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Internet of Things in Industry: Research Profiling, Applications, Challenges, and Opportunities—A Comprehensive Review

Souhini Saha , Debrupa Pal
[1,2] *Department of Computer Application*
Narula Institute of Technology, 81, Nilgunj Road, Agarpara, INDIA
Corresponding Author: Debrupa Pal

ABSTRACT: *The fourth industrial revolution, transforming the industrial sector, is driven by the growing digitization and interconnection of goods, products, value chains, and business models. Industry 4.0 is founded on the global integration of people, devices, and machines. By linking devices and sensors to the internet, we are ushering in a new era of data analysis, connectivity, and automation. This shift opens up unprecedented opportunities for innovation and progress, previously unattainable on such a scale. The concept of the Internet of Things (IoT) has gained traction alongside the vision of a world equipped with intelligent inputs and outputs capable of communicating through internet-based data and technologies. IoT is being applied across various sectors of the modern economy, including healthcare, quality control, logistics, energy, agriculture, and production. The Industrial Internet of Things (IIoT) paves the way for a deeper understanding of manufacturing processes, enabling more efficient and sustainable production. This paper explores the concepts of IoT, IIoT, and Industry 4.0, emphasizing the associated opportunities, threats, and challenges of their implementation. It also outlines the computing architecture in IoT and addresses related energy consumption concerns. Furthermore, it provides examples of IIoT applications and research profiling.*
Keywords: *dynamic structural behaviour, tall buildings, steel-concrete composite buildings, geometric nonlinearity, aerodynamic damping, human comfort assessment.*

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I. INTRODUCTION

Energy stands as one of the foundational pillars driving societal progress and economic growth. In recent years, the rise and widespread adoption of the Internet of Things (IoT) have contributed significantly to the noticeable increase in global energy consumption [1]. As technological advancements continue to expand and become more pervasive, the associated energy consumption has become inevitable. The growing energy demands from industrial, commercial, and individual sectors are impacting energy security across all continents. At the same time, the implementation of the United Nations Sustainable Development Goals has opened new avenues for broader IoT applications and the adoption of environmentally sustainable solutions in the energy sector.

According to the Deloitte Report [2], global spending on IoT-related software and hardware is projected to surge rapidly, increasing from USD 726 billion in 2019 to USD 1.1 trillion by 2023. The report also highlights that the Asia/Pacific region dominated IoT spending in 2019, with India alone investing USD 20.6 billion. Additionally, Cisco [3] forecasts that by 2030, there will be 500 billion devices connected to the Internet of Things. The Microsoft Report [3] further underscores the growing adoption of IoT, revealing that 85% of surveyed companies utilized IoT technology in 2019, a figure that rose to 91% in 2020 and stabilized at 90% in 2021. Notably, 90% of these organizations are leading one or more IoT projects that have reached the "use" stage, compared to 83% in 2020 and just 74% in 2019. This trend highlights the accelerating integration of IoT technologies across industries, reflecting their critical role in shaping the future of energy and sustainability.

Figure 1 displays the autocomplete data gathered from search engines like Google, which includes all the relevant phrases and questions users searched for related to the keyword "IoT." The analysis was conducted using the "Answer the Public" search engine. Figure 1 highlights the 56 most commonly asked questions about IoT in the United States. This analysis was performed on November 30, 2021.

