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Full-length article

An integrated outlook of Cyber–Physical Systems for Industry 4.0: Topical practices, architecture, and applications

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ABSTRACT

Industry 4.0 requires a strong understanding of Cyber–Physical Systems (CPS). An Industry 4.0-enabled manufacturing environment that offers real-time data gathering, transparency and analysis across all parts of a manufacturing process is known as cyber–physical systems, also known as cyber manufacturing. Data analytics enables executives to make data-driven choices and boost productivity, while automation speeds up manufacturing and decreases machine downtime. The main objective of deploying Industry 4.0 solutions is to enable manufacturing organisations to increase collaboration by making the correct information accessible to the right people in real time. The aim of encouraging optimal decision-making at the appropriate moment is to improve efficiency and production further. The critical terms in Industry 4.0, such as the CPS, Internet of Things (IoT), and Digital Twin, are widely used interchangeably in conversations about smart manufacturing. These are essential to Industry 4.0 and smart manufacturing because they give users access to real-time operating data of the equipment they represent. Cyber components and physical components make up the two elements of CPS. The main aim of this paper is to brief CPS and its need for Industry 4.0. Embedded Processes and Smart 5C diagrammatically elaborate architecture of CPS for Industry 4.0. Finally, the paper identifies and discusses significant applications of CPS in Industry 4.0. For this paper, we identified and then studied relevant literature on CPS for establishing an Industry 4.0 environment. CPS is integrated into several items, including vehicles and other equipment, to carry out particular functions. CPS can be utilised in any industry, including engineering, manufacturing, transportation, and even health care, because they are all easy to use. CPS network collaborative systems are built for communication. Furthermore, cutting-edge network technologies like cloud solutions are used by CPS.

1. Introduction

Cyber–Physical Systems (CPS) are considered the next step in an evolution of continual refinement and function integration within Industry 4.0. Semi-autonomous and autonomous decisions are vital components of Industry 4.0, with IoT, Artificial Intelligence (AI), new integrated systems, advanced analytics, and other technologies all playing a role [1–3]. All types of industrial businesses, including discrete and process manufacturing, as well as oil and gas, mining, and other industrial segments, can use the ideas and technologies of Industry 4.0. IoT is frequently utilised by smart manufacturing. In order to connect with other web-enabled devices, manufacturing equipment is equipped with sensors that have an IP address. This mechanisation and connection allow the collecting, analysing, and sharing significant volumes of valuable data [4,5].

The manufacture of personalised items can be done more efficiently and flexibly, which are essential benefits of this revolution. Flexibility could generate one-of-a-kind, user-defined, or one-off items and allow producers to make alterations at the last minute during various production phases. Decision-making and openness in the production process are both enhanced. Efficiency in manufacturing and production has also significantly increased. For firms aiming to take advantage of Industry 4.0, creating a hybrid multi-cloud IT infrastructure is a crucial component of digital transformation. Hybrid multi-cloud is the management of an organisation's cloud computing workloads. They

Abbreviations: CPS, Cyber–Physical Systems; IoT, Internet of Things; IIoT, Industrial Internet of Things; AR, Augmented Reality; AI, Artificial Intelligence; ML, Machine Learning

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may optimise their workloads across all their clouds since some environments are more appropriate or economical for particular workloads. Manufacturers may move their current workloads from on-premises to the ideal cloud environment available if they want to undergo digital transformation and work in a safe and open environment [6–8].

For real-time production activities, some data analysis must be done at the "edge" or where the data is created. It reduces the time between when data is generated and when a response is required. For instance, immediate action may be required if the equipment's safety or quality is compromised. Depending on network connectivity, the time needed to transport data from the business cloud to the manufacturing floor may be considerable [9–11]. Additionally, edge computing keeps data near its origin, reducing security threats. The Industrial Internet of Things (IIoT) utilises sophisticated control technology, Machine Learning (ML), and big data to allow smart machines, and eventually smart factories and warehouses, by connecting sensor data, machine communications, and automation systems that have become prevalent in industrial settings. This technology is already being utilised through real-time condition monitoring to enhance how industrial systems are maintained and serviced [12–14].

Industry 4.0 technologies necessitate increased connectivity, protecting critical industrial systems and manufacturing lines from cyber-attacks. Cybersecurity is used by businesses to protect their networks, systems, and data from cyber threats. This can provide users with real-time data to help them make decisions and improve their work output using augmented-reality glasses, eye-pieces, mobile devices, and other products [15,16]. Augmented reality (AR) technology allows users to work and make decisions independently by providing access to the correct information at the right time. While vast and deep networks of IoT devices are being built, the aspect of security compatibility among IoT devices is being overlooked. Hundreds to thousands of IoT devices can be found on a single network in industries such as maritime, mining, healthcare, and retail. These devices are made by various manufacturers and have varying firmware and security requirements [17,18]. The main aim of this paper is to study the potential applications of CPS in Industry 4.0

2. Cyber–Physical Systems

A new generation of physical process integrations with computer and networking processes are known as "Cyber–Physical Systems". It is the blending of the physical world with cyberspace. Cyberspace is used to describe the widely used, networked, and computerised digital technology that is characterised by its infrastructure for communication and computation. CPS is used in various industries, including manufacturing, energy, infrastructure, consumer goods, military, robots, smart buildings, communications, healthcare, and transportation [19–21]. Automation and self-optimisation may both be utilised to make things better. CPS combines computing, storage, and communication capabilities with monitoring and control of physical elements. That is, give physical objects "intelligence" to communicate with one another. Because they are interconnected, they use global digital networks to monitor, control, and use the information available in the virtual world and learn, cooperate, and evolve. This technology has a wide range of applications and can be used in almost any industry [22,23].

In the context of Industry 4.0, a CPS is a fusion of physical parts, transducers, and information technology systems. CPS is sometimes defined as incorporating people, such as machine operators. A CPS is, in other words, a physical world system connected to the cyber world. A CPS can be an open-loop or closed-loop system, which implies that it can perceive the physical system's real-world characteristics and regulate it or only make those data accessible for study. An Industry 4.0-enabled manufacturing enhanced cyber manufacturing, which offers real-time data gathering, analysis, and transparency across all areas of a manufacturing process. Businesses benefit from enhanced visibility, control, and data visibility across their supply chain using industry 4.0 technologies. By utilising supply chain management capabilities to get goods and services to market more quickly, affordably, and of higher quality, businesses may gain an edge over lesser effective rivals [24–26].

3. Industry 4.0

The fourth industrial revolution, known as "Industry 4.0", involves the digitalisation and automation of industry. A significant change in how goods are made is currently taking place, and it is intimately related to how the IoT will develop in the future. Robotics, 3D printing, ML, networking, data analytics, and other technological developments are transforming industrial processes and lowering human labour and judgement. By using digital technologies, manufacturing may decrease human error, shorten the time to market, and speed up the rate at which industrial processes can respond to new information. Industry 4.0 refers to the real-time interdependence of process and analytics and the convergence of operational and information technology [27–29].

