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Artificial Intelligence and Machine Learning-Based Internet of Things (IOT) and Industrial IOT(IIOT)

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A B S T R A C T

The transition from manual thing to an automation marks a remarkable change in today's world. The combination artificial intelligence with the internet of things (IOT) has the greatest possibility to break the boundary and enhance in automation, data analysis as well as in decision making across various domain. IOT system has the tendency to develop vast amount of miscellaneous data which further has the potential to compete conventional method to accumulate and process to derive desirable actions. Artificial intelligence (AI) technologies including natural language processing, deep learning, and machine learning make this challenging revolution by enabling real time analysis.

This study probe the outline future and integration of AI into IOT including federated learning, explainable AI which are provide even more intelligence, expand ability, and reliability to the Internet of Things system. Despite multiple benefits, formidable such as data privacy, with more calibration it can be computed with more sure data protection and ethical frame works. The research followed by making the system more optimizing the AI and IOT to maximize the potential and come up with more innovation in industries.

Keywords: Artificial Intelligence, Internet of Things, Industrial IOT, Data Analysis, Automation, Decision Making

INTRODUCTION

All around the globe the civilization increasing and with this increase the exploiting of the internet of things(IOT) also come to an extreme peak to develop new technology and innovation creation. The internet of things(IOT) has totally change the way how we engage with the surroundings through embedding with AI into everyday substances and joining them with internet to data exchange and smooth communication to get the desired result. This network of interconnected devices has coincided with a time of unparalleled ease, efficiency, and innovation in a number of fields, including smart homes, industrial automation, healthcare and agriculture.

But more or less we know the actual potential of IOT and not only capable of collecting and transmitting data, but also to acquire vital information and make informed decisions autonomously. This is the place where the more important technology came into role play known as Artificial intelligence (AI) in humans. AI algorithms enhance the capabilities of IOT devices by enabling them to analyze massive data streams, identify significant patterns, and modify their behaviour in response to shifting circumstances and facilitating them to operate more intelligently and efficiently.

1. BRIEF ABOUT IOT

An developing paradigm known as the Internet of Things (IoT) makes it possible for sensors and technological equipment to communicate with each other online, elevating our standard of life. The different physical devices and object around the glove through the internet is refer as IOT it is a virtual word of network in which the data is transmitted and gathered after that shared in different including computer, instrument, car, and other object which receives data over the internet. These objects are embedded with different circuit, processor, detectors along with communication technology which makes it possible to operate remotely and monitor artifacts employing this present network infrastructure. The Internet of Things is meant as an accumulation of distinctly identifiable things connected to radio frequency identification (RFID) technology. As the internet keeps growing to build it potential it is now more than just a basic computer network, but rather a network of different devices, whereas IOT operates as a network of multiple connected devices. Evolving global distribution network with norms that has the ability to self-configuring technologies and networking protocols has traditionally been known as IoT (Gokhale, Bhat, and Bhat 2018).

Many aspects of resource distribution, including production, sales, transit, usage, and recycling, as well as the actions of states, businesses, and individuals, will be significantly impacted by the arrival of the Internet of Things (IoT). IoT is currently a growing Internet-based industrial knowledge infrastructure. Standardizing business procedures is an indication that the Internet of Things is important. IoT and related support frameworks must be swiftly developed and set up during this emerging phase with the goal to meet the demands of industry.

2. AI ENABLED WITH IOT

AI-powered solutions are transforming how IoT applications operate by integrating intelligent decision-making capabilities. Deep learning models allow IoT systems to automatically recognize complex patterns within massive datasets, leading to smarter automation, fault prediction, and dynamic resource management. Speech recognition and conversational AI enhance user engagement by enabling voice-activated controls and real-time assistance, making interactions with IoT devices more natural and intuitive. Additionally, advanced computer vision algorithms empower IoT platforms to analyse visual environments, facilitating applications such as smart security monitoring, autonomous navigation, and immersive augmented reality experiences.

3. ADVANTAGE OF AI ENABLED WITH IOT

Advanced Predictive Capabilities:

AI-powered IoT devices can predict upcoming trends and events by examining both current and historical data. This empowers organizations to take proactive steps, such as forecasting machinery breakdowns for timely maintenance, managing stock levels to meet anticipated demand, and optimizing logistics routes based on traffic prediction models.

Customized User Interactions:

AI-integrated IoT systems enhance personalisation by adapting services and experiences to individual preferences, behaviour, and usage history, delivering highly tailored customer experiences across different industries.