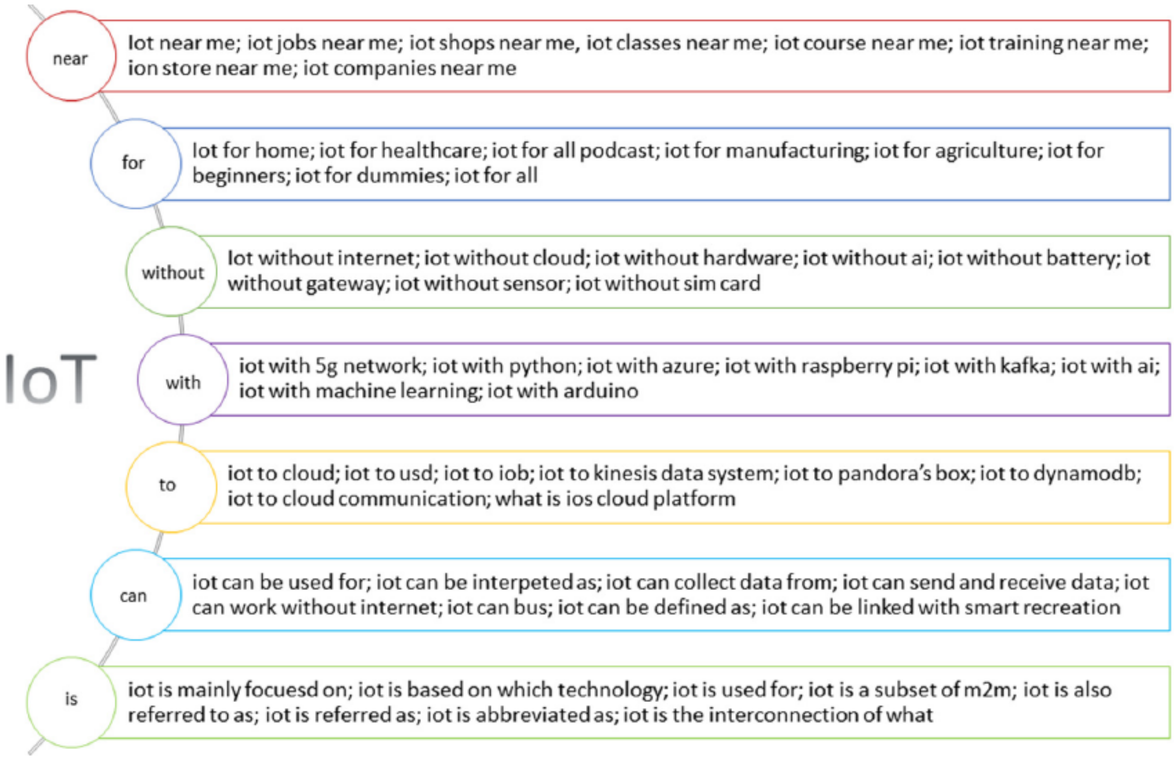

Figure 1. The 56 most commonly asked questions about IoT in the United States, based on data from the "Answer the Public" search engine.

The future of global manufacturing has undergone a permanent shift due to advancements in smart industries. This transformation has accelerated digitization and reshaped manufacturing and distribution processes across companies. The integration of IoT devices in factories not only enhances productivity but also improves safety, quality, and the efficiency of complex advancements.

IoT, along with Artificial Intelligence (AI), Cloud Computing, and Big Data Analytics (BDA), is recognized as one of the "big four technologies." These technologies enable organizations to stay connected, generate valuable data, implement automation, and make data-driven decisions. IoT plays a crucial role by facilitating automated data collection and generating insights through sensors, networks, and analytics. As a result, it stands as a fundamental component of the "digital stack."

II. INDUDTRY 4.0

Industry 4.0, also known as the fourth industrial revolution, represents the digital transformation of manufacturing systems, shifting from traditional "machine manufacturing" to "digital manufacturing" as shown in Figure 2. Previous industrial revolutions were driven by mechanization (Industry 1.0), electricity (Industry 2.0), and information technology (Industry 3.0), each leading to significant productivity gains. Industry 4.0 builds on these advancements by integrating cutting-edge information technology to revolutionize industrial processes, enhancing efficiency, connectivity, and automation in modern manufacturing.

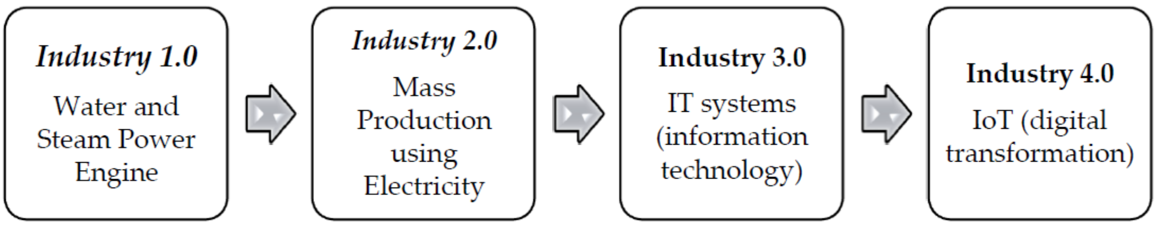

Figure 2: Four Industrial Revolution

Alongside the transformation of manufacturing models, society has also evolved through various stages, progressing from a hunting society to an agricultural society, then to an industrial society, followed by the information society, and ultimately reaching the era of the super-smart society [4], as illustrated in Figure 3.

