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Shaping Smart Manufacturing and Industry 4.0 through the Industrial Internet of Things (IIoT): A Review

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Abstract

The Internet of Things (IoT) is a technological paradigm encompassing internet-enabled sensors integrated into the physical world, enabling devices to share data without direct human-to-human or human-to-machine interaction. The IoT also referred to as the 'embedded Internet,' has its roots in Kevin Ashton's coining of the term in 1999. It has since gained prominence and is expected to revolutionize various industries, including manufacturing, smart energy, healthcare, agriculture, safety, smart climate control, buildings, and cities. The Industrial IoT (IIoT) plays a significant role within this context by analyzing, storing, and aggregating extensive data for empirical, descriptive, and predictive statistical purposes. IIoT initiatives promote smart factory products and have been adopted by IT sector organizations worldwide. Despite being in development, IIoT faces unique challenges in integrating Operational Technology (OT) with traditional IT, leading to business and cybersecurity challenges. This article aims to explore the significance of IIoT and its evolution into Industry 4.0 processes while addressing challenges in development and implementation. The focus is on system structure, layers, applications, and opportunities within the broader context of the Internet of Things.

Keywords: Internet of Things (IoT), Industrial Internet of Things (IIoT), Industry 4.0, Industrial Automation, IoT Case Studies, IIOT Architecture, Cyber security.

Introduction

Increasingly over the past few years, research and development have dedicated itself to realizing the promise of the Internet of Things (IoT). The IoT is a technological paradigm comprising internet-enabled sensors knitted into the physical world that enable devices to share data without a direct human-to-human or human-to-machine interaction [1, 2]. The idea has often been referred to as the “embedded Internet”[3]. However, the neologism ‘Internet of Things’ was coined by Kevin Ashton in 1999. It started spreading during the summer of 2010. Gartner, the market research company, mentioned ‘The Internet of Things’ for the first time in 2011.[4] The next year, the Internet of Things was the theme of Europe’s biggest digital conference, LeWeb. The acquisition of Nest by Google for $3.2 billion in January 2014 ensured IoT would enter the corporate lexicon[5].

In the broad area of social engagement, Internet of Things (IoT) technology has brought many revolutionary changes in the way we perceive applications. This momentum is expected to increase in the coming years, with the potential economic impact of IoT estimated at $900 to $2.3 trillion per year by 2025[6].

The article explores the vast scope of IoT applications spanning manufacturing, smart energy, healthcare, agriculture, safety, smart climate control, buildings, and cities. Digital devices within these domains collaborate via wired or wireless connections to achieve specific objectives. The distinction between perpendicular IoT approaches (commercial, industrial, and consumer) and horizontally oriented IoT emphasizes varied technical requirements and target markets. The commercial marketplace, particularly evident in fitness monitors, smart homes, and entertainment systems, displays significant market exposure. The commercial sector, encompassing finance and e-commerce, highly values customer experience and performance, utilizing sensors and data devices for almost a decade. The introduction delves into the history of Industrial IoT (IIoT) and its role in analyzing, storing, and aggregating extensive data for empirical, descriptive, and predictive statistical purposes. Initiatives promoting smart factory products, such as the European Factories of the Future (FoF) and the broader Industrial Internet concept, have driven IoT adoption in IT sector organizations. Despite IIoT still being in development, it plays a substantial role in IoT's ongoing evolution, facing unique challenges in integrating Operational Technology (OT) with traditional IT, leading to business and cybersecurity challenges.

The standard IIoT framework, comprising microcontrollers, application software, sensor systems, and security protocols, aligns with government initiatives promoting efficient manufacturing, Industry 4.0, Swadeshi product development, Japan's Industrial Value Chain Initiative Platform, Make In China 2025, and smart city establishment. The convergence of these initiatives, coupled with support for green technologies and favorable economic factors, has positioned industrial IoT constructively. The article aims to explore the significance and progression from Industrial IoT to Industry 4.0 processes, addressing challenges in IIoT development and implementation while providing insights into its system, structure, layers, applications, and opportunities within the broader context of the Internet of Things [7, 8].

The article highlights the rapid advancements in information technology, marked by the emergence of Cloud Computing (CC), the Internet of Things (IoT), Artificial Intelligence (AI), and Big Data Analytics (BDA). Focused on addressing challenges within the manufacturing sector and ushering in an era of intelligent manufacturing, these technologies are instrumental in industry-wide transformations. IoT, functioning as a network of interconnected devices embedded with software and sensors, enables data exchange and connection over the Internet, with embedded systems and wireless sensor networks playing a crucial role. The global impact of IoT is pervasive, evident in various aspects of life, and has limitless applications. The manufacturing sector, inspired by IoT, is undergoing significant changes, with IoT holding immense promise for revolutionizing the industry. The utilization of IoT extends beyond manufacturing, reaching agriculture, where it facilitates continuous field monitoring through a network of sensors, enhancing crop yield. The introduction emphasizes IoT's role in constant monitoring, citing examples like wearables and machines, and underscores the need for cost-effective storage devices due to the substantial volume of data collected [9, 10].

The convergence of Wireless Sensor Networks (WSN) and the Internet of Things (IoT) is pivotal for enhancing manufacturing efficiency, particularly in the context of Industry 4.0. IoT facilitates seamless data exchange among intelligent machines, empowering systems to make instantaneous decisions based on gathered information. The evolution of manufacturing in Industry 4.0 involves integrating the Industrial Internet of Things (IIoT) and Machine Learning (ML), aiming to enable machinery to self-optimize and improve overall performance. The amalgamation of IoT and Cloud Computing (CC) provides access to an extensive data pool, with Computational Intelligence (CI) translating this data into real-time manufacturing insights. However, security challenges introduced by interconnected intelligent devices need early-stage addressing [11, 12].

