

Integrating Industrial Internet of Things and Cyber-Physical Systems: A Comprehensive Overview in Smart City Scenarios

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Abstract

The Internet of Things (IoT) connects everyday objects to the Internet by integrating a vast network of interconnected smart devices into residential and commercial settings. When the Industrial Internet of Things (IIoT) changed how industries work by connecting and communicating devices and systems in industrial environments, these devices linked to the Internet gathered information from their surroundings, processed it, and sent it safely. Industry 4.0 transforms transportation and manufacturing industries by producing smart devices for total automation. This system has a substantial application in predictive maintenance. Predicting disasters in dangerous areas aids in managing safety and decreasing damage. In this paper, presented review for the integration of Cyber-Physical Systems (CPS) and IIoT in smart cities is fundamentally transforming urban services and infrastructure. Smart cities leverage technology to enhance inhabitants' quality of life, foster sustainability, and streamline municipal governance. Artificial intelligence is applied with IIoT's production and analysis data to generate speedier outcomes. The article discusses IIoT uses, supporting technologies, growth issues and how to fix them, and suggestions for growth and better performance by limitless potential, including better manufacturing, greener electricity production, self-regulating structures, and smart cities that can modify traffic patterns to reduce congestion.

1. Introduction

Industrial Internet of Things (IIoT) technologies are becoming sophisticated in automated manufacturing and intelligent factories because they provide ubiquitous, straightforward ways to handle terminal facility requests efficiently. IIoT is a subset of IoT that is especially targeted at industrial uses, such as supply chain management, manufacturing, energy, and transportation. It defines factory use of conventional IoT elements. Allows practical technological advances in an industrial ecosystem, improving manufacturing [1]. Intelligent manufacturing requires innovative solutions to improve industrial processes' sustainability, quality, and cost. As many industries use automation, this industry is growing and adapting. Large corporations worldwide are investing in IIoT, which is attributable to robust collaborations and aligning interests with developers and emerging applications [2]. Industry 4.0, the fourth industrial revolution, reshapes our lives, urban areas, and industries. At the heart of this transformation is the IIoT, which is set to link all ecosystem interactions. Integrating cyber and physical systems will fundamentally change the manufacturing and services industry, influencing how technology, organizations, and operating environments are managed. As industries continue to automate, the role of Industry 4.0 and the Industrial Internet of Things in this automation process becomes increasingly significant, driving the evolution and adaptation of industries to new technologies. While IIoT offers communication infrastructure that enables physical items and systems to exchange data and function intelligently, CPS combines sensing, computing, and actuation with feedback loops. The integration of IIoT and CPS is an

important aspect for improving the smart cities industrial infrastructure [3].

The cloud provides billions of people unlimited computing and storage capacity using intelligent mobile devices connected through 6G network technology. Advancements in AI, robots, IoT, autonomous cars, 3D printing, nanotechnology biotechnology, material science, batteries for energy, and quantum computers will merge our physical and digital worlds. Big data analytics and machine learning can make real-time city development choices better [4]. The fourth industrial revolution has rapidly increased the interconnectedness of IIoT systems. Intelligent processing of massive data is crucial to IoT applications. Thus, system networks need intelligent information processing frameworks to investigate large amounts of data. Artificial intelligence (AI), especially Deep Learning (DL), can help IIoT systems analyze massive data sets [5].

1.1. IIoT system layer

The following explains the several interconnected domains in the IIoT system components in [6, 7] as the next section.

Service computing: with cloud computing, information technology resources and services can now be stored and accessed over the internet rather than directly connecting to a server. The deployment strategies include private, public, hybrid, and community based. Files can be stored using cloud-based storage systems rather than local storage devices. The key is for customers to use resources as needed and only pay for what they consume. Google is a popular cloud service provider worldwide.



Big data: As internet-connected sensors and mobile devices expand, big data stores over one Terabyte (TB) of data and can be used for real-time decision-making. In BD, extensive and diverse data collection, or big data are examined for insights. Data acquired can be structured, semi-structured, unstructured, or all types. Standard analytical tools include Yarn, MapReduce, HDFS, and Spark. These tools enable clustering, classification, and prediction. The extensive data processing pipeline involves data gathering, training, and query using tools.

Cyber-Physical-System (CPS): The scientific foundation for the IoT and IIoT is the primary mechanism for linking previously autonomous objects. The CPS suite of products includes software and interfaces that facilitate analysis, demonstrating, design, and abstraction. It possesses a high level of connectivity, enabling it to acquire real-time data in the real world (for example, humidity and temperature with low-cost sensors) and generate valuable data through cyberspace.