Industry 4.0 transforms how companies create, enhance, and distribute their goods. Manufacturers are integrating cutting-edge technology into their production facilities and operations, including cloud computing and analytics, the IoT, AI, and ML. Industry 4.0, called smart manufacturing, integrates physical production and operations with intelligent digital technologies, such as big data and ML, to build a complete and well-connected corporate environment. The manufacturing process must be redesigned with an architecture that can absorb enormous volumes of real-time data produced by IoT sensors and other devices and enable millisecond control of the whole environment to accomplish this convergence [30–33].

4. Need of CPS in Industry 4.0

CPS must provide the integration procedures, networking, and tools required. CPS allows us to envision, construct, develop, refine, and perpetuate smart systems in domains that lead to the improvement of companies, communities, and individuals. CPS has the potential to influence technology in a wide range of Industry 4.0. In order to upgrade the various out-of-date systems of Industry 4.0 infrastructure, CPS engineers must become experts in technology [34–36]. Critical infrastructure may be more often when cutting-edge technologies are introduced to physical frameworks. The use of CPS to advance sustainability is growing. In addition to enhancing agricultural techniques and enabling scientists to minimise undersea oil leaks, CPS assist firefighters in detecting and preventing fires. CPS advancements will make systems significantly more capable, adaptable, scalable, resilient, safe, secure, and usable than the current generation of basic embedded systems [37–39].

CPS is made up of a variety of distinct components. CPS is a concept that stands out for including IoT, smart cities, operational technology, and IT infrastructures. By protecting access and data security using cutting-edge techniques, we can stop any cyber-attack from damaging our physical assets and disrupting our business operations. CPS innovation is built on contributions from several fields, and it needs a trained workforce to support and sustain its growth [40,41]. It can transform and advance the sector while solving several pressing issues. The function of CPS has altered and developed due to the growth in the number of devices linked to the IoT, resulting in increased productivity, efficiency, and financial gains. This offers capabilities for system analysis of the associated cybernetic and physical structures, as well as improvements in real-time processing, detection, and actuation between IoT systems and physical domains [42–44].

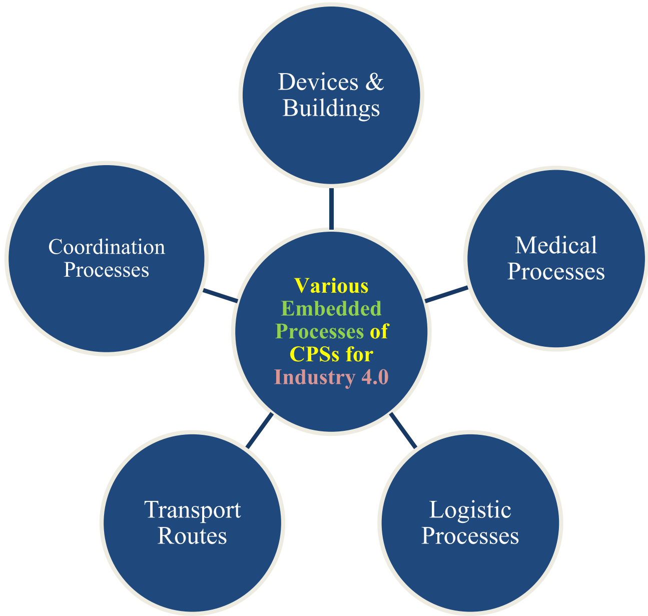

Fig. 1. Typical CPS with Embedded Processes for Industry 4.0.

5. Research objectives

CPS was made possible by the increasing usage of sensor technologies. Factories are connected and spread, enabling clients to choose from various service providers for different manufacturing phases. Industry 4.0 technologies constantly produce enormous volumes of diverse data. Vulnerability and risk may rise as a result of data management and storage. The data must be secure to organise all this information [45,46]. A strong data security strategy and a practical fix for this issue are required. Establishing and creating secure data standards is essential. The development of the procedures, networking, and technology necessary for the seamless integration of cyber and physical systems is the aim of CPS technology. However, its advantages extend beyond the realms of engineering and technology. CPS enables us to envision, design, develop, improve, and perpetuate smart systems in domains that benefit companies, communities, and people. CPS can affect technology in many businesses and organisations [47–49]. The primary research objectives of this article are as under:

RO1: - To brief CPS and their need for establishing an Industry 4.0 environment;

RO2: - to study CPS with embedded processes for establishing Industry 4.0;

RO3: - to study the Smart 5C Architecture of CPS for Industry 4.0;

RO4: - to identify significant applications of CPS in the Industry 4.0 environment.

These research objectives provide the main strength of this study. Further, to fulfil these research objectives, we studied various papers on CPS for Industry 4.0.

6. Critical CPS with embedded processes for Industry 4.0

CPS has been associated with the different embedded processes supporting Industry 4.0 culture. Fig. 1 explores several such embedded processes allied with CPS. These observed processes are elaborated as; various devices and buildings, medical processes, coordination and logistic processes, and transportation routes and systems. These processes are supportive and building blocks for exploring the opportunities for Industry 4.0 philosophy [50–52].

Digital and communication technologies started to merge. Edge/cloud computing, IIoT, AI, autonomous robotics, and other emerging technologies were all in their infancy when we observed them. The fusion of industrial and digital technologies can revolutionise production and advance the realisation of the Industry 4.0 vision [53,54]. An internet-enabled physical object like a compressor or pump has integrated computers and control elements like sensors and actuators. An entity with an allocated IP address can self-monitor, produce data on its operations, and communicate with other related entities or the outside world. Reduced costs, miniaturisation, and resilience of computers, as well as a significant rise in computing and processing capability, were all outcomes of more significant usage of electronics and computers [55–57].

Computerisation and connection are the initial two steps. The integration of computers, networking, and physical processes is still far from perfect. Using sensors and digital models allows for the real-time visibility of specialised records and processes. With digital models, industries may achieve the fourth degree of transparency by being able not only to observe what occurs but also to detect and understand it [58,59]. Comprehensive data analyses are necessary to gather and evaluate data at all levels of production. A virtual replica of a tangible item is called a digital twin. The digital twin concept stresses the relationship between physical and digital duplicates and the data produced by sensors. A Digital Twin includes transducers, AI, data analytics, and context awareness. An intelligent thermostat, for instance, can identify who is present and determine that person's preferences for the surrounding environment [60–62].

The IoT originated from networking and IT perspective with roots in the RFID environment, whereas the CPS concept was primarily driven by systems engineering and control. The Digital Twin concept arose from the field of AI. Building energy efficiency increases while energy consumption and greenhouse gas emissions are reduced using CPS. The system is made to sense temperature, humidity, and other actuators, including fans, HVAC systems, and water heaters. Using CPS, cars may connect to share information about traffic, location, and road concerns to reduce accidents and increase safety [63–66]. In reality, track and trace options lead to several IoT use cases in industries, including healthcare, logistics, shipping, mining, warehousing, and customer-focused IoT use cases. The latter has a wide range of uses and a wide range of technologies and solutions. The correct sensors and technologies can track the structural health of various items, including bridges, building components, manufacturing equipment, and cyber–physical assets in Industry 4.0 [67–69].

To effectively communicate data, hardware and software components must be significantly connected. Operators should not switch between hundreds of programmes to run the manufacturing line and analyse data. A bottleneck is created when manual decision-making is overused in production since everything must go through a worker who can only handle one choice at a time [70,71]. If people rush these judgements, they could make more errors. Artificially intelligent machines can recognise patterns and be trained to react to data the same way humans do. Only including people in decision-making when conflicting objectives, peculiar circumstances, or interference enables employees to concentrate on situations that call for their attention. It is a hub for the interchange and collection of data, enhancing the production process with automation and knowledge. The system is employed more the more diverse and substantial data sets it can hold [72–74].