The Industrial Internet of Things (IIoT) plays a crucial role in enhancing workplace safety by monitoring worker health and potential hazards. IIoT devices effectively address safety issues, particularly in high-risk environments like gas and water leakages, contributing to improved operational performance and promoting agility and flexibility in industrial settings. As the Internet of Things (IoT) progresses, it diverges into two pathways, with the Industrial IoT (IIoT) focusing on Machine-to-Machine (M2M) communication and data analysis through a Cloud Platform. IIoT operates on a different communication principle compared to traditional M2M, emphasizing continuous and dynamic interactions among IoT devices within its domain [13, 14].

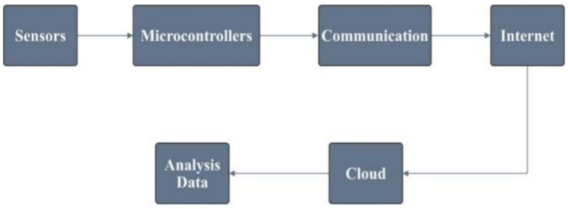

Figure (1) Block diagram of IoT-based system [15]

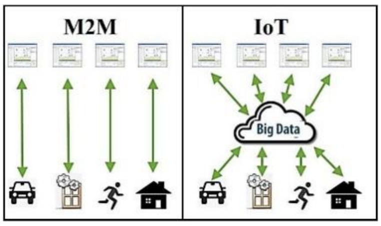

Figure (2) Difference between M2M and IoT [14]

The Internet of Things (IoT) initially targeted the commercial sector, but the Industrial Internet of Things (IIoT) has evolved as a technology uniquely tailored for industrial applications. IIoT enables the integration of diverse data types, such as sensor output, user input, service provider availability, and knowledge, facilitating the delivery of accurate and effective real-time responses. Positioned as the next industrial revolution within Industry 4.0, IIoT plays a crucial role in Smart Factories with modular structures, leveraging Cyber-Physical Systems (CPS) to monitor physical processes, create virtual replicas of the physical world, and make real-time decisions [16]. These CPSs engage in communication and collaboration in real-time [17] through the Internet of Services (IoS), offering both internal and intra-organizational services to optimize the value chain [18].

Evolution and Revolution

The Internet of Things (IoT) transcends the mere connectivity of contemporary devices like voice-activated speakers or smart thermostats, creating a technological revolution in our increasingly interconnected society. This transformation is driven by advancements such as cloud computing, enhanced artificial intelligence, and affordable sensors, coupled with the utilization of big data. This amalgamation of technologies has given rise to the Industrial Internet of Things (IIoT), ushering in a new era for various industries, including manufacturing, energy consumption, mining, and transportation, with profound implications for the overall economic landscape.

The genesis of IIoT can be traced back to 1968, marked by a pivotal breakthrough in manufacturing history engineered by Dick Marley. Marley and his team conceived the Programmable Logic Controller (PLC), a groundbreaking invention that later proved indispensable in automating assembly lines and industrial robots within factories. This landmark achievement set the foundation for the transformative journey of IIoT, positioning it as a driving force behind the evolution of major industries, promising a substantial impact on the broader economic conditions [19-21].

The proliferation of smart devices, including mobile phones and laptops, has contributed to the expansion of the Internet of Things (IoT). Within the realm of IoT, networked devices play a crucial role, employing input/output (I/O) components and single-board computers (SBCs) increasingly integrated into the manufacturing process. This integration forms the foundation of the Industrial Internet of Things (IIoT), paving the way for a seamless transition to Industry 4.0.

Industry 4.0 represents a paradigm shift in business processes, redefining manufacturing for the next generation. The synergistic combination of IIoT and Industry 4.0 holds the promise of delivering greater efficiency, enhanced quality, reduced overhead, and improved safety across various industries. This convergence signifies a transformative leap forward in industrial practices, setting the stage for a more advanced and interconnected future [22].

The depiction of the Industrial Internet of Things (IIoT) in Figure 6 highlights its role as a transformative force revolutionizing the industrial landscape in a profound manner. However, it is essential to recognize that IIoT is not a sudden revolution but rather an evolutionary process with its roots in technologies and functionalities developed by visionary automation.

The significant outcome of IIoT lies in its ability to empower end-users and machine builders to leverage their existing investments in technology and human resources, while simultaneously capitalizing on the opportunities presented by IIoT technologies. The emergence of the IIoT megatrend has sparked both anticipation and confusion among stakeholders tasked with overseeing plant operations. Much of the focus is directed towards understanding the impact of technological advancements on existing automation platforms.

The visionary perspective of IIoT envisions a world where smart, connected assets seamlessly operate as integral components within larger systems of systems, constituting the framework of the smart manufacturing enterprise [23]. This vision reflects a paradigm shift towards a more interconnected and intelligent industrial ecosystem.

