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IoT for Machine Maintenance: A Bibliometric Study

Loso Judijanto
IPOSS Jakarta, Indonesia

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ABSTRACT

This study explores the role of the Internet of Things (IoT) in machine maintenance, focusing on its integration with artificial intelligence (AI) and its impact on operational efficiency across various industries. A bibliometric analysis was conducted using data from Scopus, identifying key research trends, influential publications, and emerging technologies within the field. The findings highlight the increasing adoption of IoT for predictive maintenance in manufacturing, energy, and agriculture sectors. The study also reveals the growing intersection between IoT, machine learning, and data analytics, which enhances predictive capabilities and resource management. The results emphasize the importance of real-time monitoring and decision-making in improving industrial operations. However, challenges such as data security, interoperability, and adoption costs remain barriers to full implementation. This study provides valuable insights into the current state of research on IoT for machine maintenance, offering a foundation for future technological advancements and research directions.

Corresponding Author:

Name: Loso Judijanto
Institution: IPOSS Jakarta, Indonesia
Email: losojudijantobumn@gmail.com

1. INTRODUCTION

The advent of the Fourth Industrial Revolution has been characterized by the integration of digital technologies into traditional industrial operations, significantly transforming production and maintenance paradigms [1]. Among these technologies, the Internet of Things (IoT) has emerged as a critical enabler of smart manufacturing. IoT refers to a network of interconnected devices capable of collecting, exchanging, and analyzing data to enhance decision-making processes [2]. In the context of industrial operations, IoT facilitates real-time monitoring of machines, enabling predictive and proactive maintenance strategies that minimize downtime and extend the operational life of equipment. This paradigm shift represents a movement from reactive maintenance approaches, which rely on repairs after failures, to predictive models that leverage continuous data streams to anticipate potential breakdowns [2].

Machine maintenance is a critical aspect of industrial efficiency, directly influencing productivity, safety, and operational costs. Traditional maintenance strategies, such as preventive maintenance, are often scheduled based on fixed intervals, regardless of the actual condition of the machinery [3]. While preventive maintenance can reduce unexpected failures, it frequently leads to unnecessary maintenance activities and associated costs. In contrast, IoT-driven maintenance enables condition-based monitoring, which relies on real-time data on machine performance, vibration, temperature, and other operational parameters [4]. This approach allows organizations to optimize maintenance schedules, reduce operational costs, and enhance overall equipment effectiveness (OEE). Consequently, the integration of IoT into maintenance practices has gained considerable attention from both researchers and industry practitioners seeking to improve operational efficiency.

The proliferation of IoT technologies in industrial maintenance has also led to a substantial increase in scientific publications and research studies. Bibliometric analyses have become essential tools for understanding the evolution, trends, and impact of research within this domain [5]. Through quantitative mapping of literature, bibliometric studies provide insights into research productivity, collaborative networks, key authors, influential journals, and emerging research topics. Such analyses are particularly valuable for scholars and practitioners aiming to identify knowledge gaps and prioritize future research directions. In the context of IoT-based machine maintenance, bibliometric studies can elucidate how research efforts have evolved over time, highlight dominant research themes, and provide a consolidated view of the knowledge structure in this interdisciplinary field.

The integration of IoT for machine maintenance also intersects with other emerging technologies, including artificial intelligence (AI), machine learning (ML), and cloud computing. AI and ML algorithms are commonly employed to process the vast amounts of data generated by IoT sensors, enabling predictive analytics and anomaly detection [1]. Cloud computing facilitates data storage, processing, and accessibility, allowing maintenance data to be analyzed remotely and in near real-time. Moreover, the convergence of these technologies supports the development of smart factories, where autonomous systems can self-diagnose, self-optimize, and self-maintain with minimal human intervention [6]. This integration represents a significant shift towards Industry 4.0, emphasizing efficiency, sustainability, and resilience in industrial operations.