Remote Monitoring and Management:

AI-enabled IoT networks provide the ability to observe and control devices remotely via internet-connected platforms. In critical sectors like healthcare, AI-driven monitoring systems can track patient health metrics, detect irregularities, and instantly alert healthcare professionals, ensuring prompt action and minimizing the need for hospital visits.

Cost Optimization:

By automating repetitive processes and reducing downtime with scheduled repairs, AI-driven IoT technologies help organizations significantly lower operational costs. Efficient use of energy and materials also contributes to long-term.

Flexible and Scalable Deployment:

AI-enhanced IoT frameworks offer inherent scalability and flexibility, enabling organizations to simply integrate or eliminate sensors, devices, and applications as their operational needs change, ensuring smooth growth.

Improved Safety and Protection:

AI-powered IoT solutions strengthen security systems by quickly identifying potential risks and responding in real-time. Intelligent surveillance cameras can detect unusual behaviour and send alerts to security personnel, in contrast, smart home systems have the ability to alert homeowners of any unwanted access attempts and immediately lock doors.

4. AI’s DISADVANTAGES WITH IOT

Privacy Risks:

The widespread adoption of IoT appliance that gather and process huge amounts of personal information brings serious concerns about data privacy. AI-integrated IoT systems often access sensitive insights into individuals’ lifestyles, locations, and habits, which, if improperly managed, could result in major privacy violations and misuse of personal data

Security Threats:

AI-driven IoT networks are vulnerable to cybersecurity risks such as ransomware, hacking, and unauthorized data access. Breaks in IoT appliances could allow attackers to infiltrate networks, compromise confidential information, or disrupt critical operations, posing severe threats to businesses and individuals alike.

Data Governance Challenges:

The lack of clear guidelines over who owns and controls the data generated by AI-powered IoT devices often sparks disputes. Users may unknowingly give up rights to their personal data, with organizations leveraging this information for profit without informed consent, raising ethical and legal concerns.

Over dependence on Automation:

As AI systems increasingly manage key industrial and personal tasks, organizations risk becoming overly dependent on automated decision-making. Reduced human oversight may lead to unchecked errors, system failures, or the perpetuation of biases embedded in AI models.

Ethical Implications:

AI-driven IoT solutions raise critical ethical questions surrounding bias, accountability, and transparency. If not properly addressed, AI systems can reinforce societal inequalities by making biased decisions based on flawed data, leading to unjust or discriminatory outcomes in various sectors.

5. INDUSTRIAL IOT(IIOT)

Industrial IOT connects various machine and devices in industries such as power generating station, transport, oil and gas, and even in transmission of power, mine as well as in ship ports connected by software for communication. Without outside interference, the corresponding programs and even the wireless gadget that makes them up will track, record, share, analyze, and respond to information quickly with the aim to make intelligent changes to their surroundings or behaviours. The development of the Internet of Things frame work need to assure IOT functionality that connects simulated operation and the physical surroundings.

5.1 EVOLUTION OF IIOT

The first industry revolution since 18 century, IIOT has made a phenomenal development in market industry, which is further categorised into four different stages.

a) ***The first evolution:***

The very first industrial revolution, or Industry 1.0, began in 1784 by the invention of the steam engine. Manufacturing dominated this age, which mainly relied on physical labour. With the advent of railroads and tools that could automate certain aspects of the production process, it caused significant social changes.

b) ***Second evolution:***

Industry 2.0 - Industrial workers got a big break when Henry Ford, the founder of Ford Motor Company and often called the father of mass production, introduced the assembly line in 1870. This made it possible to produce automobiles much faster and with less manual effort. It marked the beginning of Industry 2.0.

c) Third evolution:

Industry 3.0 - Industry 3.0 began around 1969, driven by major breakthroughs in technology. The rise of computers, the development of networking systems like LAN and WAN, the miniaturization of circuit boards, and the growth of electronics and industrial robots all played a big role. But the biggest game-changer was the birth of the Internet, which took automation to a whole new level.

d) ***Fourth evolution:***

Industry 4.0 - Industry 4.0 began around 2010, when heavy industrial machines started getting connected to smart devices through the internet. The fourth industrial revolution began at this point.Since then, we've moved beyond the old client-server systems to a world of constant, seamless connectivity.