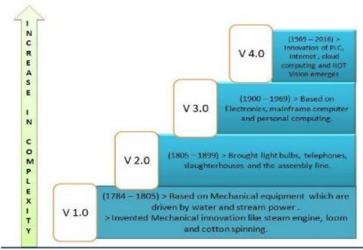

Figure (۳) Evolution of IOT [24]

In the exploration of technology integration, it is crucial to underscore the significant contributions of Computer-Aided Manufacturing (CAM) and Computer-Aided Engineering (CAE). CAM plays a pivotal role in the control of manufacturing operations, while CAE supports decision-making processes, contributing to the overall efficiency of manufacturing systems. Beyond these technologies, several others play vital roles in the integration of product and manufacturing design. Cloud Computing facilitates collaborative access to shared resources and software tools. Artificial Intelligence (AI) and Machine Learning (ML) provide capabilities for optimization, pattern recognition, and intelligent decision-making. Robotics and Automation enhance efficiency and productivity in manufacturing operations. Advanced Simulation and Virtual Reality (VR) facilitate immersive visualization and design validation. Supply Chain Integration Technologies ensure seamless coordination and visibility across the supply chain. Data Analytics and Business Intelligence (BI) support data-driven decision-making and process optimization. These technologies collectively contribute to a comprehensive framework for effective integration within the manufacturing landscape [25].

IOT to IIOT

The Internet of Things (IoT) is a technology that links physical objects through both wired and wireless networks. In contrast, the Industrial Internet of Things (IIoT) specifically focuses on intricate physical machinery connected to industrial sensors and associated software. The IIoT encompasses not only the interconnection of machines but also includes a human interfacing unit to ensure a system free from errors [26].

There is a substantial likelihood that the Industrial Internet of Things (IIoT) or Industry 4.0 will supersede routine and repetitive jobs, including production assembly, administration, quality control, and planning. Recent reports indicate that the overall outlook for Industry 4.0 is not bleak; in fact, it presents significant benefits for specific job profiles, notably in the fields of Information Technology (IT) and Research and Development (R&D). Current observations suggest that the technology facilitated by IIoT will not only amplify the efficacy of new product offerings but also revolutionize business models, such as machines-as-a-service, and enable on-the-spot 3D printing [27].

The inception of Industry 4.0 can be traced back to Google's groundbreaking move in 2010 with the introduction of Google Street View. Following this, the Chinese Government incorporated the Industrial Internet of Things (IoT) into its five-year plan, signaling a significant commitment to technological advancement. Subsequently, the German Government propelled the revolution forward.

In the context of IoT, the term "things" refers to devices that extend beyond simple remote on-off capabilities. These devices possess distinctive characteristics:

- They are "smart," featuring self-processing units.
- They employ various techniques to exchange information with one another.
- They can both send and receive information, exerting control over the overall network, including the Internet [28].

The Industrial Internet of Things (IIoT) takes connectivity to a new echelon by providing a systematic approach and a standard for universal interconnection via Internet Protocol (IP). IP serves as the linchpin for exchanging information across the internet, irrespective of the device involved in the exchange. This universality allows devices to communicate seamlessly within their network, leveraging the same protocols and architecture. The pivotal role of Internet Protocol (IP) is evident in facilitating the interconnection of both physical devices and network infrastructure, underscoring its significance in the realm of IIoT [29].

IIoT integrates machine learning and big data technologies alongside traditional components such as Programmable Logic Controllers (PLC) and Supervisory Control and Data Acquisition (SCADA), enhancing automation by incorporating self-diagnosis and rectification capabilities. Notably, within process control industries, where physical devices like pressure, temperature, vibration, flow, and level sensors traditionally collect data, IIoT represents a transformative shift. These data, once primarily collected, are now utilized in innovative ways for correction, analysis, and exchange, marking a significant evolution in the application of data within industrial processes [24]. According to experts in Industrial Internet of Things (IIoT), the incorporation of these technologies is anticipated to bring about substantial enhancements in quality control, sustainability practices, and efficiency in supply chain management. The transition of IoT from a commercial level to an industrial level, as depicted in Figure 2, signifies a significant transformation that profoundly impacts the efficiency and continuity of industries worldwide [30].

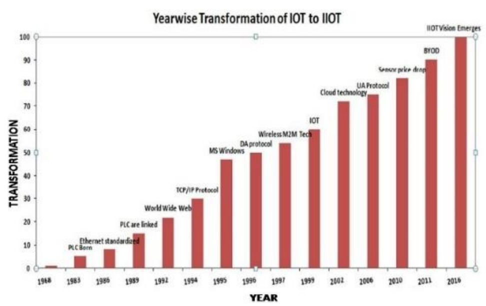

Figure (4) Transformation of IOT to IIOT [24]

A. IIOT Architecture

IIoT extends the Internet of Things concept to the enterprise level, recognizing that each enterprise possesses unique clusters of devices with limited interfaces. However, addressing the challenges associated with this integration requires acknowledging that there is no one-size-fits-all solution. The key components integral to this paradigm include the Industrial Control System, a comprehensive term encompassing software and hardware integration for critical infrastructure control. These systems are typically developed using a range of technologies such as distributed control systems (DCS), programmable logic controllers (PLC), supervisory control and data acquisition (SCADA) systems, remote terminal units (RTU), control servers, human-machine interfaces (HMI), intelligent electronic devices (IED), and other industry-specific systems [31].