Despite the growing interest in IoT-driven maintenance, challenges remain regarding the adoption and implementation of these technologies. Industrial organizations often face technical, economic, and organizational barriers when integrating IoT solutions into their maintenance frameworks. Technical challenges include interoperability among heterogeneous devices, standardization of communication protocols, and data security concerns. Economically, the high initial investment costs and uncertainty regarding return on investment can deter small and medium-sized enterprises from adopting IoT-based maintenance solutions. Organizationally, workforce skills and resistance to change can hinder successful implementation. These challenges underscore the need for a comprehensive understanding of the research landscape to inform both academic inquiry and industrial practice.

Despite the increasing research on IoT for machine maintenance, there remains a lack of comprehensive bibliometric analyses that systematically map the evolution of scientific knowledge in this field. Most studies have focused on case studies or technological implementations, leaving a fragmented understanding of research trends, influential authors, collaboration networks, and emerging topics. Consequently, scholars and practitioners lack consolidated insights into the development, gaps, and future directions of IoT-enabled maintenance research. This knowledge gap limits the ability to strategize further research and hinders the adoption of best practices in industrial maintenance. This study aims to conduct a comprehensive bibliometric analysis of IoT applications in machine maintenance.

2. METHODS

This study employs a bibliometric research approach to systematically analyze the scientific literature on IoT applications in machine maintenance. Bibliometric analysis is a quantitative method used to examine the development, trends, and structure of research within a specific domain by analyzing publication metadata such as authorship, journals, keywords, citations, and collaboration networks [5]. The objective of this method is to provide a comprehensive overview of the research landscape, identify influential publications and authors, and uncover emerging themes and research gaps. This approach is particularly suitable for interdisciplinary fields like IoT-based machine maintenance, where the literature spans multiple domains including manufacturing, computer science, and industrial engineering.

The data for this bibliometric study were collected from Scopus, which are widely recognized for their coverage of peer-reviewed journals and conference proceedings. The search strategy involved a combination of keywords related to "Internet of Things," "IoT," "machine maintenance," "predictive maintenance," and "smart maintenance," ensuring comprehensive retrieval of relevant publications. Inclusion criteria were applied to select articles published in English between 2010 and 2025, reflecting the period of significant growth in IoT applications for industrial maintenance. After removing duplicates and irrelevant entries, the resulting dataset was cleaned and prepared for further analysis.

Data analysis was conducted using VOSviewer, which enable visualization of co-authorship networks, keyword co-occurrences, citation patterns, and thematic evolution over time [7]. Co-occurrence analysis of keywords was performed to identify major research themes and trends, while citation and co-citation analyses helped determine the most influential articles, authors, and journals in the field. The results from these analyses were synthesized to generate a comprehensive overview of the research landscape, highlight knowledge gaps, and inform recommendations for future research directions.