Figure 3: Societal advancement

The transformation to Industry 4.0 is driven by a strong emphasis on applications and the need for change due to evolving operational conditions and rapid technological advancements (application-pull and technology-push) [9]. According to Zheng [5], this shift is fueled by the demand for faster delivery, more efficient and automated processes, improved quality, and customized products. Industry 4.0 integrates key technologies such as **cyber-physical systems (CPS), IoT, smart factories, embedded systems, sensors, big data analytics (BDA), cloud manufacturing and computing, RFID, automation, autonomous robots, additive manufacturing, virtual reality (VR), augmented reality, data mining, advanced materials, AI, machine learning (ML), and cybersecurity** [6,7]. By embedding these technological pillars into core manufacturing processes, Industry 4.0 represents a major advancement beyond the third industrial revolution, which primarily focused on computerization and process automation [8].

III. INTERNET OF THINGS (IoT)

The Internet of Things (IoT), a concept that emerged at the end of the 20th century from radiofrequency technology developed at the Massachusetts Institute of Technology in 1999, is increasingly gaining widespread support due to its universal design and ease of use on a massive scale. Essentially, IoT comprises a variety of devices with embedded systems connected to the internet, capable of generating and transmitting information autonomously without direct human intervention. These devices, which include smartphones, smart household appliances, remote-controlled heating and lighting systems, and networked industrial machinery, form Machine-to-Machine (M2M) networks that enable intelligent communication and independent decision-making based on shared data. With nearly limitless potential, IoT is widely applied in fields such as economy, medicine, and households. As of now, there are approximately 5 billion IoT devices globally, with projections estimating this number could reach 29 billion by 2022, or 9.27 billion according to other sources like Matsumoto et al.

Various smart technologies, including sensors, actuators, and intelligent systems, can be integrated to enable the digitalization of organizations and industries, introducing a new paradigm in business operations. This transformation is supported by the development of Cloud computing technologies, which offer borderless information sharing and access. The vast amount of data generated by IoT facilitates efficient analysis, playing a crucial role not only in digitalized and connected societies but also in industries such as healthcare, transportation, and the economy [9-12]. From small businesses to large enterprises, the demand for high data storage capacity with scalable solutions is rising, which can be achieved by adopting Cloud, Fog, and Edge paradigms. The computing architecture of these paradigms is illustrated in Figure 4 [13].

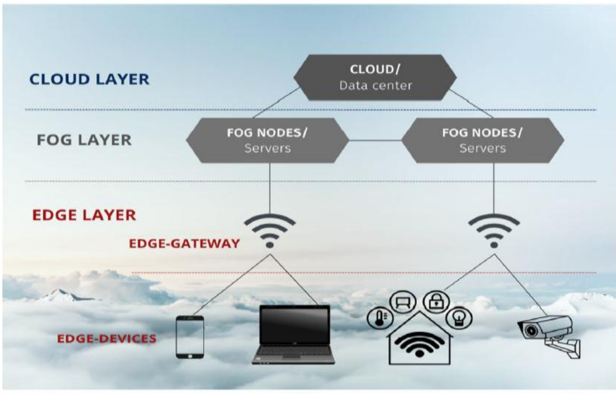

Figure 4: Four Industrial Revolution

Decentralized Blockchain operates with multiple users sharing decision-making, whereas a centralized Blockchain relies on a single central entity as the primary decision-maker. Initially introduced for Bitcoin cryptocurrency applications, Blockchain technology has since expanded across various industries. Each transaction, file, or data block is assigned a cryptographic hash and linked to the previous block. Once verified by a certain number of network members (nodes), it is added to the chain, forming a Blockchain that typically includes a shared ledger, permissioning, smart contracts, and consensus mechanisms [14]. This technology enhances transparency, security, authenticity, and auditability of shared data [15, 16], while also ensuring privacy protection through encryption and verification. To address the block creation time limitations of traditional Blockchain, Ethereum was introduced. Unlike Bitcoin, Ethereum allows developers to create smart contracts, enabling Blockchain customization for specific applications. This makes it possible to configure IoT devices and authenticate operations within a public key infrastructure. As a result, Blockchain technology is gradually expanding beyond currency-related applications into various non-financial domains [17].

IV. INDUSTRIAL INTERNET OF THINGS (IoT)

A systematic literature review aims to provide a comprehensive understanding of existing research and share findings from relevant studies on a specific topic or field. The most common approach for identifying relevant literature is through keyword searches. A graphical visualization illustrating co-occurrence networks, generated using VOSviewer software (Leiden University, Leiden, The Netherlands), is displayed in Figure 5.