- **Devices** such as sensors, interpreters, and translators play a pivotal role in interfacing with Industrial Control Systems (ICS). Additionally, they connect with transient data stores, channels, and processors to deliver data to end-users through applications. These industry-specific devices facilitate machine-to-machine interaction, human-to-machine interaction, and vice versa, enhancing the capabilities of the Industrial Control System [32].
- **The Transient Data Store** operates as a subordinate element within the master architecture, temporarily housing the transient representation of data objects. Its primary purpose is to guarantee durability in the face of operational failures and system breakdowns, including issues with networks. This temporary storage mechanism plays a crucial role in maintaining data integrity during various failure scenarios.
- **Local Processors** serve as low-latency data processing systems, offering rapid processing capabilities. These processors can be seamlessly integrated with the device, enabling on-device data processing. Within this category, processors can be further classified into various functions such as data filters, event managers, data processors, rule-based engines, signal detectors, algorithms, routers, and more [33].
- **Applications** play a vital role in offering real-time insights into field operations. These applications empower staff to efficiently manage devices, interact with other systems, and manipulate data. Through features such as notifications, alerts, and visualization, these applications facilitate informed and calculated decision-making by the staff [34].
- **Channels** serve as the medium for data exchange between the system and the application, encompassing network protocols, satellite communications, APIs, routers, and more.
- **Gateways** act as connectors bridging various networks and protocols, facilitating data transfers between different IIoT devices. This category includes intelligent signal routers and information transfer protocols.
- **Collectors** play a pivotal role in gathering data from gateways using standard protocols. These devices can be custom-made, and tailored to the specific needs of different industries.
- **Processors** stand as the central components in any IIoT solution, handling functions such as data transformations, signal detection, analytical models, complex event processing, and more. They form the core of the IIoT infrastructure.
- **Permanent Data Store** serves as a long-term data storage system integrated into the IIoT infrastructure. Functioning as a historian for devices, it accumulates data from various sources and feeds it to processors for advanced analytical processing and model preparation. This category encompasses a vast array of elements, including parallel processing data stores, cloud storage, data repositories, relational database management systems (RDBMS), open-source data, and more [35].
- **Models**, in any IIoT solution, come in two primary types: Analytical Models and Data Models. Data models provide a structural framework for the data, while analytical models are custom-built to cater to industry-specific requirements. These models play a pivotal role in IIoT solutions, typically constructed by leveraging data from permanent data stores, human experiences, and industry standards. Analytical models undergo training using historical datasets or advanced machine learning techniques, such as clustering, regressions, and mathematical and statistical modeling. Examples of data models include semantic models, entity-relationship mapping, JSON, XML/XSD, and others [36].
- **Security** constitutes a crucial aspect of IIoT-based systems, extending through the pipelines from the data source to consumption. This comprehensive security framework encompasses elements such as data authorization, encryption, authentication, user management, firewalls, masking, and more [37].
- **Computing Environments** within IIoT systems can vary significantly across industries, adapting to specific business needs and landscapes.
- **Fog Computing** strategically brings analytics closer to the data source.
- **Cloud Computing** facilitates the global scaling of analytics across industries.
- **Hybrid Computing** represents a blend of fog and cloud computing, optimizing operations and tailoring solutions to the specific needs of diverse fields [38].
- **Edge computing** can be understood as a concept designed to bring the capabilities of cloud computing closer to the data source. In contrast to relying on a centralized cloud server, edge computing strategically places the processing and storage capabilities in proximity to the devices themselves. This strategic positioning serves to minimize latency and improve response times, rendering edge computing particularly suitable for real-time applications within the Internet of Things (IoT).

In the realm of connecting devices in the digital landscape, several IoT architectures are available, with hierarchical, mesh, and hybrid architectures being among the most common. Each architecture has its distinctive approach to organizing and managing the flow of data between devices [39].

B. Industry 4.0 and IIoT

Industry 4.0 and the Industrial Internet of Things (IIoT) hold great promise for the future, as they offer the potential for reduced production costs and increased flexibility in adapting to new products on the production line. IIoT has evolved from the initial concept of the Internet of Things, enabling the connection of devices from various locations, providing real-time status updates, and allowing effective control through visual interfaces. In the industrial setting, operations and visualization have traditionally been localized. However, IIoT has extended IoT principles to the plant floor by incorporating Programmable Logic Controllers (PLCs), which have become a key component of IIoT. Despite the advancements brought by IIoT, PLCs remain essential for industrial control and have become smaller, more affordable, and capable of operating in harsh environments due to technological progress. The introduction of IIoT raises the question of whether centralized or decentralized control is the optimal choice. The selection of the most suitable control option, along with other operational challenges that have driven the evolution of IoT technologies in industrial settings, has led to the emergence of IIoT. As we move forward, the integration of Information Technology (IT) and Operational Technology (OT) in the supply chain, facilitated by IIoT, forms the foundation for implementing Industry 4.0 strategies. These technologies enable the interconnection of numerous machines across multiple factories, regardless of their geographical location.

The rapid advancements in technology have resulted in the emergence of numerous software tools and hardware devices that students studying automation must familiarize themselves with. This knowledge is crucial for accelerating the adoption of these technologies in industrial and commercial settings. As the COVID-19 pandemic continues to drive the adoption of technology and automation, businesses worldwide are facing challenges in finding workers equipped with digital skills. A recent survey conducted by KPMG in Canada revealed that the inability to attract and retain talent is the primary threat to the growth prospects of businesses across the country. The survey also highlighted that nearly 80% of businesses acknowledged a shift in their work practices due to the pandemic, leading to an increased demand for workers with IT skills. The skill sets required for implementing digital strategies in industrial workplaces encompass various areas, including programming microcontrollers and sensors for Internet of Things (IoT) applications, PLC programming and visualization, networking concepts and technologies, MQTT (Message Queuing Telemetry Transport) publish/subscribe protocol, database programming and internet technologies, Open Platform Communications (OPC) Data Access (DA) and Unified Architecture (UA), cloud computing, condition monitoring and predictive maintenance, data analytics, and Artificial Intelligence (AI) application development.[40]

The enablers of Industry 4.0 and IIoT are shown in Figure 5.