3. RESULTS AND DISCUSSION

3.1 Keyword Co-Occurrence Network

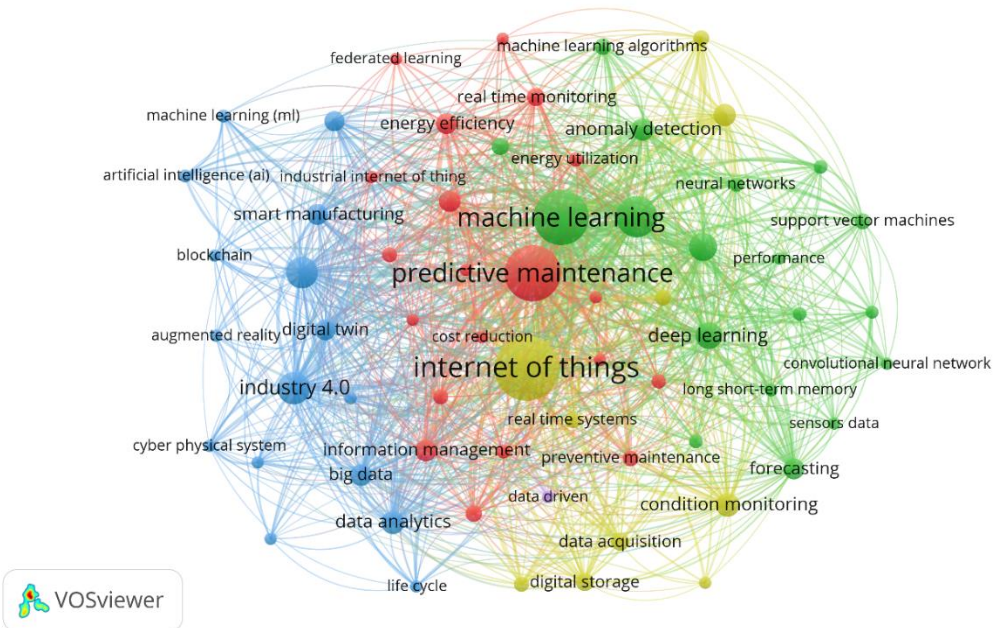

Figure 1. Network Visualization
Source: Data Analysis Result, 2025

Figure 1 highlighting the relationship between various terms in the field of Internet of Things (IoT) for machine maintenance. The map clusters terms into different colors based on their co-occurrence in the research literature. The largest cluster, in red, is centered around "machine learning," which appears to be a dominant theme in predictive maintenance applications for IoT. Machine learning techniques like "anomaly detection," "support vector machines," and "deep learning" are tightly connected, emphasizing their importance in detecting failures and predicting maintenance needs in industrial settings.

The green cluster focuses on "predictive maintenance" and is closely tied to terms such as "condition monitoring," "forecasting," and "data acquisition." These terms suggest a shift from traditional maintenance methods to more data-driven, real-time approaches. Predictive maintenance leverages IoT data to predict equipment failure before it happens, thus optimizing maintenance schedules and minimizing downtime. The link between "machine learning" and "predictive maintenance" highlights the integration of AI models for better prediction accuracy and resource management.

The blue cluster is primarily concerned with foundational IoT and Industry 4.0 concepts. Keywords like "industrial internet of things," "smart manufacturing," and "cyber physical systems" point to the evolving landscape of interconnected systems that combine physical machinery with advanced computing and network capabilities. These interconnected systems provide the data needed for more intelligent and efficient predictive maintenance models, fostering a more responsive and automated manufacturing environment.

The yellow cluster incorporates terms such as "real-time systems," "digital storage," and "data analytics." This cluster underscores the importance of managing and processing large amounts of data in real-time, a key feature in IoT for machine maintenance. The connection between "data analytics" and "real-time monitoring" shows that data must not only be collected but also analyzed promptly to trigger maintenance actions. Additionally, terms like "big data" and "information management" highlight the critical role of data infrastructure in supporting IoT-based predictive maintenance.

The purple and red terms emphasize the technological advancements, including "blockchain" and "augmented reality," which are emerging in the IoT space. Blockchain, for instance, could be applied to ensure the integrity and security of data transmitted across IoT networks. Augmented reality (AR) could enhance maintenance operations by providing real-time visual support to technicians.