7. Smart 5C architecture of CPS for Industry 4.0

Five different architecture levels have been observed while attempting with the CPS for Industry 4.0 culture. Fig. 2 details the 5C architecture of CPS for the Industry 4.0 domain. These architectures are used for: providing the interconnected and channelised systems for work effectively; converting the working data set for some fruitful outcome; cyber level, which provides the feeling of having a safe and protective working environment for the system; cognition level,

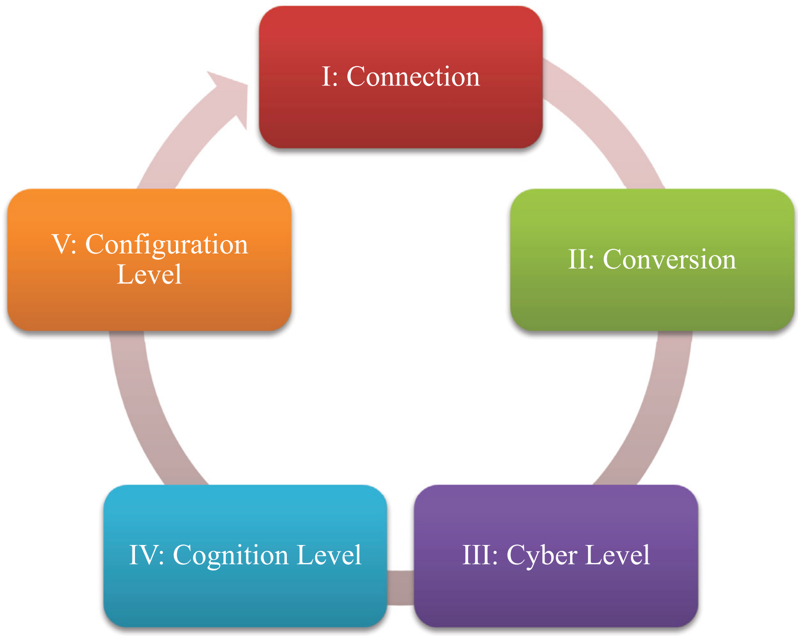

Fig. 2. 5C Architecture of CPS for Industry 4.0.

for understanding the systems requirement and offer the better treatment for attaining the best of customers responses; and configuration level [75–77].

The fact that Industry 4.0 covers a broad spectrum of technology. Businesses can continually enhance best practices that help the sector because of their capacity to handle and analyse large amounts of data ranging from orders placed by customers to the production and output of products. The risk to organisations increases as more companies adopt digital transformation owing to the ongoing danger from vulnerabilities and those who take advantage of them [76, 78]. The cyber–physical lab provides a platform for teaching, learning, and demonstrating in this digital transformation era, which is equipped with the hardware and resources required for investigating and analysing cyber-attacks and preventative measures. Many sectors are concentrating on becoming successfully sustainable and aiming towards a carbon-neutral society as the status of our planet is continuously under examination. In order to guarantee production levels while improving environmental circumstances, the system includes energy monitoring [79–81].

Large mainstream corporations are also challenged by the need for data and machine-learning technologies under Industry 4.0. Because large companies rely primarily on large-scale industrial production for competitive advantage in our current development stage, adding sensing and IoT systems to their production lines will necessitate a relatively significant investment. Large corporations must also incorporate machine-learning technologies into production lines and product design, necessitating innovation for human talent and management philosophy. Automation can relate to a wide variety of process technology, from micro-accurate robotic pneumatic valve stations to production line sensors and actuators. Electromechanical and pneumatic automation technologies are the most often utilised in the food and beverage sector [82–85].

In order to build predictive maintenance capabilities, a sizable amount of sensor data must be gathered and analysed. This decision support data is essential for a production line to be adaptable, allowing for fast modifications and line rebalancing. Instead of sheer performance, the issue is typically centred on production efficiency. Happily, cutting-edge digital technology and unprecedented internet connectivity are giving us the means to make this a reality [86,87]. Industry 4.0 is focused on digitising the whole value chain in addition to asset connectivity. This revolution is primarily concerned with the manufacturing industry and is typically described as a result of institutional activities. The point at which two systems that value being connected to a network will affect this connectivity's quality, flexibility, and capabilities. In this regard, when comparing two industrial systems with the same physical capacity and capability, the fourth industrial revolution promises greater productivity to the industrial system that can process data better and work more integrated [88–90].

A network of connected objects is referred to as the IoT. These are physical devices that number in the billions worldwide. The term IoT comprises two parts: the internet and things. The link is made via the internet. Things are billions of physical devices. This interconnection via the internet enables collaboration and interaction in data collection, sharing, and exchange. Because of low-cost processors and wireless networks, it is simple to integrate a physical object into the IoT. Vehicles, sensors, buildings, machines, and so on are examples of devices [91–93]. Data is produced by smart sensor networks, devices, log files, and other systems in production. As a result, it is anticipated that this data will be pretty different and can be either organised or unstructured, given the variety of data sources. Big data provides quantity, validity, velocity, diversity, and volatility. Due to their collaboration with the IoT and CPS, data is generated with wide variety and veracity. IIoT and Industry 4.0 are commonly used synonymously. They are comparable in theory since both aim for a linked industrial world. When seen from an industrial perspective, IIoT covers a broader range and is focused on asset connection [94–96].

8. Cyber–Physical Systems applications in Industry 4.0

A CPS consists of several heterogeneous components, necessitating the adoption of complicated models to describe each subsystem and its behaviour. The overarching model functions as a control entity to guarantee the behaviour of each sub-deterministic system and then the dynamic interactions between the sub-systems. The current design tools must be modified to consider interactions between subsystems, interfaces, and abstractions. Performance in terms of latency, bandwidth, and reliability of communications significantly impact the dynamic interactions between subsystems [259–261]. CPS has a considerable impact on Industry 4.0 to boost productivity. The approach focuses on variables that can be changed, such as humidity, light intensity,

Table 1
CPS applications in Industry 4.0.