5.2 CONSTRUCTION OF IIOT

5.2.1 COMPONENET OF IIOT

A traditional IIoT consists of a collection of devices connected by communication and sensing technologies that gather and exchange valuable data, analyze the data to extract meaningful information in order to carry out faster and smarter business conclusions. [Lin, S. W., Miller, B., Durand, J., Joshi, R., Didier, P., Chigani, A., ... & King, A., 2015, Ungurean, Ioan, Nicoleta Cristina Gaitan, and Vasile Gheorghita Gaitan, 2016].

5.2.2 DRIVERS OF IIOT

The drivers of IIOT ensure the efficiency operation, Decision-making based on data and enhanced productivity across various industries These factors, combined with the ability to connect devices and machines, enable businesses to improve competitiveness, minimize expenses, and streamline their operations.

1. Operational Efficiency and Cost Reduction

- Preventive repairs and real-time tracking increase asset life and save downtime..
- Automation lowers labour costs and improves productivity.
- Energy management through IIoT optimizes resource usage.

2. Predictive Maintenance

- IIoT sensors detect equipment issues before failures occur, minimizing expensive unplanned downtime.
- Maintenance is done *when needed* instead of *scheduled*, saving money.

3. Data-Driven Decision-Making

- real-time information from devices and workflows enables faster, smarter decisions.
- Advanced analytics (AI, ML) uncover insights that improve operational strategies.

4. Supply Chain and Asset Management

- IIoT improves tracking of goods, materials, and equipment across supply chains.
- Inventory and logistics management become much more efficient and responsive.

5. Customization and Flexibility

- Factories can shift toward *smart manufacturing* (Industry 4.0), enabling more flexible, smaller-batch, customer-specific production runs.

5.3. IIOT PROTOCOLS

IIoT protocols are communication standards that allow industrial devices (sensors, machines, controllers, etc.) to exchange data reliably, securely, and often in real time.

1. MQTT (Message Queuing Telemetry Transport)

- A simple publishing/subscribing messaging system with lightweight.
- Made for networks with high latency along with limited bandwidth.
- Very popular in IIoT for sensor communication to cloud servers.

2. OPC UA (Open Platform Communications Unified Architecture)

- A service-based, platform-independent framework.
- Secure and robust data sharing among industrial equipment as well as systems.
- Supports complex information modeling, making it ideal for automation industries.

3. CoAP (Constrained Application Protocol)

- Specialized for lightweight, simple devices.
- Works over UDP, making it faster but less reliable than TCP-based protocols.
- Good for small, low-power sensors

4. AMQP (Advanced Message Queuing Protocol)

- An open protocol for system-to-system communication.
- Reliable queuing, delivery guarantees.
- Heavier than MQTT, but more feature-rich (transactionality, security).

5. DDS (Data Distribution Service)

- A current time publishing/subscribing protocol for important, fast systems.
- Designed for decentralized architectures (no central broker like MQTT).

Table 1: Comparison between some IIOT Protocol

FEATURE	MQTT	OPC UA	DDS	CoAP	AMQP

Real Time	NO	WEAK	YES	NO	WEAK
Scalability	YES	WEAK	YES	YES	WEAK
Closed Firewall Friendly	YES	WEAK	WEAK	YES	YES
interoperability	YES	YES	YES	WEAK	YES
Low bandwidth usage	YES	NO	WEAK	YES	NO
Low Latency	WEAK	WEAK	YES	YES	WEAK
Quality of service	YES	YES	YES	WEAK	YES
Intelligance over handling	WEAK	YES	YES	NO	YES
Failure notification	WEAK	YES	YES	NO	YES

5.4 APPLICATIONS of IIOT

With the fast growing of industrial evolution, the IIoT enabled applications are spreading in every sector of the social and economic world rapidly. Some of the eminent IIoT enabled applications are discussed as follows (Lee, In, & Kyoochun Lee, 2015)

a) The concept of Cyber Manufacturing has evolved from the broader idea of Cyber- Physical Systems (CPS). Advanced technologies like cloud computing, artificial intelligence (AI), and big data analytics are used in cyber manufacturing to improve Industrial Internet of Things (IIoT) applications. These technologies are essential in designing smart manufacturing systems, addressing operational challenges, and ensuring efficient data management. By integrating digital and physical processes, Cyber Manufacturing enables real-time monitoring, maximization, decision-making and leading to smarter, more flexible, also highly efficient manufacturing environments. (Conway, John, 2016)