Artificial Intelligence (AI): produces human-like robots. AI uses machine learning to enhance software's future predictions. For industrial-edge intelligence responses, AI and edge computing may be integrated. Devices need intelligence to be innovative. AI is defined differently across disciplines, including philosophy, computer science, statistics, sociology, and psychology. AI technology creates systems with reasoning power, like human decision-making.

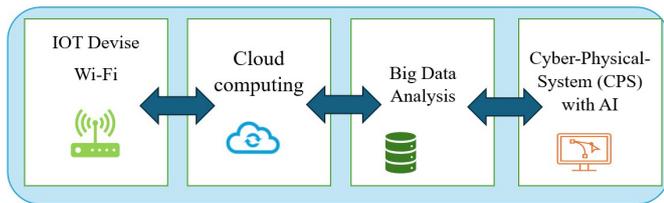


Fig. 1 the IIoT Layer components [6].

The main contributions of this work are summarized as follows:

1. Introduce the description of IIoT system components, characteristics and applications.
2. Covering the CPS with IIoT in the smart framework for the development industry.
3. Provide the important work related to CPS with IIoT for a research overview of important techniques for improving IIoT.

The organization of the paper is as follows: Section 2 provides the IIoT characteristics and application. Section 3 covers the IIoT architecture with CPS. Section 4 includes real work, section 5 introduces the challenges between CPS and IIoT, and section 6 concludes with future work.

2.IIoT characteristics and application on smart cities

Industries employ many gadgets, plants, and specialist equipment in factories and services. Connecting this equipment to the Internet improves control and data sharing, providing insights and a competitive advantage. The Industrial Internet of Things promotes brighter, greener industries with affordable, high-quality products through efficient procedures. A great instance of the Industrial Internet of Things is using sensors in plants and equipment, wireless data collection, analysis, and analytics to improve industrial operations as presented in next section [8, 9].

Maintenance: This strategy reduces frequent or time-based preventative maintenance costs through smart metered connections. The IIoT network comprises networked sensors, analyzers, and additional devices employed for the movement and management of factories, all linked to processors for industrial applications. This newfound connection may boost production, efficiency, and other economic benefits. Procedures help determine the state of training equipment and predict maintenance schedules. Predictive maintenance is rising with advances in big data processing and cloud computing.

Accuracy and precision: The coordination of these four essential domains. ICT infrastructure delivers timely resources and detailed information for better planning and scheduling. Improved product quality boosts consumer happiness and corporate growth. Consider design, production, inspection, and traceability for better product quality. The product design is adjusted to address gaps, and quality inspection is conducted during production using the latest technology.

Scalability: involves connecting virtually all systems and humans via interfaces while maintaining hardware connectivity. Physical systems increasingly possess self-control and automated connectivity inside an information network. It consists of smart products and services, providing precise items at the right time and place for optimal needs and conditions. Invisible, peaceful, and transparent management frees personnel from logistics control.

Risk and security measures: The industry's use of IIoT reduces safety concerns, which are the primary concerns. Early identification of potential concerns reduces risks and prevents actual hazards. Improved industrial safety leads to safer travel for staff through effective processes and remote real-time troubleshooting.

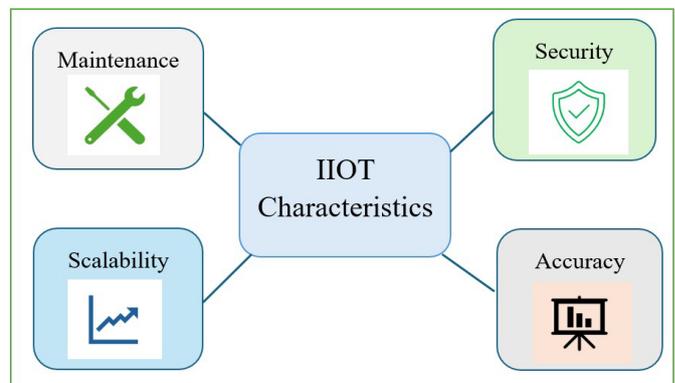


Fig. 2 the IIoT Characteristics in Smart Environments [10].

With industry 4.0, IoT integrates equipment within and outside the facility, forming a network of devices, systems, platforms and applications with built-in technology for indoor and outdoor communication and interaction. Industry 4.0 aims to transform industrial production by integrating the Internet and technological advances with traditional industries. Three major changes drive it: increased digital information, exponential computer ability, and innovative strategies. The IIoT application illustrates as follows:

1. **Healthcare:** The healthcare industry enables remote management, machine cooperation, and intelligent sensor exploitation through IIoT. It can change how doctors treat patients and keep the environment safe. Represents the future of healthcare. New AI technologies will enable

intelligent healthcare solutions in the health sector [10]. Innovative gadgets will enable solutions with hyper-connected intelligent healthcare facilities. Healthcare IIoT enhances patient engagement by letting consumers spend longer with doctors. Healthcare IoT tools improve care with the newest ecosystem technologies [11].