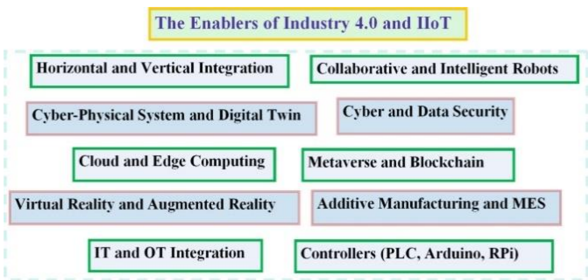

Figure (5) List of enablers for Industry 4.0 and IIoT[41, 42]

C. Industrial Automation and IIOT

The categorization of actuators, sensors, and low-level devices crucial for enabling IoT or IIoT reveals a distinct advantage in the realm of Industrial Automation. Many industries are currently anticipating the categorization of these low-level connected devices to enable the implementation of IoT within their specific domains. The integration of IoT into industrial automation, evolving from a commercial to an industrial level, introduces the contemporary and revolutionary technology of Industry 4.0, commonly referred to as IIoT [43]. The Industrial Internet of Things (IIoT) is set to transform the design and utilization of Industrial Automation networks, both now and in the future. It is anticipated that IIoT will enhance productivity by utilizing a wide array of categorized connected end devices. The value of new data generated at the end device, along with improved cybersecurity practices, adds sophistication to the system. IIoT acts as a protective shield against system downtime, identifying early signs of malfunction and preventing their escalation. The integration of IoT sensors into industrial systems provides real-time and accurate insights into equipment status, performance, and security, enabling proactive decision-making. Predictive capabilities contribute significantly to improved speed of response, performance, accuracy, and security. In summary, IIoT represents a substantial advancement in industrial automation, elevating standards in responsiveness, performance, accuracy, and system security [44].

D. Data Analytics and Cyber Security

Cybersecurity is the safeguarding of internet-connected systems, encompassing hardware, software, and data, to prevent unauthorized access and hacking. Systems incorporating Industrial Internet of Things (IIoT) must prioritize cybersecurity measures. In modern industry, data analysis plays a crucial role in enhancing productivity and operational efficiency. Big data in IIoT is categorized into data storage, data security, and data analysis. Data analytics in IIoT can be tailored to specific applications, including offline analytics, real-time analytics, business intelligence-level analytics, memory-level analytics, and massive analytics. The data used for further operations in analysis includes sensor data, audio, images, and videos [45].

Further classification of data analytics involves four key processes:

1. **Inspecting:** Identifying corrupted or inaccurate records from the database and forwarding them for further operations.
2. **Cleansing:** Modifying, deleting, or replacing corrupted data using data wrangling tools through scripting, with the resulting data proceeding for the transforming process.
3. **Transforming:** Converting data from one format to another before proceeding to the modeling stage.
4. **Modeling data:** Creating a data model for an information system using formal techniques in the data modeling process [46].

The future research agenda should prioritize the development of guidelines for the secure integration of emerging technologies such as the Internet of Things (IoT), Industrial Internet of Things (IIoT), Artificial Intelligence (AI), Big Data (BD), and Cloud Computing (CC) within the industry 4.0 (I4.0) ecosystem. An essential aspect of this initiative involves establishing a maturity model that can serve as a comprehensive framework, guiding the implementation of effective security measures across the interconnected landscape of Industry 4.0. This forward-looking approach aims to address the evolving challenges and complexities associated with the integration of advanced technologies, ensuring a robust and secure foundation for the industrial ecosystem of the future [47].

Various Case Studies

Organizations falling within the initial category incorporate IoT technologies to enhance their operational efficiency and processes, whether focused internally or spanning an entire supply chain. Noteworthy examples include Silverstein Properties and U.S. Bank, employing IoT technologies to refine their internal operations, while entities like Amec Foster Wheeler, IBM, Human Condition Safety, and Ericsson leverage these technologies to offer clientele profound insights into their operations, industries, and the broader global context.

A. IBM: Facilitating Enterprise Transformation via the Internet of Things (IoT)

In the rapidly evolving landscape of IoT technologies, IBM stands as a pivotal force, assisting clients in implementing transformative technologies that not only enhance operational efficiency but also reshape customer experiences and redefine business models. Chris O'Connor, IBM's general manager for IoT, notes that the IoT revolution is driving significant changes in strategies, technologies, and business models, challenging companies to adapt swiftly. IBM's role in this transformation ncludes providing technological infrastructure to support the launch of new business lines. A case in point is its collaboration with Daimler, where IoT technologies facilitated the creation of car2go, an on-demand fleet of eco-friendly Smart cars, revolutionizing the automotive giant's role in the transportation industry. Similarly, IBM's partnership with Whirlpool in the home-appliance sector exemplifies the integration of IoT-driven insights to optimize performance, enhance service delivery, and foster community impact. These instances underscore IBM's central role in leveraging IoT for meaningful transformations across diverse industries, making it an indispensable player in the era of technological revolution [48-51].