S. no	Applications	Description	References
1.	Controlling and interacting with a physical process	A CPS is an amalgamation of several systems with the primary objective of controlling and interacting with a physical process while also adapting real-time to changing conditions through feedback. Typically, CPS are interconnected by global digital networks connecting them to the virtual world. They result from the fusion of physical processes, networks, and cybernetic computers. CPS are a group of interactive systems backed by intelligent machines that communicate operational data to skilled personnel under the direction and control of a central organisation. For an Industry 4.0-enabled smart factory, AI and its subset ML are realistically necessary. Eliminating manual processing is the fundamental tenet of this new industrial revolution, and AI is the primary tool for doing so. AI can reprogramme workflows, optimise equipment, and find general improvements that may be adopted to increase income and efficiency using the data supplied by smart connected factories. Networked industrial systems ultimately boost profit margins by maximising efficiency and effectiveness. Thus to achieve this, automation must be used throughout the production process or in several operational segments. Automation using AI or robots is made possible by the communication and interconnection in an industry 4.0-optimised facility.	[97–102]
2.	Efficiently fulfil the market need	With CPS, computing, networking, and physical processes are orchestrated as a single unit to provide future factories autonomy, human supervision, and the capacity to react rapidly and efficiently to shifting consumer and market needs. In the context of the digitised industry, connectivity and interoperability are essential because they enable the integration of goods, machines, people, and the environment into a single intelligent production system. Information technologies help with data storage, collecting, and analysis, whereas operating technologies help generate tangible value. Data management for Industry 4.0 helps make sense of the never-ending stream of information produced by conducting business. Business intelligence and financial planning procedures are simplified by real-time data analytics; supply chain, vendor relationship management, and manufacturing workflows are improved by automation and ML. Applying these technologies to customer service and marketing procedures might increase their worth even more. Virtual representations of a smaller unit of a CPS, such as a component or a machine, are also known as digital twins. They represent physical objects or real-world processes in an individualised way. They are regarded as critical components of CPS and are required for presenting information that can help a business. Cloud computing is a widely used medium for communication between physical twins and their digital twins. Data is still available to various users via the internet.	[103–107]
3.	Innovation	Innovation in CPS is built on contributions from many fields, requiring a trained workforce to support and sustain its growth. It can change and advance the sector while tackling several vital problems. The IoT has enhanced productivity, efficiency, and economic advantages while also changing and evolving the function of CPS. The advancements in real-time processing, sensing, and actuation between IoT systems and physical domains are part of this integration, along with system analysis tools for the related cybernetic and physical structures. It simplifies retrieving data from both local and mobile devices, increasing cybersecurity in some circumstances and backing up data. The cyber manufacturing paradigm incorporates real-time data management, enhanced procurement and supply chain efficiency and transparency, and automation-driven process improvement across the organisation's business divisions. This provides virtual reproduction of a physical equivalent in the actual world, such as a hardware or software programme. They are utilised to offer testing data that may be used for predictive maintenance and new version development, as well as to enhance the performance of its more tangible counterpart. Like a physical ecosystem, a company's procurement, inventory, production, finance, marketing, customer service, and sales departments are the interrelated "organisms" that make up the manufacturing ecosystem.	[108–113]
4.	Automation	In recent years, the use of automation in water distribution systems has increased using CPS. Pipes, wells, pumps, tanks, and reservoirs make up the water delivery systems that provide water to our dwellings. In order to keep an eye on the water distribution system's various operations, devices are utilised in the systems. Thus to determine the amount of water overflow from a pressure pipe or tank, for instance, a sensor can be utilised. The systems also have programmable control logic for valves that open automatically. CPS are technological systems that communicate with the real world. They are present in various services and applications and are increasingly becoming a component of contemporary industrial processes. In terms of execution, one of the biggest obstacles is cybersecurity. Linked machinery and processes make them more prone to failure and put vital industrial infrastructure at risk. There is no escaping the reality that security weaknesses in CPS can have catastrophic effects. It is crucial to ensure that current systems are adapted to accept the anticipated advantages and that the technology does not offer a substantial liability risk when integrating IoT and CPS devices into existing corporate networks. For IoT devices to interact in line with the goal operating model, organisations need a robust ecosystem mapping and monitoring framework to assist them in identifying and tracking all IoT devices and sensors, data management procedures, data flows, and different data protocols. An ecosystem monitoring programme can be implemented to guarantee the best CPS performance.	[114–118]

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temperature, and watering. These are designed to react to particular computer programmes to support growth. The device also gives the user ongoing input, so they are always aware of the greenhouse's condition. Remote management of feedback is possible via network services. Additionally, station sensors for temperature, soil moisture, light, and humidity are mounted to the designs [262–265]. In this section, we have identified and studied 30 major applications of CPS for Industry 4.0. These are core applications of CPS for the industry 4.0 domain. Table 1 elaborates on the significant applications of CPS for Industry 4.0.

It is impossible to exaggerate that Industry 4.0 is more comprehensive than just those technologies. It also considers the duties of the employees and the influence of society. Security is also a crucial aspect of Industry 4.0. The General Data Protection Regulation, the ePrivacy Regulation, and upcoming regulations in several areas, including energy and ecology, green facilities, and personal data in the

Table 1 (*continued*).

S. no	Applications	Description	References
5.	Improve productivity	Using CPS increases productivity in several industries, including engineering, healthcare, smart buildings, transportation, smart greenhouses, and many more. The IoT is a system of interconnected intelligent devices that detect and respond to changes occurring at different levels in the physical world. Industry 4.0 is changing how companies produce, enhance, and distribute their goods. Manufacturers integrate cutting-edge technology into their production facilities and operations, including the IoT, cloud computing and analytics, AI, and ML. These intelligent factories use cutting-edge sensors, embedded software, and robots to gather data, analyse it, and help them make smarter decisions. CPS developments may result in intelligent machines with machine-learning capabilities, which might contribute to the individualisation of contemporary society. When installing IoT devices in nations with weak infrastructure, they can do so while maintaining tight contact with clients and temporary test settings. Organisations must carefully evaluate, prioritise, and iteratively test good use cases. It is preferable to a big-bang strategy since related risks and obstacles may be carefully reduced. A CPS roadmap that starts with basic implementations and progresses to more intricate, AI-driven systems must be created and maintained over time.	[119–124]
6.	Optimise workflow	Industry 4.0 revolution enables manufacturers to construct digital twins, virtual clones of processes, manufacturing lines, factories, and supply networks. A digital twin is created using information from IoT sensors, gadgets, PLCs, and other internet-connected things. Manufacturers may optimise workflows, boost production, and create new products with the aid of digital twins. Manufacturers, for instance, can simulate the process and test modifications to see whether they can reduce downtime or increase capacity. Industry 4.0 opens up opportunities for technology to help with complicated tasks that still call for human judgement, such as sending warnings and notifications to spot errors, quality declines, or flaws in the manufacturing cycle. Businesses may construct simulations and test environments using augmented reality and cloud computing to see issues before they turn into expensive blunders and develop remedies they can reliably implement. Humans can use industrial technology to help them with challenging or risky work. For ensuring consistent performance and maximising equipment longevity, maintenance is essential. Maintenance, however, has often been a reactive process. Humans can manually gather data and spot maintenance needs, but it can be challenging to spot issues before they lead to unscheduled downtime or failure.	[125–130]
7.	Quality improvement	Quality is increased in smart factories using cutting-edge IoT devices. Manufacturing mistakes are decreased, and money and time are saved by replacing manual inspection business models with AI-powered visual insights. Quality control professionals may easily set up a smartphone connected to the cloud to monitor production operations from any location. By utilising ML algorithms, manufacturers may identify mistakes earlier rather than later when repair work is more expensive. The things that make up the IoT have technology built into or attached to them, enabling them to detect, gather, and communicate data for a particular use. This might involve gathering information on movement, location, the presence of gases, temperature, the 'health' of equipment, and other things, depending on the target and objective. The actual value will come from analysing and acting on this data in the context of the IoT project objective. IoT devices can also receive data and commands, depending on the 'use case'. CPS, which are connected things, are subject to this. Additionally, the additional functions made possible by CPS, such as structural health monitoring, tracking, and tracing, are use cases for the IoT.	[131–134]
8.	Intelligent networking	CPS enhances information and communication technologies and intelligent industrial machinery and processes networking. It refers to a concept that originated from manufacturing industry efforts. Through early stakeholder participation and vertical and horizontal integration, the objective is to allow autonomous decision-making processes, real-time asset and process monitoring, and equally real-time connected value generation networks. Industry 4.0 is a vision, policy, and idea that is constantly changing, complete with reference designs, standardisation, and definitions. Most Industry 4.0 is in its infancy and has a modest scale. Actuality, in the third and second industrial revolutions, technology provided the background for the great majority of digitisation and digitalisation activities. In essence, the technologies that support Industry 4.0 extensively use existing data and various new data sources, such as information from linked assets, to improve efficiency at many levels and revolutionise current industrial processes. CPS and cybersecurity Computer-based algorithms can regulate or monitor CPS linked to digital, analogue, physical, and human components. Through feedback loops, computers and networks in Industry 4.0 monitor and regulate all physical processes. The system employs software to interpret actions and track outcomes as the physical system does.	[135–141]
9.	Autonomous decision-making	At the core of Industry 4.0 is the transfer of autonomy and autonomous decision-making to CPS and machines. Industry 4.0 provides information-intensive transformation of manufacturing in a connected environment of big data, processes, systems, people, services, and IoT-enabled industrial assets, with the generation, leverage, and utilisation of actionable data and information as a means to realise smart industries and industrial innovation and collaboration ecosystems. Engineering, manufacturing, and mechanics all consider CPS as the subsequent development. The crucial features include the convergence of information technology and operational technology and bridging the digital and physical worlds, which internet technology may make possible. Cyber–physical systems can share data. They have sophisticated control systems, embedded software, and communication capabilities because of their ability to be connected to other CPS in a network. CPS can be explicitly recognised. They are components of an Internet of Everything and have an IP address, which enables them to be addressed specifically.	[142–146]