2. *Smart City*: a different application in IIoT usage, has captivated people worldwide. They use IT technologies for surveillance, automated transport, power management, urban security, and environmental control. Auto digital technology has focused on improving internal operations. Thus, improving the in-car experience is gaining attention. A connected car improves operation, repair, and passenger enjoyment with on-board sensors and internet connection. Transportation is where progress converges most. Fashion designers use straight programming methods, such as the transportation model, to optimize transportation usage. Regardless, self-driving vehicles and data assistance will render specific drivers obsolete. Additionally, one-moved automobiles will consider increased utility rates and restriction-free working hours. Big automakers and some daring entrepreneurs are developing connected car technologies [12].
3. *Agricultural*: this application combines innovation with organized frameworks in horticulture to increase profitability and efficiency by consolidating information from various sources. Unrest modifies agribusiness devices, resulting in great farming. A typical time of high rural equipment piques interest in computerization. In the IOT scenarios, there is limited performance in some cases. These devices are sturdy, interoperable, and do not require any special preparation [13]. Due to limited media infrastructure in rural areas, horticulture 4.0 devices are developed to function even in places without mobile phone coverage. Field temperature and moisture sensors are employed directly. Sensors can automatically indicate time and quantity for sowing, weeding, harvesting, storage, and packing. Cameras and microphones are applied to monitor and control pests. A sensor network with numerous sensors must be constructed in farmed regions. Material flows from field to plate via this network. Additionally, this data can be integrated with satellite data for storage, analysis, and processing [14].

3. IIOT with cyber-physical systems in smart cities

In Cyber-Physical Systems (CPS) enables real-time physical process monitoring, analysis, and control by integrating computational and physical components. IIoT is a network of machines, sensors, and linked devices in industrial settings. Through data collection and communication, these devices enable predictive maintenance, increase efficiency, and enhance procedures. CPS and IIoT combined in smart cities are completely changing urban services and infrastructure. Smart cities use technology to increase citizens' quality of life, promote sustainability, and simplify municipal administration. Sensors and Internet of Things devices must be placed all over the city to gather data on traffic, air quality, waste management, and energy use. When IIoT is combined with CPS in a smart city context, it enables several key benefits presented in the figure below in next section [15, 16].

Efficient Resource Management: The most significant obstacle an IoT ecosystem faces is the management of devices. Maintaining the device's status and logs is ongoing; collecting

device information is essential. Industrial systems connect devices like smartphones, temperature sensors, and actuators in varied contexts. These sensors, devices, and gateways connect to cloud services and applications via communication networks. Cloud computing refers to devices controlled and maintained centrally on the cloud, although in many environments. Decentralized edge/fog computing is an alternative for processing data closer to the source to enhance service quality.

Smart Maintenance: This variety in connectivity is a significant obstacle to the interoperability of protocols and solutions that various manufacturers have created. Consequently, interaction with diverse IIoT devices is a significant challenge when designing solutions for the Internet of Things. A system is interoperable if it can use another system's components. A software designer can easily integrate systems within the same domain or implementation within their stack. In the IIoT ecosystem, devices and apps operate on their platforms and clouds.

Environmental Monitoring: Industry 4.0 technologies, such as IoT, Cloud, Edge computing, and big data, might transform a basic cooler into an asset. This assessment outlines a structured development from requirements, structure, model, and testing to commercialization and projects. IoT in smart homes improves power efficiency, personalization, maintenance, and system updates, resulting in higher customer loyalty.

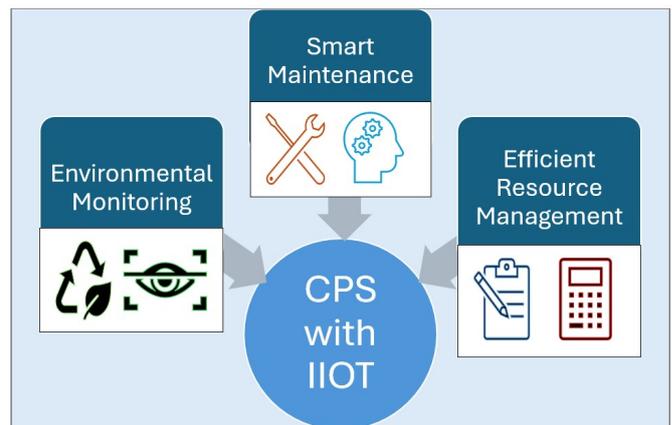


Fig. 3 the most enabling benefits from CPS in IIoT [15].