B. Ericsson Maritime ICT: Revolutionizing the Shipping Industry through IoT Technologies

In 2013, ships transported approximately 9.6 billion tons of cargo, constituting 80 percent of global trade by volume and over 70 percent by value. Despite this significant role, the supply chain's fragmented nature, spanning from production to warehouse to shore to ship, has posed challenges in effectively monitoring cargo between ports. The maritime industry, historically connecting distant places, faces unique logistical and connectivity issues due to the isolated nature of ships at sea. Ericsson, the Swedish communications company, addresses these challenges with its innovative solution, the Ericsson Maritime ICT Cloud platform. This platform unifies shipping organizations, connects vessels onto a shared network, and employs sensors to monitor various parameters such as vessel location, speed, and cargo container conditions in real-time. The system not only enhances efficiency but also ensures safety by analyzing potential dangers and inefficiencies. By integrating engine- and hull-monitoring systems, the platform reduces costs and risks, providing connectivity for proprietary maritime systems. Satellite technology further enables sea-to-shore connectivity, facilitating informed decisions to enhance crew welfare, protect goods, and optimize routes. Beyond its direct impact on the maritime ecosystem, increased connectivity offers downstream benefits for employee and vessel wellness, providing shipping companies with a recruiting advantage. Improved crew connectivity fosters enhanced operational intelligence, enabling more informed decision-making through increased data exchange between land-based operators and crews at sea [48, 52, 53].

C. Daimler: Enhancing Speed and Safety in the Trucking Industry through IoT Technologies

German automaker Daimler envisions a future transportation industry with zero fatalities, utilizing IoT innovation to enhance vehicle safety and efficiency. Daimler has consistently been at the forefront of adopting IoT technologies in its vehicles and is now advancing towards highly assisted or driverless operations for its trucks. The company has already implemented various technologies such as proximity control, stop-and-go assist, emergency brake assist, lane-keeping assist, and 3-D maps to improve road safety. Integrating stereo cameras and radar sensors into its road-monitoring systems enhances accuracy and response times. Daimler aims to introduce a commercially available vehicle with a "Highway Pilot System" for increased road safety by relieving drivers during potentially hazardous sections. A recent study revealed that highly automated driving reduces driver sleepiness by 25%, offering benefits beyond safety, including improved fuel efficiency through communication with infrastructure and other road users. Daimler's proactive approach to embracing IoT technologies showcases its commitment to innovation, setting an example for companies across industries to leverage the transformative power of the IoT revolution for the benefit of customers and road safety worldwide [48, 54-56].

D. John Deere: Bridging Agriculture and the Cloud through Connectivity

John Deere, renowned for its heavy machinery, has embraced technological advancements, playing a pivotal role in ushering farming into the IoT age. With its distinctive green-and-yellow farm equipment integral to American agriculture for nearly 180 years, John Deere addresses the historical lack of connectivity in the agricultural industry. Leveraging the IoT, the company connects each vehicle to the JDLink platform, providing farmers and dealers with remote access to fleet data. The John Deere Operations Center provides extensive Internet of Things (IoT) solutions, encompassing features such as wireless data streaming, mobile monitoring, and real-time reporting on weather conditions and crop status. Networked sensors and historical and real-time data empower farmers to optimize operations, ensuring equipment reliability and achieving "agronomic optimization" through collaborative data analysis with trusted partners. Patrick Pinkston, Vice President of Information Solutions, emphasizes the significance of enabling better agronomic decisions, machine performance, and job performance for farmers facing increased pressure to produce more with less. John Deere's vision extends beyond individual farms, aiming to transform the entire agriculture industry by fostering collaboration across dispersed sectors. Real-time data transfer allows remote advisers to engage in up-to-the-minute decision-making, enabling efficient problem diagnosis and reducing downtime. Despite challenges in cultural and technological collaboration among different sectors, John Deere remains committed to bringing IoT to agriculture as a natural extension of its longstanding goal to enhance producers' efficiency, effectiveness, and profitability [48, 57].

E. Silverstein Properties: Modernizing Real Estate for the 21st Century through Connectivity

When Hurricane Sandy wreaked havoc on the East Coast of the United States in 2012, causing widespread damage and leaving a lasting impact on New Jersey and New York, prominent property development and management company, Silverstein Properties, seized the opportunity to implement a combination of mobile and digital IoT technologies. The devastation prompted the company to enhance tenant safety, communication tools, and building integrity through advanced monitoring and informed decision-making. Silverstein's innovative mobile application allows tenants to place and monitor work orders, track shuttle bus locations, and serve as an emergency alert system for effective communication during catastrophic events. A centralized monitoring system for buildings, including 4 World Trade Center, exemplifies Silverstein's commitment to secure, safe, and effective IoT innovation in real estate. The company analyzes utility usage, reduces energy costs, and collaborates with Cisco to develop a smart Power over Ethernet (PoE) lighting system, emphasizing energy efficiency and enhanced lighting controls. Silverstein prioritizes security by adopting a segmented approach, minimizing the risk of compromised assets causing significant damage to the overall system. Sandy Jacolow, Chief Information Officer at Silverstein Properties, highlights the company's commitment to creating smarter, more efficient, and environmentally conscious buildings, showcasing their leadership in implementing disruptive IoT technologies for improved building and tenant management systems [48].

F. U.S. Bank: Revolutionizing the Banking Sector through IoT Integration

U.S. Bank, a notable player in the financial industry, has been a trailblazer in adopting new technologies to enhance banking convenience and security, spanning from ATMs to online, branchless banking. In the era of mobile technology and the Internet of Things (IoT), the U.S. Bank distinguishes itself with a proactive approach to innovation. Beyond improving its own operations, the bank actively contributes to the broader IoT industry through its innovation lab. This lab explores unconventional devices, linking financial opportunities to IoT innovations and addressing consumer expectations for convenience, security, and privacy. Prototypes range from Withings scales connecting weight-loss goals to financial rewards to innovative visual notifications of bank transactions. U.S. Bank's innovation team delves into the potential of connected car devices, envisioning embedded financial capabilities in the era of driverless cars. The bank aims to play a crucial role in the future of connected finance by ensuring seamless automation and secure interactions between financial accounts and IoT devices, solidifying its position at the forefront of technological advancements [48, 58, 59].