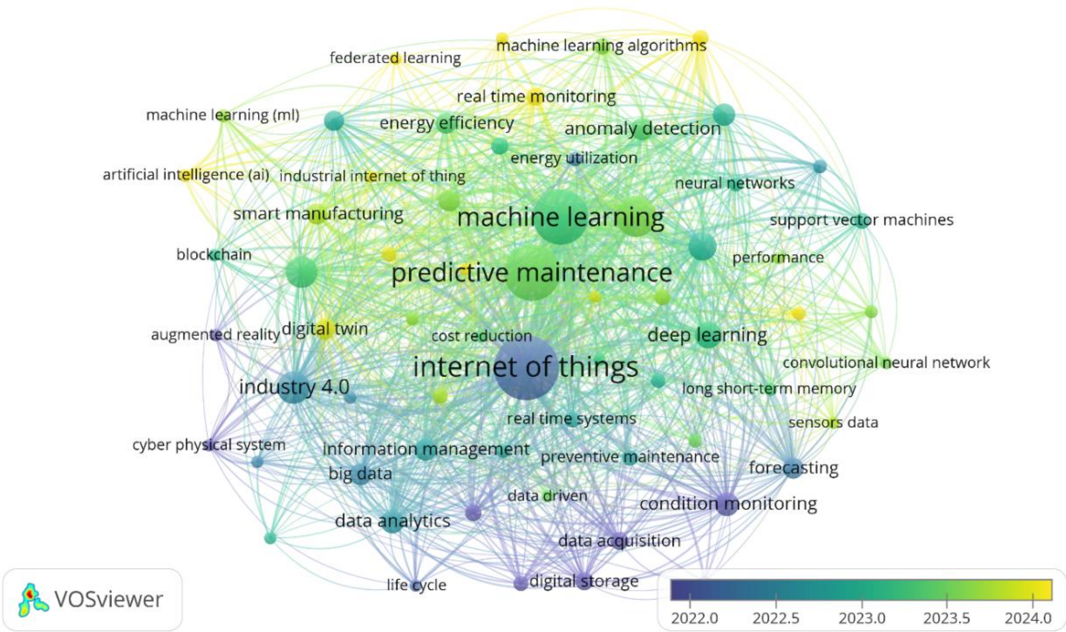

Figure 2. Overlay Visualization
Source: Data Analysis Result, 2025

Figure 2 focusing on the field of IoT for machine maintenance, with a temporal component highlighted by the color scale at the bottom. The colors range from 2022 (represented in blue) to 2024 (represented in yellow), allowing us to observe the progression and emerging trends in research. The larger and more interconnected nodes, such as "machine learning" and "predictive maintenance," reflect the ongoing focus in recent literature, while terms like "real-time monitoring," "anomaly detection," and "data-driven" show a steady rise in importance as time progresses. The map also indicates the growing interest in integrating multiple technologies, including "artificial intelligence (AI)," "big data," and "smart manufacturing." These terms are particularly prominent in more recent research, with AI and machine learning continuing to play central roles in advancing predictive maintenance capabilities.

The emergence of concepts like "energy efficiency" and "energy utilization" aligns with the increasing emphasis on sustainability and efficiency within IoT systems for machine maintenance. Additionally, terms such as "blockchain" and "augmented reality" are gaining traction, signaling their potential applications in securing IoT networks and enhancing maintenance processes through visual and data-driven support. The temporal scale depicted by the colors shows that research on IoT for machine maintenance is gradually evolving towards more complex and integrated approaches. The transition from 2022 to 2024 demonstrates an increasing focus on predictive capabilities, real-time data processing, and advanced machine learning models like "deep learning" and "neural networks." These advancements indicate that the field is progressing towards more sophisticated, data-rich solutions for machine maintenance, where real-time decision-making and predictive accuracy are key areas of development.