3.1. Emerging technologies in CPS with IIoT

Several emerging technologies have the potential to significantly improve the Industrial Internet of Things (IIoT) in smart cities. Here are some examples:

6G with Edge Computing: Using edge intelligence, sensing devices increase accuracy and quality and eliminate delays by managing data and communications. The intelligent edge algorithm brings more systems closer to users. Intelligent algorithms in devices or network edges for specific location coverage are recommended for essential applications. Disaster response safety applications now provide context-aware insights and real-time experiences. Together with 6G, IoT delivers modern applications and services that can provide organizations with intelligent transportation and organization systems. These frameworks provide standardized arrangements for specific demands and objectives, enhancing efficiency, benefit, and activity [17].

Artificial Intelligence (AI) and Machine Learning (ML): Many companies use edge AI to turn IIoT's production and analysis data into faster results. Companies using IIoT and IoT must transport massive amounts of combined data to central cloud-based systems of their design to make recommendations based on ML and AI models. Edge AI solutions have become more popular for IoT development due to the high cost of cloud-based storage, bandwidth restrictions, and privacy concerns [18].

Blockchain: Blockchain technology, a digital smart contract, is used in cryptocurrency to meet conditions. In simple terms, a blockchain is a chain of blocks linked logically using cryptographic hashes. It has become a disruptive technology in recent years. Bitcoin, a P2P electronic payment system, has popularized technology. It is a distributed system that distributes control and authority among participants and is used in various industries, including healthcare, banking, and government [19].

Digital Twins: Digital twin technology has gained attention from industry and academics in recent years. Innovations in Industry 4.0 have accelerated their development, particularly in manufacturing. The digital twin is seamless data transmission between physical and virtual machines in both directions. In a Digital Twin context, accurate analytics enable real-time analysis and decision-making. This overview covers the digital twin application, its technology, problems, and ongoing research in healthcare, industry, and urban intelligent environments [20].

Cybersecurity Solutions: Industry 4.0 provides an innovative approach to manufacturing, such as intelligent manufacturing, using advanced technology with multiple capacities. Many variables in Industry 4.0 generate security issues. New technologies must be ready for many cyber security dangers [21]. Policy and practice enforcement addresses cyber security concerns. Share collected data and decision-making under various scenarios with safety management application stakeholders. Data, network, and storage device security are crucial to prevent deliberate hacker attacks. In other studies, in APV, privacy data for smart cities implemented the best result when predicting risks early and can improve security [22].

consumption and carbon emissions. This system encompasses computers, electronic devices, and relevant accessories. Large energy consumption has increased carbon emissions. Typically used, low-power devices powered by batteries can hinder continuous operations. Numerous sensor nodes and intelligent gadgets enable IIoT data collection. Optimizing computation, sensing, and communications can reduce energy usage in IIoT devices. (WSNs) are the primary energy consumption platform and the backbone of IIoT [23].

3.2. IIOT with CPS challenges in smart cities

New challenges are being introduced because of the ongoing transformation that Industry 4.0 is bringing about in how we experience our environment. Listed below are the primary challenges that you might encounter in the future. The complexities of operating an industrial Internet of Things network with various valuable devices are only now recognized. IIoT components, like other networked devices, pose cybersecurity threats. These gadgets maximize their potential needs for pre-planning and assessment.

High-Investment Cost: Sometimes, the actual cost-benefit needs to be clarified. A few applications are only possible in simulation, not real life. It could be due to real-time implementation costs or the event's nature. It shouldn't be considered experimental. Simulations can precede implementation. Successful simulations can lead to prototypes for real-time risk analysis and efficiency enhancement. Iterative tasks such as idea identification, simulation, prototype, and evaluation should be completed until all stakeholders are satisfied. When developing IIoT efforts, industries must accurately calculate daily operational costs, potential revenue from new services, operational cost savings, and ROI timeframe. Developing and operating a connected service firm involves numerous costs [24].

Secure Data Storage and Management: The main concern with IoT devices is security weaknesses, as private data can be transferred automatically. Protecting privacy in IoT is more challenging than in traditional ICT due to the increased number of ways to attack IoT organizations. Adopting IIoT might increase security vulnerabilities and issues without a secure and encrypted network. In an IIoT context, all users (devices, end-users, processes, applications. Must be authenticated and authorized, preventing unauthorized access or malicious alterations [25].