G. Amec Foster Wheeler: Revolutionizing Global Energy Supply Chains for Enhanced Safety

Over a century after the tragic sinking of the RMS Titanic, the harsh marine environment near the Grand Banks of Newfoundland, characterized by icebergs and extreme weather conditions, is now a critical area for oil extraction. Amec Foster Wheeler is at the forefront of IoT innovation, taking the lead in crafting safety and environmental monitoring systems tailored for the demanding conditions of oil and gas operations. By capturing continuous streams of meteorological and oceanographic data in real-time, the company provides energy companies with valuable information for asset movements and logistics planning, enhancing efficiency and safety while significantly reducing risks. The integrated IoT system allows for the analysis of vast amounts of current and past data, enabling informed decision-making and reducing the likelihood of environmental accidents. Amec Foster Wheeler's expertise in deploying sensors, measuring atmospheric conditions, and tracking the movement of oil platforms, icebergs, and vessels contributes to increased rig uptime and worker safety. The application of IoT and sensory technology is not confined to marine environments, as demonstrated by the company's use of sensors embedded in highways to broadcast live data for pavement temperature and road conditions, leading to improved road safety and resource efficiency. Overall, the IoT is revolutionizing business operations and risk management in challenging environments, providing innovative solutions to support decision-making processes [48, 60].

H. Human Condition Safety: Enhancing Workplace Safety through Sensor Technologies

In 2014, the construction industry accounted for over 20% of worker fatalities, with the "fatal four" factors—falls, electrocutions, strikes by objects, and being caught in or between objects—contributing to nearly 60% of deaths. Recognizing the challenges posed by construction sites and the need for enhanced safety, AIG strategically invested in Human Condition Safety (HCS) in 2016. HCS utilizes IoT and wearable technology, originally designed for high-performance sports, to identify and mitigate job-site risks across various high-risk sectors like energy, manufacturing, and large-scale construction. The technology provides real-time alerts for workers entering danger zones, enabling them to move to safer locations or triggering automatic machinery shutdowns. Additionally, site managers can access atmospheric data to make informed decisions about suspending work during severe weather, while upstream planning roles benefit from longitudinal data to enhance safety in initial designs. HCS's vision for work-site safety involves leveraging past knowledge and current understanding to predict and mitigate future risks, offering a significant advancement in creating safer work environments [48, 61, 62].

I. ABB Group: Predictive Maintenance for Heavy Industry

As a global leader in power and automation technologies, ABB Group has implemented a diverse range of equipment worldwide, with a focus on connecting and optimizing these devices to ensure safety and operational efficiency. ABB's robots, integral to various industries, posed challenges in monitoring and maintenance due to their widespread deployment. To address this, ABB leveraged innovative IoT technologies, enabling real-time monitoring of over 5,000 devices in the field. Cloud-based solutions, including data aggregation and statistical analysis, offer proactive monitoring and predictive maintenance, reducing downtime and maintenance costs. ABB adopts a flexible approach, combining cloud-based solutions and localized monitoring to tailor services based on client needs. The remote monitoring of ABB's gearless mill drives (GMDs) exemplifies the effectiveness of real-time monitoring, providing timely alerts for proactive maintenance and preventing unplanned outages. ABB's in-depth knowledge of its machines extends to optimizing related operations, such as improving engine efficiency in the marine industry. ABB's adaptability to new strategies and services serves as a model for companies seeking to enhance their IoT innovations [48, 63].

J. Microsoft: Revolutionizing Industries through a Comprehensive IoT Solution

Microsoft is at the forefront of IoT solutions, offering innovative tools like the Azure IoT Suite that empower businesses to gain actionable insights and real-time intelligence from their existing devices and data throughout the supply chain. This suite provides preconfigured solutions for remote monitoring, asset management, and predictive maintenance, catering to businesses of all sizes. Microsoft collaborates with its customers to identify crucial processes and implement IoT solutions for enhanced efficiency and value. Notable success stories include ThyssenKrupp, which utilizes Azure IoT to connect elevator sensors for real-time diagnostics, and Rockwell Automation, where Microsoft's IoT technology predicts equipment failures, tracks performance, and refines designs, leading to significant reductions in downtime, maintenance costs, and increased productivity in the oil-and-gas production supply chain [48, 64].

K. OTOY: Enhancing Visualization through Simulation with Virtual Reality

California-based OTOY is revolutionizing data visualization in the IoT realm by utilizing virtual reality (VR) technology to simulate the performance of products, buildings, and objects under different conditions. Leveraging the extensive data sets from universal sensors, OTOY aims to provide detailed and realistic virtual demonstrations, allowing users to interact with designs based on real-time IoT-connected sensor data. Particularly impactful in architecture and construction, OTOY can use IoT sensors to gather accurate, real-time atmospheric data, incorporating inputs on materials to simulate real-world performance and inform decision-making on factors like energy efficiency and flood protection. This innovative approach transforms the way IoT data is visualized and analyzed, enhancing the decision-making process [48, 65].

L. M2Cloud: Transforming South Korea's Pharmaceutical Supply Chains for the Next Generation

Boksan Nice has partnered with M2Cloud and Telenor Connexion to enhance the stability and reliability of their supply chain management (SCM) for medical products. The collaboration enables real-time visibility and tracking of the location of medical products during shipment and inventory processes. The solution incorporates remote monitoring systems that continuously transmit data on location and temperature, preventing spoilage and facilitating early detection of potential issues. This initiative aligns with the South Korean government's efforts for an agile vaccine response, supporting effective preparation for the mass distribution of COVID-19 vaccines. The Korea Children's Hospital Association has also signed an MOU to implement the same solution for proper vaccine handling throughout the supply chain management process [66].