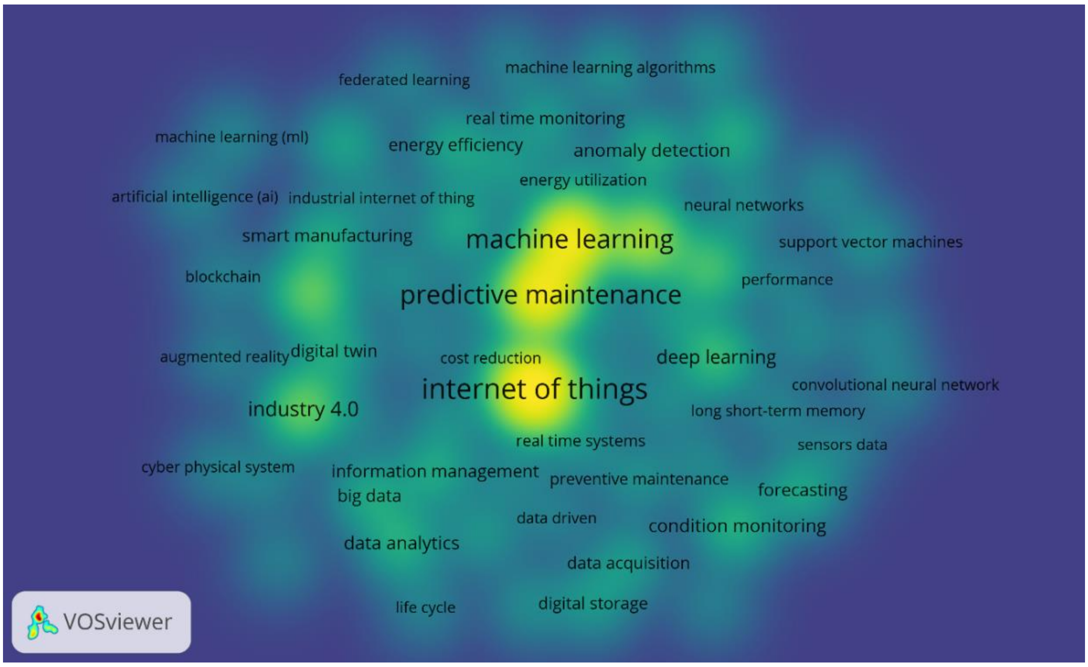

Figure 3. Density Visualization
Source: Data Analysis, 2025

Figure 3 reveals the density of research topics in the domain of IoT for machine maintenance. The most densely connected and emphasized terms are "machine learning" and "predictive maintenance," surrounded by key concepts like "real-time monitoring," "anomaly detection," "energy efficiency," and "data-driven." These dense clusters indicate that these topics are central to recent studies in this field, particularly in using machine learning and data analytics to optimize maintenance processes and improve predictive capabilities in industrial settings. The prominence of terms such as "support vector machines," "deep learning," and "neural networks" suggests a growing focus on sophisticated AI techniques to enhance predictive accuracy.

The fading of research intensity toward the outer regions of the map, marked by cooler colors, shows a diminishing focus on certain older or less explored topics such as "blockchain," "augmented reality," and "digital twin," despite their potential relevance. However, the map clearly reflects that machine learning, predictive maintenance, and IoT are at the forefront of research, with an increasing emphasis on real-time systems, condition monitoring, and forecasting.