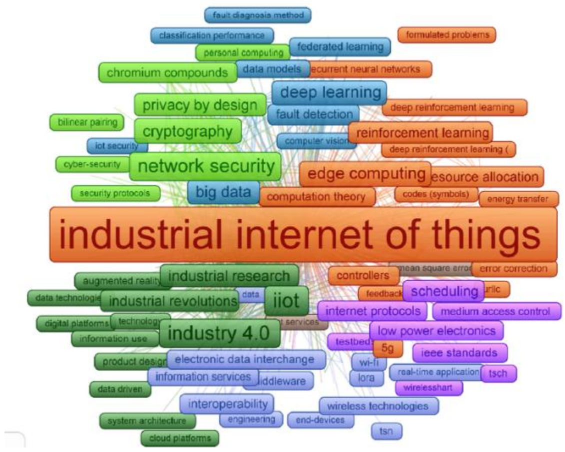

Figure 5: Network generated from the bibliometric analysis of Scopus data.

The research profiling was conducted using the Scopus database (www.scopus.com; accessed on 16 October 2021) by searching for the keyword "IIoT" in the article titles, abstracts, and keywords, with no temporal restrictions applied. Scopus was chosen over Web of Science due to its broader coverage, as the latter is limited to International Scientific Indexing (ISI) journals. This search yielded 3815 papers published between 2010 and 2021, as illustrated in Figure 5. The metadata of these papers were exported in CSV format for further analysis, and VOSviewer software was utilized for macro-level bibliometric analysis. By setting a minimum threshold of 5 occurrences for the keyword "IIoT," 1053 keywords out of a total of 14,444 were identified. The total strength of co-occurrence links for each of these keywords was calculated, with the most significant terms selected based on their total link strength. For instance, "Industrial Internet of Things (IIoT)" appeared 1811 times with a total link strength of 15,350, while "IIoT" and "Industrial Internet of things" had 295 and 277 occurrences, with total link strengths of 2586 and 2946, respectively. Keywords with the lowest occurrences (equal to 5), such as "public works," "process industries," "power plants," "practical swarm optimization," and "diverse applications," also had the lowest total link strengths, amounting to 41.

Using VOSviewer software, a two-dimensional map (Figure 5) was generated to visualize the co-occurrence network of keywords. In this map, highly relevant keywords are automatically grouped into clusters, each represented by different colors and node sizes for enhanced clarity. The relationships between nodes are depicted as curved lines, illustrating their connections. Analysis of the terms within the eight identified clusters enabled the recognition of specific subject areas, as detailed in Table 1. Notably, some clusters encompassed more than one subject area, reflecting the interdisciplinary nature of the research.

Table 1: Cluster analysis based on Scopus bibliometric analysis

Cluster No.	Color	Item No.	Proposed Subject Area
1	Brick red	222	Software engineering, System engineering
2	Green	211	Industry 4.0
3	Turquoise	168	Deep Learning, Data Mining
4	Lime green	128	Data management
5	Lilac	104	Internet of Things
6	Blue	93	Sensors, Automation, Process management
7	Orange	68	Computing
8	Brown	59	Traceability, Inventory control, Inventory management

Source: own work based on obtained Scopus metadata by VOSviewer software.

The IIoT, represented as the largest red node in the visualization, is connected to a wide range of terms, including Industry 4.0, network security, edge computing, cryptography, deep learning, reinforced learning, interoperability, resource allocation scheduling, IEEE standards, blockchain, and many others. This demonstrates the extensive and diverse correlations associated with the IIoT keyword. The term "IIoT" was first introduced in 2011 by Chen et al. [18], and over the following decade, the number of publications featuring this keyword grew significantly. By 2020, there were 1248 documents, and by October 2021, an additional 1134 documents had been published, highlighting the rapid expansion of research in this field.

Security in the cloud represents a critical area of research that demands increased attention, particularly as businesses increasingly adopt hybrid cloud environments that combine private and public clouds. This shift underscores the heightened importance of robust security measures to safeguard against cyber-attacks and ensure data protection.

[19] outlined a set of security components aimed at enhancing IoT security. They also highlighted numerous security and privacy challenges, including:

- User privacy and data protection,
- Authentication and identity management,
- Trust management and policy integration,
- Authorization and access control,
- End-to-end security,
- Attack-resistant security solutions.

V. DISCUSSION AND CONCLUSION

The ongoing revolution of IoT marks the beginning of a new era of data, significantly impacting daily life and behaviors in both private and corporate settings. As IoT applications continue to expand across industries, they bring tangible benefits by enhancing automation, logistics, process management, enterprise operations, and intelligent transportation systems. The Industrial Internet of Things (IIoT) remains a focal point of interest, offering solutions that enable unmanned operations and reduce human exposure to hazardous environments, such as mines, high-altitude sites, and deep-sea locations. Despite its many advantages, IoT is still in its early stages and faces various challenges, barriers, and risks. Organizations must carefully assess whether the benefits of IoT adoption outweigh its associated challenges to ensure successful implementation.

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