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wake of consumer market scandals, have all impacted data protection, including personal data protection. This includes data protection, including personal data protection, as vital infrastructure and industrial assets; this has hazards of vulnerabilities and a rise in attacks in industry 4.0. [266–269]. Cybersecurity is combined with business continuity, risk management, and other fields in what is known as cyber resilience, which is becoming more and more crucial as we continue to transform. This is because attacks are becoming more common, and the consequences can be severe. So, Industry 4.0 technologies help manufacturers use their resources more effectively at every level of

Table 1 (*continued*).

S. no	Applications	Description	References
10.	Product design and development	In areas like product design, prototyping and development, remote control, services and diagnosis, condition monitoring, proactive and predictive maintenance, planning, innovation capability track and trace, structural health and system health monitoring, agility, real-time applications, and others, the CPS act as the basis for new capabilities. The "smart" phenomenon frequently garners the most attention and is made possible by Industry 4.0's new capabilities. This includes everything from the smart grid, smart energy, and smart logistics to smart facilities like smart buildings, smart plants, and smart offices to the previously mentioned smart manufacturing, smart factories, smart cities, and so forth. Automation, process improvement, and productivity/ production optimisation are frequently the early aims of Industry 4.0; more developed objectives include innovation and the shift to new business models and income sources based on information and services. Industry 4.0 is the current trend of automation and data exchange in manufacturing technologies, including CPS, the IoT, cloud computing, and cognitive computing, as well as the development of the smart factory. Enhancing productivity, automating and optimising operational processes, business processes, and the top IoT use case from an IoT spending perspective: manufacturing operations, followed by maintenance and smart manufacturing, are all areas where Industry 4.0, which is the digital transformation of manufacturing in more ways than one, is still primarily focused from a benefit and potential standpoint.	[147–152]
11.	Collections of intelligent physical things	In an IoT, Data, and Services setting emphasising processes, CPS consists of intelligent physical things, systems, and components with integrated computing and storage capabilities connected via networks. CPS is based on the most current control systems, embedded software platforms, and an IP address from an Industry 4.0 perspective. Industry 4.0's primary objective is accelerating manufacturing and allied industries like logistics while also moving beyond automation and efficiency to identify new business prospects and models. Businesses who adopt thorough Industry 4.0 plans think they are much more successful in terms of financial performance, societal effect, talent, and technological investment. The Industry 4.0 maturity models include several approaches to the specified phased methods. One maturity approach views information, operational, and manufacturing systems as real Industry 4.0 from an autonomous machines and systems standpoint. Industry 4.0 strategy is a tiered approach with chances for value creation at each level and a focus on increasing overall value throughout the journey's phases, preparations, implementations, and actions.	[153–157]
12.	Enhance production capabilities	In essence, CPS enables us to provide industrial systems with the ability to connect and communicate with one another, hence enhancing current production capabilities. They create new opportunities in fields like structural health monitoring, track and trace, remote diagnostics, remote services, system health monitoring, remote control, and condition monitoring. Moreover, these possibilities have previously described realities like the linked or smart factory, smart health, smart cities, smart logistics, and so on becoming a reality, made possible by networked and communicative cyber–physical modules and systems. The end-to-end digital supply chain, suppliers, and the origins of the materials and components needed for different types of smart manufacturing, as well as the final consumer, regardless of the number of intermediary steps and participants, must all be taken into account in order to understand Industry 4.0 fully. In a digital supply chain paradigm, this means enabling more direct methods of personalised manufacturing, service, and consumer engagement, as well as lowering the costs and inefficiencies of intermediaries. Industry 4.0 is a comprehensive vision with distinct frameworks and reference architectures primarily characterised by the fusion of actual industrial assets with digital technology in CPS.	[158–164]
13.	Remote control	In Industry 4.0, CPS provide new production capabilities, including track and trace and remote control. CPS enables smart manufacturing, logistics, and other smart application sectors, such as energy, oil and gas, and utilities. Industry 4.0 and its overseas analogues are heavily reliant on the IoT. CPS also contain sensors, actuators, and other IoT parts. The IoT and CPS both require connectivity. The situation determines the particular networking technology needed. Manufacturing companies have not always understood the importance of CPS. It is crucial to consider a cybersecurity plan when starting an Industry 4.0 digital transformation that incorporates both IT and OT equipment. Embedded sensors and networked machines provide essential data for industrial organisations. Data analytics allows these organisations to analyse previous trends, spot patterns, and improve choices. Smart factories can also integrate data from other organisational/departments and their broader network of suppliers and distributors to acquire more profound insights. Manufacturers can analyse human resources, sales, and warehousing data to make production decisions based on people and sales margins. A comprehensive digital depiction of operations can be made as a digital twin.	[165–171]
14.	Decrease dependency	Industry 4.0 is dependent on communication, both between machines and people. To make data-driven choices and decrease our dependency on human labour, factory and industrial processes need extensive integration between the hardware and software used in production. This networking idea is made possible via the IoT. It enables producers to gather information from their machinery and equipment and access it through a database in meaningful ways. It is now feasible to connect thousands of devices in a confined space while maintaining dependable indoor coverage because of developments in networking technology. Customised products that better fit the demands of specific clients can be produced by smart factories. By utilising cutting-edge simulation software tools, new materials, and technologies like 3D printing, manufacturers may produce small quantities of specialised things for particular consumers. Industry 4.0 is focused on mass customisation, as opposed to the previous industrial revolution, which was focused on mass manufacturing. A transparent, effective supply chain is essential to industrial operations, and as part of a holistic Industry 4.0 plan, it must be connected with production processes. The method manufacturers receive raw materials and distribute completed items is altered. Manufacturers may more effectively plan delivery by providing suppliers with basic manufacturing information.	[172–176]

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Table 1 (*continued*).