b) To meet the growing demand for controlled production systems in industries like packaging and printing, Industrial IoT (IIoT) technologies can be applied to create smart manufacturing environments. In such a system, sensor data is continuously collected, transmitted, and processed using advanced IoT techniques. Intelligent sub task scheduling methods are employed to optimize production outcomes. Since the entire production process cannot be handled within a single facility, the work is divided into multiple subtasks, each managed at different locations. AI-based scheduling algorithms are used to efficiently assign these sub tasks, aiming to minimize both production costs and delays. These algorithms operate based on fitness functions designed for overall cost optimization and overall delay optimization. As a result, the IoT- assisted packaging and printing manufacturing system achieves better production efficiency, reduced costs, minimized delays, and improved resource utilization. (Li, Wenxiang, et al., 2015).

c) Logistics chain management In IoT, logistics chain is a leading composite problem. To make it simple, it can be treated as several service provider pools, each of which accommodates multiple enterprises that produce related services (Yin, Jie, Jun Li, & Peichao Ke, 2013). When a job is directed to logistics chain, the logistics chain manager will check whether the available service providers fulfill the request or not. If the request is accepted, then it is analyzed and is sent to corresponding pools. As each pool has several service providers, it is a vital task to find the suitable one. Thus, it effectively improves the overall reputation of logistics chain.

d) Industrial IoT (IIoT) applications allow real-time tracking and management of supply across the entire distribution network. With IIoT, businesses can track inventory at the line-item level globally, offering accurate insights into available materials, the expected arrival of new goods, and the current status of production. Additionally, the system can automatically notify customers of any significant changes or delays. By providing greater visibility and control, IIoT helps optimize the entire supply process and reduces costs throughout the value chain.

5.5 CHALLENGES of IIOT

The survey conducted by Morgan Stanley automation word industry automation survey in april 2016 and found that there a major nine threat that can cause harm to industrial IOT (Morgan Stanley, 2016).

a) Cyber- security:

Cyber security is one of the most critical and challenging concerns in terms of Industrial Internet of Things (IIoT). In the modern age of Industry 4.0, IoT and smart manufacturing promise to establish robust revenue streams through consistent connectivity and the efficient use of next-generation embedded systems. These systems continuously generate, analyze, and share critical and delicate business statistics, making strong security measures essential. Without proper protection, cyber-attacks could not only cause severe damage to organizations but also pose risks to human safety. Therefore, ensuring security and privacy is a fundamental challenge within the IIoT ecosystem. To address these concerns, security measures are applied across different phases:

- Techniques like symmetric and asymmetric key generation and crypto graphic key distribution are part of **pre-active phase security**.
- Techniques like group signature algorithms, safe routing, access control, and authentication are the primary focus of **active phase security**.

- Mechanisms such as threshold cryptography, intrusion detection, and intrusion tolerance constitute a component of **post-active phase security**.

By implementing layered security strategies across all phases, the protection of data, systems, and privacy in IIoT environments can be effectively maintained.

b) Lack of standardization:

When trying to add modern technology to older systems, one of the biggest challenges is dealing with all the different standards and designs used by each part of the system — from communication protocols to other components in Industrial Internet of Things (IIoT) ecosystem. Many of protocols created for IIoT are still new and not yet fully standardized. For everything to work smoothly, machines need to communicate with each other easily, no matter what operating system, connection type, or protocol they use. That's why standardization is so important

c) legacy installed base :