3.2 Co-Authorship Network

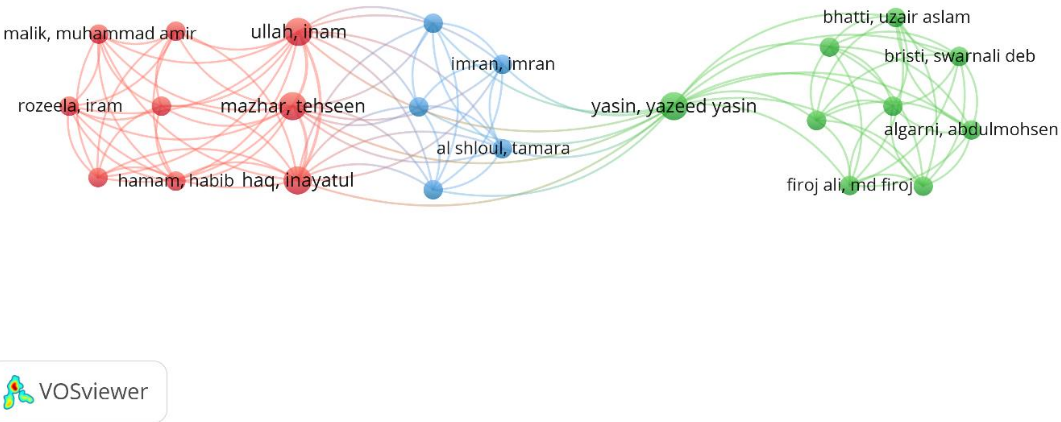

Figure 4. Author Collaboration Visualization

Source: Data Analysis, 2025

Figure 4 visualizes the co-authorship relationships between researchers in a particular study. The clusters are color-coded to show groupings of researchers based on their collaboration. The red cluster, which includes authors like "Ullah Inam," "Rozeela Iram," and "Hamam Habib Haq Inayatul," represents a group of researchers who have frequently collaborated. Similarly, the blue cluster, which features "Imran Imran" and "Al Shloul Tamara," indicates another group with shared co-authorship. The green cluster, including "Yasin Yazeed Yasin," "Uzair Aslam Bhatti," and "Bristi Swarnali Deb," represents a distinct set of researchers. The strength of the connections between nodes within each cluster reflects the frequency and intensity of their collaborative efforts.

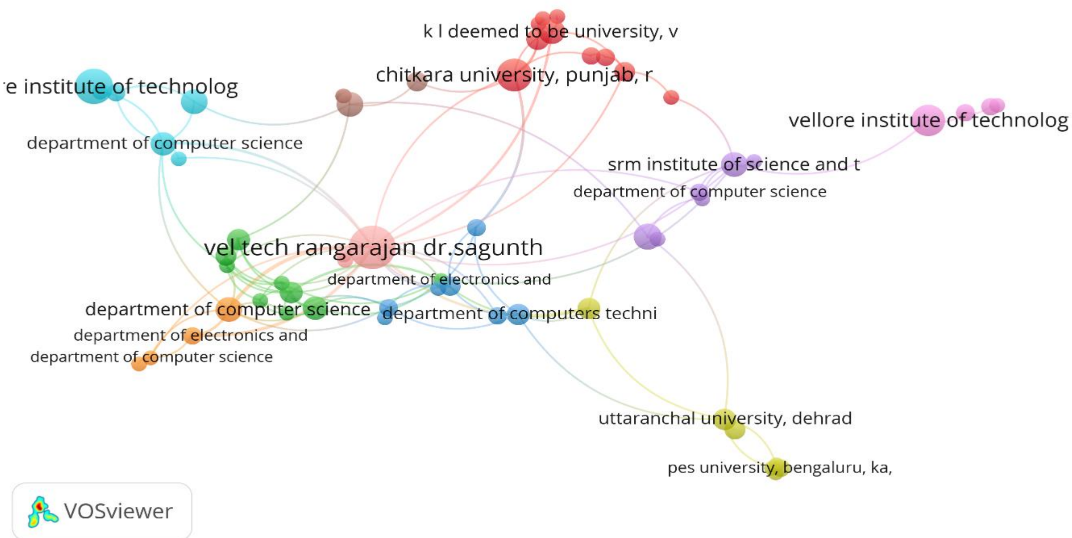

Figure 5. Affiliation Collaboration Visualization

Source: Data Analysis, 2025

Figure 5 isualizes the collaboration between various universities and departments, with the nodes representing institutions and departments in the field of computer science and electronics. The color-coded clusters indicate how different institutions and departments are connected based on their co-authorship or collaborative projects. For instance, institutions like "VIT University," "Veltech Rangarajan Dr. Sagunth University," and "Chitkara University" form distinct groups, showcasing their internal collaborations. Some institutions, like "VIT University" and "SRM Institute of Science and Technology," are linked by shared research or collaborations in computer science. The map also highlights various departments, such as "Department of Computer Science" and "Department of Electronics," reflecting how different academic units within the same university or across different institutions collaborate.