S. no	Applications	Description	References
15.	Transparent information	Industry 4.0's interconnection makes information more transparent and enables firms to gather enormous volumes of data across the whole manufacturing process. Using this aggregate data, operators can see issues, inefficiencies, and previously hidden possibilities. In addition, producers of IoT devices may gather data even after the product has left the plant, which enhances their capacity to optimise, adjust, and rectify items. A vital element of any Industry 4.0 plan is cloud computing. For smart manufacturing to fully materialise, connectivity and integration between engineering, supply chain, production, sales and distribution, and service are necessary. This is made feasible through the cloud. Additionally, the ordinarily colossal volume of data being saved and analysed may be processed more effectively and affordably using cloud computing. By enabling small and medium-sized manufacturers to assess their demands and scale as their businesses develop appropriately, cloud computing may also help them save initial costs. CPS can develop embedded network solutions since they are reliable and smart. Additionally, as the system develops through time, its adaptive nature endows it with intelligent traits. Manufacturing companies generally employ CPS to self-monitor operations and production processes. The manufacturing process is considerably enhanced by the information exchanged between tools, business systems, supply chains, suppliers, and consumers.	[177–180]
16.	Safe workplace	Although industrial businesses have continually strived to make their workplaces safer for their workers, there are still plenty of hazardous jobs that need to be completed by people. By using robotics to help people with activities involving caustic chemicals, molten materials, confined spaces, heavy lifting, and other potentially dangerous situations, Industry 4.0 is altering this. Industry 4.0 supports human decision-making and allows robots to make regular, easy decisions. Smart greenhouses may greatly benefit from using CPS. Saving money, time, and work is one such benefit. Additionally, it fosters a more productive atmosphere. CPS is frequently utilised in the medical industry to monitor patient status in real-time and operate sensors. As a result, fewer patients need to be hospitalised, and the aged and disabled receive much better care. A network closed loop and a human loop are combined to improve this system's functionality and security further. Investments in physical and technical processes, as well as infrastructure, are necessary to prepare for CPS. The network's latency, bandwidth, and stability significantly impact the interactions of the various parts of a CPS and the capacity to carry out concurrent operations. The need for a network infrastructure that can be controlled and is versatile.	[181–186]
17.	Effectively usage of production resources.	When systems are connected, the business may use its production resources more effectively by automatically responding to delays, changes in the supply chain, and other factors that can have a distinct impact on each location. System integration is the integration of a manufacturer's multiple divisions, including manufacturing, information technology, quality assurance, and sales. CPS connect ML, IoT, and robotics. Any mechanical process that is automatically managed by software is fundamentally a CPS. The software performs algorithms that decide how the machinery, equipment, or infrastructure should be operated using sensors and other inputs from mechanical components. It is straightforward to adapt a CPS to the changing demands of a manufacturer since it can respond to changes in its surroundings and function in several settings and configurations. Industrial companies will increasingly rely on CPS concepts as Industry 4.0 develops to achieve operational excellence through productivity increases, effective resource allocation, customer happiness, and elevated shareholder value. Industry 4.0 was made possible by the extensive use of electronics and computers in Industry 3.0, which automated many industrial production processes.	[187–192]
18.	Linkage of equipment	The idea is to digitally transform every manufacturing element and link all equipment, personnel, and processes along the entire value chain, tying vendors, clients, and partners together in a virtual ecosystem. Industry 4.0 can completely change the manufacturing industry, setting new standards for productivity, efficiency, and safety. In an Industry 4.0 future, production settings self-configure, self-optimise, and self-adjust to real-time operational conditions. Flexibility, agility, safety, cost-effectiveness, and productivity will all enhance. Based on its evaluation, each firm determines the machinery, equipment, or other physical systems of its industrial plant that have the potential to provide the most value. Thus to develop a CPS network, businesses must continue integrating them with cyber systems. For instance, the main plant of a refinery complex may be connected to on-site and off-site tank farms by pipes, control valves, and pumping stations. The current norm for tank farm maintenance is manual inspection and periodic maintenance, both expensive and ineffective.	[193–196]
19.	New opportunities for products	New opportunities in the form of new products and business/service models appear as CPS becomes widespread. Additionally, it will automate manual processes that are now performed. Inadequate management might lead to societal injustice when clever CPS systems omit workers with low skill levels. This balances CPS completing repetitive work and humans identifying and awarding value-added activities. Manufacturers can effectively utilise the abundance of data created on the production line and across all their business divisions from partners and outside sources using AI and ML. AI and ML may produce insights that give operations and business processes visibility, predictability, and automation. For instance, industrial machinery might break down while a product is being made. Businesses may do predictive maintenance using data from these assets and ML algorithms, boosting uptime and efficiency. Manufacturers may enhance workflows, develop new products, and increase efficiency with the aid of digital twins. By modelling a production process, manufacturers, for instance, might test adjustments to increase capacity or minimise downtime. From planning to actuators, the smart factory connects several manufacturing processes.	[197–201]

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the supply chain, giving them a greater sense of potential for inventory management, quality control, and logistical optimisation. With IoT at a plant, workers can have improved global insight over their assets. Standard asset management procedures, including transfers, sales, reclassifications, and modifications, may be expedited, managed centrally, and in real-time [270–272].

Table 1 (*continued*).