M. Husqvarna: Expanding Customer Reach Through IoT

In a bid to expand its customer base, Husqvarna implemented a sharing economy model, enabling users to rent garden tools on a daily basis. The company transformed a shipping container into a fully automated and connected tool-rental shop, completing the project from concept to launch in just six months. The Telenor Connexion Managed IoT Cloud serves as the central system overseeing all interactions. Husqvarna leveraged Telenor Connexion's partner ecosystem to swiftly and seamlessly achieve a comprehensive solution. This initiative not only allows Husqvarna to access valuable user data but also facilitates feedback from end-users [67].

N. Anticimex: Leveraging IoT for Pest Control through Connected Traps

The Internet of Things (IoT) is spearheading a digital transformation in the pest control sector, empowering industry leader Anticimex to interconnect their Anticimex Smart traps. These traps can now be monitored continuously 24/7, regardless of their location. Leveraging global connectivity through Telenor Connexion, Anticimex has successfully expanded into new markets more swiftly and efficiently than dealing with local operators. By delivering results beyond just traps, Anticimex has enhanced efficiency in pest protection, elevated customer experience, and significantly reduced the use of toxins in conventional traps. The integration of IoT and smart traps facilitates data collection, generating valuable business insights, and enabling prompt action in response to alarms [68].

O. Emnify: Assisting Italy's Second-Largest Public EV Charging Network

Be Power, through its subsidiary Be Charge, stands at the forefront of the burgeoning electric vehicle (EV) charging landscape, having installed over 6,000 charge points and offering access to 18,000 charge points. As a charge point operator (CPO) and e-mobility service provider (EMSP) based in Italy, Be Charge is dedicated to creating a widespread public charging network, providing EV drivers with a seamless, fully digital charging experience. With an ambitious vision to expand its charging network to over 31,000 points by 2030 and promote sustainable mobility across Europe, Be Power has strategically partnered with Emnify to ensure constant and secure communication between charging stations and the management backend, irrespective of scale. This collaboration underscores Be Power's commitment to advancing EV infrastructure and fostering a sustainable transportation ecosystem [69].

P. Shenzhen: Connecting Water and Gas Utilities through the Internet of Things (IoT)

In Shenzhen, ensuring efficient water and gas supply has been a historical challenge, but there is a notable increase in investment aimed at enhancing the delivery of these utility services not only in Shenzhen but also in broader Chinese markets. The country is witnessing substantial infrastructure investments, including the installation of 40,000km of new gas pipelines connecting 470 million people and a parallel investment in water infrastructure to address issues like leakage and improve overall management. To showcase the advantages of NB-IoT-connected smart meters for utility companies, China Telecom and Huawei have collaborated with Shenzhen Water and

Shenzhen Gas, demonstrating a commitment to leveraging IoT technology for improved efficiency and management in the delivery of essential services [70].

IIoT Applications in Business Areas

Among the diverse and impactful applications of the Industrial Internet of Things (IIoT), predictive maintenance stands out as a crucial aspect. This application involves collecting extensive sensor data, including parameters such as vibration, temperature, humidity, density, current, and voltage, utilizing machine learning algorithms to predict potential failures in advance. The ultimate goal is to minimize accidents, environmental incidents, safety issues, and breakdowns in industrial processes.

Predictive maintenance systems rely on sensors to monitor machine health data points and issue warnings as needed. However, their limitation lies in their inability to provide insights into the reasons behind failures or predict when a system will fail. The essence of predictive maintenance is to develop systems capable of offering accurate probability predictions, enhancing the ability to foresee potential issues rather than merely reporting data.

For instance, in manufacturing units, an automated IIoT system can take charge of the entire operation. The system has the capability to predict when a component is likely to fail, enabling it to place an order for the replacement component in advance. This ensures that the replacement arrives in time for the maintenance crew to execute the replacement within a scheduled timeframe, maintaining the overall efficiency of the unit. This approach not only streamlines maintenance processes but also contributes to increased productivity and cost efficiency [71].

The transportation sector represents the second-largest market segment in the context of IIoT. Transportation and logistics firms are actively seeking ways to enhance their value chain systems through the implementation of technical communication and monitoring systems based on IIoT. Overall, IIoT is ushering in substantial transformations in the automation industry on a global scale [72].

Conclusion

In conclusion, the evolution of the Industrial Internet of Things (IIoT) has undoubtedly revolutionized various industries, including manufacturing, energy consumption, mining, and transportation. Throughout this paper, we have highlighted the transformative impact of IIoT within Industry 4.0, shedding light on its implications for job roles in Information Technology and Research and Development.

Key takeaways from our discussions underscore the significance of IIoT in reshaping industrial processes and empowering end-users and machine builders. The potential future outlook for IIoT points towards continued advancements that maximize existing technology investments, driving enhanced automation, efficiency, connectivity, and safety across industries.

As we contemplate the future, it becomes evident that IIoT will play a critical role in propelling substantial transformations in the global industrial landscape. It is clear that IIoT not only holds potential for significant growth and advancements but also paves the way for a more advanced and interconnected future.

In closing, the significance of IIoT in shaping the future of industrial processes cannot be understated. It is imperative that further research and exploration are encouraged to delve deeper into the continued impact of IIoT on industries. As such, we advocate for a continued focus on understanding and harnessing the potential of IIoT for the betterment of industrial practices and global connectivity."

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