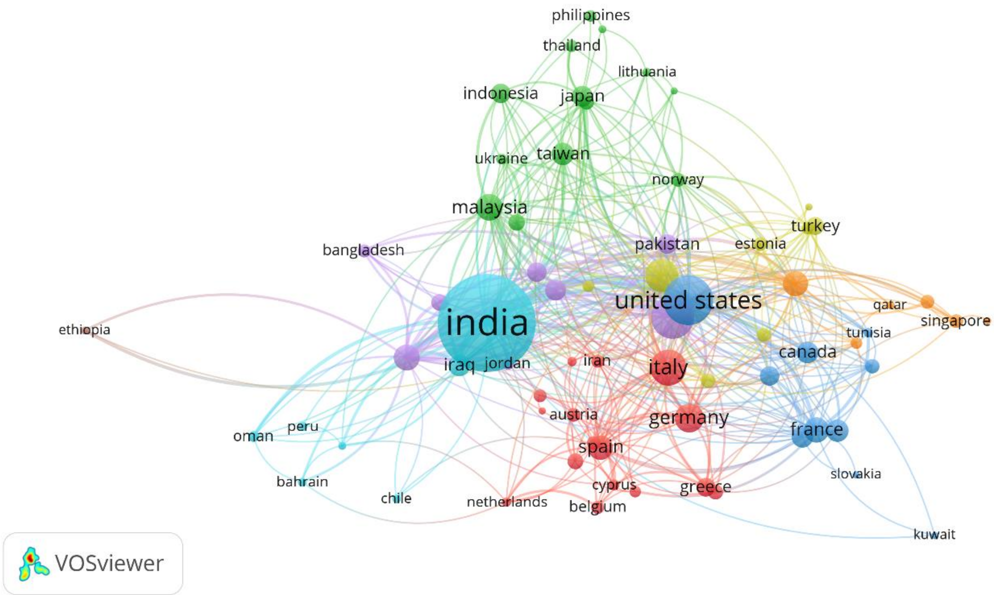

Figure 6. Country Collaboration Visualization
Source: Data Analysis, 2025

Figure 6 visualizes the global co-authorship relationships between countries, highlighting the frequency of collaborations in research. The map is color-coded to reflect clusters of countries with strong co-authorship connections. The central nodes, "India" and "United States," are the largest and most interconnected, indicating that they have the most frequent collaborative research links with other countries. Surrounding them are countries such as "Germany," "Italy," "France," and "Spain," forming dense clusters in red and blue, showing significant collaborations within Europe. The green cluster, including "Malaysia," "Indonesia," and "Thailand," represents Southeast Asian countries with strong research networks. Other countries, like "Canada," "Turkey," and "Singapore," are more isolated but still show notable connections with specific regions.

3.3 Citation Analysis

Table 1. Top Cited Research

Citations	Authors and year	Title
893	[8]	Artificial intelligence in sustainable energy industry: Status Quo, challenges and opportunities

Citations	Authors and year	Title
641	[9]	From Artificial Intelligence to Explainable Artificial Intelligence in Industry 4.0: A Survey on What, How, and Where
554	[10]	Industrial internet of things: Recent advances, enabling technologies and open challenges
428	[11]	Internet of things for smart factories in industry 4.0, a review
426	[1]	Data-driven predictive maintenance planning framework for MEP components based on BIM and IoT using machine learning algorithms
417	[2]	Predictive maintenance system for production lines in manufacturing: A machine learning approach using IoT data in real-time
322	[12]	Augmented reality in support of intelligent manufacturing – A systematic literature review
307	[13]	A survey on the 5G network and its impact on agriculture: Challenges and opportunities
281	[14]	Data Collection and Wireless Communication in Internet of Things (IoT) Using Economic Analysis and Pricing Models: A Survey
272	[15]	Remaining Useful Life prediction and challenges: A literature review on the use of Machine Learning Methods