S. no	Applications	Description	References
20.	Handle potential problems	It helps to handle potential problems before they develop into significant problems. Automation, internet-connected equipment, real-time data, and predictive analytics may help to be more proactive in addressing and resolving possible supply chain management and maintenance concerns. We may use it to lower expenses, boost earnings, and support growth. The administration and optimisation of supply chain and production operations are more accessible with industry 4.0 technologies. We may use the real-time data and insights it offers to make quicker, more informed business choices that will eventually increase the productivity and profitability of the whole enterprise. Increased automation, predictive maintenance, self-optimisation of process improvements, and, most significantly, a degree of efficiency and customer response that was previously unreachable are all benefits of this digital technology. The manufacturing sector has great potential to embrace the fourth industrial revolution by building smart factories. Real-time visibility of manufacturing assets is ensured by analysing enormous volumes of big data gathered from factory floor sensors.	[202–208]
21.	Predictive maintenance	Business and operational operations can benefit from insights, predictability, visibility, and automation provided by AI and ML. For instance, industrial machinery is prone to malfunction throughout the production process. Businesses may do predictive maintenance using data from these assets and ML algorithms to increase efficiency and uptime. With the digital revolution of Industry 4.0, manufacturers may develop digital twins, virtual clones of processes, factories, supply networks, and manufacturing lines. In Industry 4.0, communication is necessary for every business, procedure, employee, department, and piece of machinery engaged in production. All phases of the research and development process, the supply chain, the manufacturing floor, customer support, marketing, and sales must be transparent and coordinated. System integration in Industry 4.0 refers to blending diverse production-related software and hardware. Whatever manufacturers the apps and equipment are, they must function intelligently and flawlessly together.	[209–213]
22.	Better insight into the supply chain	Manufacturers have better insight into the whole supply chain and production process using data analytics and IoT-enabled devices. With this degree of visibility, AI, and ML capability, supply chain optimisation is now simply achievable in real-time. Supply chain management may be significantly improved by building networks, automating everything, installing sensors everywhere, and analysing everything using the IoT, sophisticated robotics, and advanced big data analytics. Combining conventional cybersecurity protections inside the software with sophisticated security engineering, authentication, cryptography, encryption, and physical security measures is necessary to provide CPS security and integrity. The management of CPS development requires using new-generation process solutions that are extensible and integrable with a wide range of tools and technologies and offer hybridised artefacts, management, orchestration, automation, enforcement, traceability, and visibility. Flexible orchestration, implementable on several deployment platforms and implementation modalities, made available worldwide to different and scattered stakeholder audiences and specialisations, with extensive process automation and automatic traceability.	[214–217]
23.	Integrated option of design and modelling	CPS can provide integrated abstractions and options for modelling, design, and analysis. This relatively new concept and solution receive much attention when looking at digital transformation in businesses. However, there is still much potential for this technology, which is being developed and improved worldwide. A fundamental CPS problem is defining and promoting new cooperative engineering paradigms that enable this combination of mechanical and software design and development. Physical systems are realised in substance, as opposed to logical systems, which are conceptualised in software. Different approaches based on domain context must be enforced, progress and results must be collected and correlated, and it is frequently necessary to display pertinent data across several domains in understandable ways. Providing predictive analytics, engineering responsibility, and auditability through cross-domain traceability is essential for monitoring change effects. This transition is considered the manufacturing revolution and is advancing what was started in the previous revolution through smart and autonomous systems powered by data and ML.	[218–221]
24.	Lean manufacturing	Lean manufacturing companies place a high priority on minimising waste and boosting productivity. Industry 4.0 technologies are integrated with the lean manufacturing production approach to promote efficiency initiatives at every level of the manufacturing process. When numerous Industry 4.0 technologies are implemented simultaneously, lean manufacturers profit by saving time, money, energy, material resources, and human resources. The large and expanding integration of traits into the primary subsystems of modern road vehicles is an example of CPS. Modern cars have many processors, networks, sensors, and embedded systems, which essentially makes them a system of systems. A complex and extensive process, application development and testing for CPS must continually consider implementation hardware and system concerns and restrictions. All stakeholders involved in the development process are interested in producing high-quality software applications using a unified software engineering platform, which offers an engineering environment that assures data integrity despite frequent changes. Data streams link people and devices in the context of production. For instance, a sensor and its digital counterpart might be connected to a business's systems. While the digital twin is put through various use scenarios to obtain insight into potential process improvements, hardware updates, and other performance aspects before those changes are deployed in the actual world, the physical sensor gives the system data in real-time.	[222–226]

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9. Discussion

CPSs are a collection of several systems whose primary function is to govern a physical process and, through feedback, adapt to changing circumstances. They are real-time integrations of computers, networking, and physical processes. Similar to how the internet altered how people interacted with information, CPS alter how individuals engage with designed systems. The role of people in this scenario will not change. Because they are the most flexible and intelligent "thing" in the CPS, humans act as a kind of "highest-level controlling instance", monitoring the performance of most automated and self-organising processes. One element of smart factories is the IoT. In order to connect with other web-enabled devices, manufacturing equipment is equipped with sensors that have an IP address. Simply put, automation and

Table 1 (*continued*).

S. no	Applications	Description	References
25.	Maximising machine utilisation	By utilising sensors and other IIoT devices for predictive and prescriptive maintenance, maximising machine utilisation, swiftly pivoting and innovating in response to market fluctuations, identifying and mitigating bottlenecks, making real-time decisions like automatically stopping a machine in the case of a safety issue, increasing shop floor visibility, optimising warehouse space, and data sources, manufacturers who use Industry 4.0 technology can reduce downtime. Industry 4.0 encompasses all aspects of design, inventories, quality, engineering, scheduling, sales, and customer and field service. Everyone provides knowledgeable, current, and pertinent perspectives on business and production processes and far more thorough and timely analytics. It develops and increases the team's ability to work together. Businesses that invest in Industry 4.0 solutions can boost productivity, enable predictive and prescriptive analytics, enhance departmental collaboration, and give employees like operators, managers, and executives the ability to better utilise real-time data and intelligence while managing their daily tasks.	[227–232]
26.	Monitoring the manufacturing floor	The manufacturing floor and all of its equipment are physical systems represented digitally in these instances. Data may be utilised to inform automated choices because of the CPS's ability to link and monitor the whole manufacturing floor as a whole system. In these CPS, machines converse with one another and with people. Smart sensors gather information from the shop floor, including metrics and statistics on machine usage, part counts, and quality. Because they only pay for the resources they use, manufacturers can swiftly scale up and down their IT infrastructure using cloud computing. This makes it possible for companies to deploy IoT devices in nations with inadequate infrastructure while setting up temporary test environments and keeping IT staff near clients. CPS are technological systems communicating with the physical environment using robots and networked computers. CPS is used in various products and services and is swiftly integrated into contemporary manufacturing processes, and it is essential to look at their impact in this field.	[233–237]
27.	Gather and analyse data	Industry 4.0 is data, particularly the capacity to gather and analyse data from sensors and intelligent devices embedded within machines or processes. The knowledge created from this data is subsequently used in various industrial applications, such as predictive diagnostics, analytics-driven production optimisation, and preventative maintenance. Industry 4.0 strategy and implementation, as well as the state of Industry 4.0 and organisational maturity as they move from early stages to innovative approaches. Industry 4.0 is on the way to an end-to-end value chain with Industrial IoT, and decentralised intelligence in production is the progression to CPS. This manual explores the CPS, its elements, and its significance in the development of manufacturing and industry. Data modelling and mapping covering the previously described end-to-end product life cycle and value stream is the foundation of Industry 4.0. The integration of all the technologies in Industry 4.0 must be taken into consideration.	[238–243]
28.	Optimise resources	The industry has always sought to optimise its resources to increase output. As a result, the advantages of automated connectivity are ideally suited for various areas of the industrial and production markets. CPS's creation optimises production and resource management capabilities and user feedback, including customer interactions with the product. The production floor has been computerised and mechanised; the real revolution connects it through sensors, computing modules, and processing centres. IoT considerably changes machine-to-machine communication. Two-way communications are used rather than merely pushing data from one system to another. Additionally, the cloud increases the potential for machine-to-machine communication. IoT buyers' need for additional connectivity choices is causing a move away from embedded point-to-point communication towards open interactions between devices. It can create an endless amount of integration opportunities. IIoT is helpful for the manufacturing industry's collaboration and interconnectivity of machines, data, and people. As a result, it uses IoT devices, sensors, and data that are all seamlessly connected and interfacing. In the IIoT, every aspect of manufacturing operations can be networked and connected, and the data generated can be used to optimise efficiency across all manufacturing operations.	[244–249]
29.	Control the amount of energy	The cyber–physical network controls the energy used throughout production by controlling the amount required for each process and recycling access energy. It contains software programmes that enable computerised control of industrial processes since it is a CPS. This enables connection between each station to a centralised platform, allowing convergence across management, production planning, and logistics, as opposed to individual control via an onboard controller. Intelligent platforms are encouraged to make decisions on their own via end-to-end system integration. The system may self-monitor and make decisions on important issues to increase productivity by utilising sensors and other IoT measuring tools. Decision hierarchy levels provide for quicker dispute resolution in both machines and people. With enhanced automation, businesses can decide on any problem or new necessity more quickly. It boosts productivity, improves productivity, and promotes manufacturing's adaptability and agility. Industry 4.0 urge producers to use resources more effectively at every level of the supply chain and to keep a better eye on possibilities for quality, inventory, and logistics optimisation. With IoT at a plant, workers can have more global insight into their assets. For instance, real-time management of transfers, asset sales, reclassifications, and changes can be expedited.	[250–254]

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connection make it possible to gather, analyse, and share vast volumes of essential data. Manufacturing companies can now make the most of data collected on the shop floor, across all of their business divisions, and from partners and outside sources using ML and AI [273,274].