Connectivity Outage: Compared to traditional networks, the number of devices hosted by IIoT networks is significantly higher. As a result, enhancing the dependability of the Internet of Things network is essential. Forming an Internet of Things network through converging several networks has several advantages. If even a tiny connectivity issue arises, the entire network may fail in an environment characterized by IoT [26].

Infrastructure: Industrialists seek long-lasting equipment. They want to implement new technologies like IIoT slowly. Instead, they seek to integrate traditional equipment into modern solutions. Industrialists must design new and efficient approaches to collect meaningful data from all network equipment [27].



Fig. 4 The emerging technologies in IIOT.

Energy Harvesting and Wireless Power Transfer: As Industrial IoT systems become increasingly complex, key challenges must be considered. One issue is rising energy use. Implemented to decrease industrial system resource

3. Related works in IIOT with CPS application

This section reviews IIoT resource sharing and scheduling research. These studies address the difficulties of controlling and arranging limited edge resources for optimal task

execution and resource utilization in IIoT applications operating in industrial settings. In [28], a CPSS is proposed to analyze high communication traffic areas utilizing telecom data. The model creates a graph for social network analysis. Hotspot extraction is accompanied by an analysis of social networks, which quantifies the value of each hotspot using network metrics. These measurements help assign importance to each location in a telecom data connection.

The study in [29] introduces an anonymous privacy strategy for CPSs. The CPS is a fundamental component of the modern smart grid, aggregating power usage from smart devices while protecting user privacy and anonymity. The proposed ALPHA scheme utilizes orthogonal bit codes and a standardized technique to provide user data privacy and untrace ability with minimal communication and computation costs. In [30], this paper introduces a privacy-aware, secure, human-centric mobility-aware (SHM) paradigm for analyzing physical and human domains in IoT-based wireless sensor networks. The suggested paradigm is validated by precise testing combining software, hardware, and designing with mathematics to ensure secure communication. This model balances energy efficiency and quality of service needs, comparing performance to other models/protocols.

The authors in [31] present a bond graph-based technique for analyzing cybersecurity in CPS. Modeling the cyber and physical layers using system motion provides a comprehensive graphical picture of a CPS, enabling interaction among IT and OT professionals, unlike previous methodologies. In [32], a blockchain-based key management mechanism for AI-enabled industrial cyber-physical systems (ICPSs) is introduced. The developed key management protocol establishes keys between IoT-enabled smart devices and gateway nodes. To complete blocks, fog servers transfer safe data from smart devices to cloud servers, which complete and mine them for blockchain verification and addition.

In [33], the study proposes (CPS) a CPS-based person reidentification architecture for intelligent surveillance. IoT-based vision sensors in smart cities are crucial for urban security and vital CPS elements. Using the upcoming edge, AI approaches to reidentify targeted individuals are still presenting hurdles. Used an AI-based framework for CPS in IoT contexts to enhance efficiency at the edge and overcome traditional video camera sensing. The researchers in [34] present a robust detection framework with streamlined architecture and essential advancements. This framework includes a focus module for lossless down sampling and increases the input image channel for enhanced feature representation. Also, an attention mechanism should be included to improve the model's capacity to extract and pinpoint crucial image sections. In [35], the model comprises three layers with various functions. Our model starts at the data-gathering layer, which Smart CPS moved to the following tier. CPS handles pre-processing, storage, and analysis in the information processing layer. It then graphs and analyses social networks. Instead of typical centrality measures, we propose Eigenvector and k-shell for social network similarity and Jaccard and cosine for social behaviors.

4. Conclusions

This research reveals that local industries must adopt IIoT to optimize efficiency and revenues. This would benefit customers by lowering prices and maintaining supply. Research indicates that the obstacle to implementing IIoT in

local industries is the need for pioneering organizations that have made these technical breakthroughs. Research on worldwide adaptation and localization of IIoT principles can help close this gap. In conclusion, this paper laid the groundwork for industrial IoT adoption. Also, this research paper includes the incorporation of CPS and IIoT in smart cities and is fundamentally transforming urban services and infrastructure. Smart cities leverage technology to enhance inhabitants' quality of life, foster sustainability, and streamline municipal governance. (IIoT) systems can be used and monetized, and system performance can be improved for other technologies by collecting and analyzing large amounts of data. This publication highlights IIoT research. While IIoT links these systems across domains, CPS provides the system-level intelligence in a smart city, allowing urban systems to sense and react to their physical surroundings. Further study can prioritize assets into essentials such as shelters, company infrastructure, lines of communication, vehicle tracks, roads, standing water, and train tracks. A suitable approach can be applied to minimize asset damage based on the category. Various degrees of protection can be set for specific use scenarios. Recovery plans can be generated based on use case types.

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