Source: Scopus, 2025

Table 1 presents the top cited research in the field of Artificial Intelligence (AI), the Internet of Things (IoT), and Industry 4.0, showcasing the most influential papers published in recent years. The paper by [8], titled "Artificial intelligence in sustainable energy industry: Status Quo, challenges and opportunities," leads the list with 893 citations, reflecting the growing importance of AI in driving sustainability within energy industries. Other highly cited works focus on the application of AI and IoT in manufacturing and predictive maintenance, such as the studies by [10] on Explainable AI in Industry 4.0 and [2] on predictive maintenance systems using IoT data. Research on data-driven predictive maintenance, particularly by [1], [11], highlights the integration of machine learning algorithms with IoT and Building Information Modeling (BIM) for more efficient maintenance strategies. Other notable papers explore the role of augmented reality in intelligent manufacturing, 5G networks in agriculture, and wireless communication in IoT, with a consistent emphasis on advancing industrial processes through emerging technologies like AI and IoT.

Practical Implication

This study underscores the significant role of artificial intelligence (AI) and the Internet of Things (IoT) in advancing sustainable practices and operational efficiency within various industries. As industries continue to embrace digital transformation, AI and IoT technologies are enabling real-time data collection, predictive maintenance, and intelligent decision-making processes. The findings suggest that organizations in sectors such as manufacturing, energy, and agriculture can greatly benefit from integrating AI and IoT into their operations. For instance, predictive maintenance systems, as outlined in studies such as [2], demonstrate the potential for reducing downtime and improving the overall productivity of production lines. Additionally, AI's application in sustainable energy, as discussed by [10], offers a roadmap for industries to reduce energy consumption and environmental impact, aligning with global sustainability goals. The insights from this study can guide businesses in identifying the technologies that align with their operational needs, thereby enhancing efficiency and competitiveness.

Theoretical Contribution

The theoretical contribution of this study lies in the synthesis of existing literature on AI, IoT, and Industry 4.0, and its impact on various industrial sectors. By aggregating studies from diverse fields such as smart factories, predictive maintenance, and wireless communication, the study provides a comprehensive understanding of how AI and IoT are reshaping industry practices. The research contributes to the development of frameworks like data-driven predictive maintenance and highlights the intersection between AI, machine learning, and IoT in Industry 4.0. The study also extends theoretical discussions on the role of IoT in facilitating real-time decision-making and predictive capabilities, which were previously less explored in the context of industrial applications. Moreover, the work offers valuable insights into the application of machine learning algorithms for optimizing processes and addressing challenges such as energy efficiency and lifecycle management.

Limitations

While this study provides valuable insights into the integration of AI and IoT in industrial settings, it does have limitations. First, the majority of the studies reviewed focus on specific industries or geographic regions, which may limit the generalizability of the findings across different sectors or global contexts. For example, the research heavily emphasizes manufacturing and energy industries, potentially overlooking other sectors that could also benefit from AI and IoT integration. Additionally, the study primarily relies on literature from recent years, which may not fully capture the evolving trends and long-term impacts of these technologies. Further research could benefit from examining the longitudinal effects of AI and IoT integration, particularly in industries like agriculture or healthcare, where their adoption is still in early stages. Lastly, the study does not explore in-depth the challenges organizations face when implementing AI and IoT solutions, such as data privacy, security concerns, and the cost of technology adoption, which could provide a more holistic view of the practical implications.

4. CONCLUSION

This study highlights the transformative potential of artificial intelligence (AI) and the Internet of Things (IoT) in driving operational efficiency, sustainability, and innovation across various industries. The findings emphasize the growing integration of AI and IoT technologies, particularly in predictive maintenance, smart manufacturing, and energy management, offering significant benefits such as reduced downtime, improved resource utilization, and enhanced sustainability. By synthesizing key literature on the subject, the study contributes to the understanding of how these technologies intersect and reshape industrial practices in the era of Industry 4.0. However, despite the promising outcomes, the study also acknowledges limitations, including a focus on specific sectors and regions, and the need for further research on long-term impacts and challenges associated with the adoption of AI and IoT.

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