In contrast to the cloud, edge computing uses dispersed resources near the data collection point. Faster timeframes to insights, ideally in real-time, are possible with decentralised data analysis at the plant. As soon as a safety risk is identified, machines may be stopped instantly because to edge computing rates that are almost identical to real-time for humans. To help reduce equipment failures and downtime, this is widely utilised for preventative and prescriptive maintenance. Automation and connectivity in the manufacturing sector are not new ideas. Manufacturing has always included physical to digital and digital to digital. However, with the introduction and implementation of the

Table 1 (*continued*).

S. no	Applications	Description	References
30.	Software management	CPS technologies have spurred significant innovation in software management. The container is one such technology: a simple and elegant concept designed to abstract application dependencies to increase modularity and ease deployment between different systems. We can deploy and operate traditional embedded applications with cloud-native tools and infrastructures by leveraging the same construct. Software documentation regimes previously overwhelmed by CPS are now required to be managed and coordinated in the development lifecycle and throughout and across multi-domain lifecycles. CPS adds new abstractions and artefacts. It is frequently necessary to synthesise multiple artefacts, abstractions, and models related to different design features into forms and formats that have meaning in other pertinent domains. Software within a CPS, which commonly implements life-critical functionality and must offer and be accountable for human safety, needs quality assurance even more. Successful CPS innovation requires the connection and traceability of various quality processes.	[255–258]

enablers above and robotics, the manufacturing segment can now advance to a more flexible and fully connected level, generating value both within the factory and across various supply chains.

It is now an essential component of the manufacturing process. In previous years, the IT role was to support the operational process; however, in the current era, it has drastically evolved. It supplements and plays a central and primary role in the manufacturing process. ML techniques allow for the automatic reconstruction of models in order to solve complex problems. These advancements have primarily resulted in increased product quality and decreased product rework or waste. Industry 4.0 is driven by reliable and fail-safe technology and data analytics solutions, which are all used to power smart, connected products and tech-enabled systems. Incorporating IT in an Industry 4.0 regime necessitates data becoming the lifeblood of industrial production. This data includes all aspects of manufacturing and associated services, such as product data, R&D data, supply chain data, equipment data, operational data, and user data. On the one hand, data is critical in the training and optimisation of machine-learning algorithms. The deployment of machine-learning algorithms necessitates constant data generation to control the associated production processes properly.

As Industry 4.0 imposes increasingly specific and detailed data flow requirements, various modules in the manufacturing process will become increasingly refined. Each component of the production line becomes more modular and detailed, allowing for personalised production while better reflecting and anticipating the users' needs, resulting in a virtuous production-sales-feedback product cycle. Management teams gain a clear picture of the exact process phases and bottlenecks that the product goes through from design to shipment by collecting real-time data from every machine, production space, and warehouse, as well as design, research, and quality assurance data. It is accomplished through intelligent edge and fog computing networks connecting hundreds of sensors and modules. Data is processed at the edge, and critical information is sent to the cloud or a central network for monitoring. Most tasks can be completed autonomously at the fog or edge level, close to the machines or modules to which they are connected.

10. Limitations and future scope

Since data is at the centre of Industry 4.0 settings, creating a data architecture that satisfies the strict performance, scalability, and availability standards of industrial environments is a problem. As a result, it might be challenging to adopt new data flow technologies and connect them to existing legacy systems. The IIoT may help in this situation by offering the heavy asset sectors reduced costs, more straightforward installation, better data accuracy, and remote monitoring.

Future industry sectors and the Industry 4.0 paradigm will both have CPS. CPS will introduce future industry standards for production processes. Greater agility, flexibility, and cost-effectiveness will be achieved through self-configure, self-tune, and self-optimise production environments. Many firms are still in the proof-of-concept stage, even though linked automation and robots are anticipated to become widely used in the food and beverage industry in the upcoming years. While the deployment of the IIoT will fundamentally alter the industrial environment, the automation sector is also struggling with it. IIoT has ushered in a new era of efficiency, growth, and knowledge by integrating the physical and digital worlds, offering organisations a comprehensive perspective of crucial assets and production processes. A rising variety of digital and cloud-based solutions can now perform what once required analogue equipment and wasteful processes. Manufacturers will be able to use predictive maintenance by building intelligence into equipment.

Businesses will embrace digital transformation at varying rates and in various ways. On the other side, the clear and well-defined implementation route towards the whole Industry 4.0 paradigm. The core idea behind Industry 4.0 is that manufacturing companies can achieve higher efficiency, productivity, and autonomous production processes by ensuring that machines/plant equipment, logistics systems, work-in-progress components, and other elements directly communicate. A manufacturing organisation must transform current physical entities into CPS to connect its goal with Industry 4.0. Not only will technologically sophisticated products be essential for this industrial revolution, but also the knowledge and abilities that must be developed alongside them. This will help create a new generation of highly effective and lucrative production processes and open the door for Industry 4.0 concepts.

11. Conclusion

CPS are systems that have both physical and digital components, and to manage actual activities and gather data from sensors, the embedded software interacts with the network. As a result, a feedback loop is created that helps to improve behaviour at the boundary between the physical and virtual worlds. CPS system is changing again because the role of the human being has been changed, which provides new development of Industry 5.0. Data technologies simplify identifying and addressing possible maintenance, logistical, or material issues before they wreak havoc. Industry 4.0 is built on CPS or smart machines. They connect to and are addressed via IoT using contemporary control systems, embedded software, and an Internet address. These are the same features we are accustomed to from the Industrial IoT, like track and trace and remote monitoring. For the present trend of automation and data interchange in manufacturing technologies, including CPS, IoT, cloud computing, and cognitive computing, as well as the establishment of the smart factory. A well-designed communication network with the reliable quality of service guarantees is a critical platform for building various novel CPS applications. When properly designed, CPS entities can communicate with one another seamlessly, and the network serves only as a transparent enabler. Bottlenecks, congestion, delays, and other issues that arise as a result of poor design can suffocate not only CPS applications but also the development of new CPS applications. IoT security vulnerabilities might thus take many different forms. This includes authentication, access control, non-repudiation, privacy, trust, secrecy, and secure middleware. It is possible to see the IoT as a technical foundation for developing and realising CPS.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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