapid evolution of IIoT.

Elimination of Duplicate Studies: To prevent redundancy, duplicate studies identified within the chosen digital libraries were removed.

Selection of Primary Studies

To identify primary studies for the research, a three-phase exclusion process was conducted. In the initial phase, the number of studies retrieved from each scientific database using the search string was recorded, resulting in a total of 736 studies, as outlined in Table 2. During the second phase, inclusion and exclusion criteria were applied based on a brief examination of the title, abstract, and keywords of each publication. This process led to the acceptance of 133 studies. Subsequently, in the third phase, a comprehensive review of each study was undertaken to determine the presence of relevant information and alignment with the research topic. Following the completion of the primary study selection phases, 16 studies were identified as suitable for inclusion, forming the foundational basis of this research article.

4. Results, analysis and interpretation.

Following the systematic literature review, the analysis focused on how the findings related to the research goals. Studies were sorted based on their relevance to the study's two main aims: (a) pinpointing prevalent emerging technologies in IIoT, and (b) evaluating technologies that bolster the efficiency of IIoT systems.

Discussion of the results of RQ1

Several key technologies are playing a crucial role in shaping the future of IIoT:

1. Pervasive Edge Computing (PEC) enabled by 5G and beyond. Narayanan et al. (2020): PEC is a critical technology for IIoT, allowing for real-time data processing at the edge of the network, reducing latency and improving overall system efficiency.

2. Blockchain integration with 5G networks. Kaur et al. (2022): Blockchain technology enhances security and transparency in IIoT systems, ensuring the integrity of data and transactions within industrial environments.

3. Machine Learning (ML) for Industry 4.0. Zhou et al. (2023): ML algorithms are instrumental in analyzing vast amounts of data generated by IIoT devices, enabling predictive maintenance, quality control, and process optimization in industrial settings.

4. Cloud Manufacturing and Cloud Computing. Haghnegahdar et al. (2022): Leveraging cloud technologies in IIoT enables scalable and flexible manufacturing processes, facilitating intelligent additive manufacturing and enhancing overall operational efficiency.

5. Privacy Protection and Energy Optimization in 5G-Aided IIoT. Humayun et al. (2020): Ensuring privacy and optimizing energy consumption are crucial aspects of IIoT systems, especially with the integration of 5G technology in industrial environments.

6. Blockchain-Based Scalable Domain Access Control. Usman (2024): Access control frameworks based on blockchain technology provide secure and scalable solutions for managing access to IIoT devices and data.

These technologies collectively contribute to the advancement of IIoT, enabling smart manufacturing, predictive maintenance, enhanced security, and improved operational efficiency in industrial settings.

Table 2. Selected studies by source

Source	**Initial studies (First activity)**	**Relevant studies (Second activity)**	**Primary studies Task 1(Third activity)**	**Primary studies Task 2(Third activity)**
ACM Digital Library (ACM)	51	1	0	0
IEEE Digital Library (IEEE)	312	37	21	7
Springer Link (SP)	66	29	5	3
Science Direct (SD)	137	19	5	3
Scopus (SC)	170	47	10	3
Total	**736**	**133**	**51**	**16**

Discussion of the results of RQ2

The efficiency of Industrial Internet of Things (IIoT) systems can be significantly enhanced by the integration of various emerging technologies. Among the technologies mentioned, Pervasive Edge Computing (PEC) enabled by 5G and beyond stands out as a crucial contributor to efficiency (Narayanan et al., 2020). PEC allows for real-time data processing at the edge of the network, reducing latency and improving system efficiency, which is essential for optimizing operations in industrial settings.

Machine Learning (ML) plays a vital role in improving efficiency within IIoT systems (Zhou et al., 2023). ML algorithms enable the analysis of large volumes of data generated by IIoT devices, facilitating predictive maintenance, quality control, and process optimization. By leveraging ML capabilities, industrial processes can be streamlined and made more efficient.

Cloud Manufacturing and Cloud Computing technologies are instrumental in enhancing the efficiency of IIoT systems (Haghnegahdar et al., 2022). By utilizing cloud-based solutions, manufacturers can achieve scalability, flexibility, and intelligent manufacturing processes, ultimately leading to improved operational efficiency and productivity.

Adoption of Blockchain With 5G Networks Kaur et al. (2022): Blockchain technology enhances security and transparency in IIoT systems, ensuring the integrity of data and transactions. By providing a secure and tamper-proof data storage and exchange mechanism, blockchain contributes to the efficiency and reliability of IIoT systems.

While various emerging technologies contribute to the efficiency of IIoT systems, Pervasive Edge Computing, Machine Learning, Blockchain and Cloud Manufacturing technologies play significant roles in driving efficiency improvements within industrial environments.

5. Conclusions

The adoption of emerging technologies such as Machine Learning, Pervasive Edge Computing, Cloud Manufacturing, and Blockchain in Industrial Internet of Things (IIoT) systems is becoming increasingly prevalent. These technologies are often integrated to create comprehensive solutions that address various aspects of industrial operations, from data processing and analysis to security and connectivity. This integration allows for a comprehensive approach to addressing various aspects of industrial processes, promoting sustainable economic development by increasing efficiency and reducing waste.

The utilization of these advanced technologies has led to a significant improvement in operational efficiency within industrial settings. By leveraging Machine Learning for predictive maintenance, Pervasive Edge Computing for real-time data processing, Cloud Manufacturing for scalable production processes, and Blockchain for secure data transactions, organizations can streamline their operations, reduce downtime, optimize resource utilization, and ultimately enhance productivity. These technologies enable predictive maintenance, real-time data processing, scalable manufacturing processes, and secure data transactions.

The strategic adoption and integration of these emerging technologies in IIoT systems have not only revolutionized industrial processes but have also paved the way for more efficient, secure, and intelligent operations in the Industry 4.0 era.

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