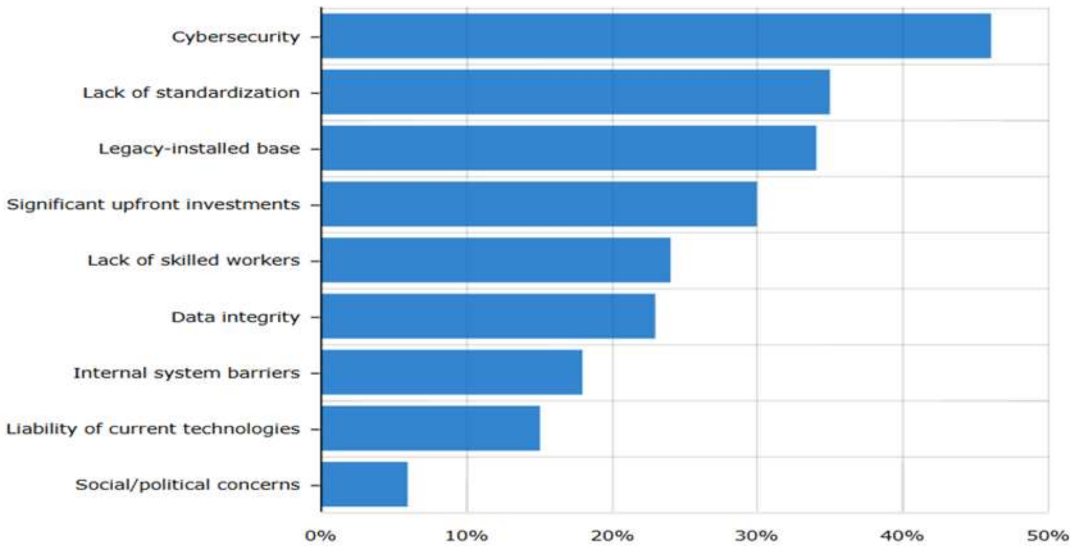
Compared to conventional networked devices or traditional machine-to-machine (M2M) communication, connecting industrial systems to the Internet of Things (IoT) becomes more complicated. One major challenge is that many older machines, known as legacy devices, weren't built to work with modern IoT technologies. They often use outdated protocols and lack the ability to connect to the internet or send data to the cloud. In fact, according to the International Data Corporation (IDC), about 85% of machines and sensors currently in use can't do this at all. The big challenge now is figuring out how to upgrade or adapt these older devices so they can work with today's advanced technologies.

d) Heterogeneity of underlying machinery and enabling technologies:

Industrial Internet of Things (IIoT) brings together a broad variety of heterogeneous devices, complex system architectures, and diverse hardware and software platforms. This diversity creates significant challenges in communication, particularly when using sensing technologies and enabling ubiquitous access to machine-generated data. As a result, managing and integrating such a wide range of systems has become a major issue for IIoT applications. Addressing heterogeneity is crucial to ensure seamless connectivity, interoperability, and efficient data sharing across the IIoT ecosystem. (Ning, Huansheng, Hong Liu, & Laurence Yang, 2013).

e) Lack of skilled industry people/workers:

One of the major reasons many businesses are still hesitant to adopt Industrial IoT (IIoT) is the shortage of skilled workers. Surveys have shown that 36% of respondents cited limited access to the necessary skills and expertise as a key barrier, directly impacting essential functions like data integration and system management. Similarly, a report by Morgan Stanley (2016) indicated that 24% of respondents identified the lack of skilled labor as a significant concern. In today's era of ubiquitous connectivity, it is clear that companies cannot manage the entire IIoT ecosystem on their own. Instead, they must rely heavily on advanced networking technologies, collaborative ecosystems, and operating platforms, all of which are critical for successful IIoT deployment and operation.



Major threats that cause harm to Industrial IOT

6. CONCLUSION

In conclusion, the way organisations and daily environments operate is changing as the consequence of the integration of intelligence and machine learning into Internet of Things (IoT) and Industrial IoT (IIoT) applications. By enabling devices to learn from data, predict outcomes, and making smarter options, these technologies are driving greater efficiency, flexibility, and innovation. From personalized experiences and predictive maintenance to smarter manufacturing and improved supply chain management, machine learning has unlocked powerful new possibilities. However, with these advancements come new challenges — especially around security, data privacy, and the need for skilled expertise. Moving forward, organizations must balance the opportunities with careful planning and robust strategies to fully harness the potential of intelligent IoT and IIoT systems, creating smarter, safer, and more connected worlds**.**

7. FUTURE SCOPE OF AI MACHINE LEARNING ENABLED WITH IOT

AI and IoT are set to play a major role in improving safety, efficiency, and profitability across construction sites. These technologies make it possible to track how workers, machinery, and materials interact on-site in real time, alerting supervisors to potential safety risks, design issues, or delays in productivity. While there are concerns about job displacement, it's unlikely that AI and IoT will fully replace human workers. Instead, they're expected to reshape business models in the construction industry, reduce errors, prevent accidents, and streamline operations. Many companies are already adopting AI and IoT tools to enhance workplace safety, using them to keep a close eye on site activity and flag concerns before they escalate into bigger problems. When coming to industrial IOT the industry 5.0 will have a more automations and robots implementation with a more improved industrial cyber security. The supply chain and asset management will be more convenient with this technology, it will boost up the manufacturing by adding smart manufacturing which make industry more feasible towards market growth.

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