The Role of Cyber-Physical Systems and Internet of Things In Development of Smart Cities for Industry 4.0

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Abstract

The pace of urbanisation is currently increasing. Modern cities are striving to become more technologically advanced and "smarter", combining the concept of sustainable development with an improved quality of life. At the same time, digital transformation is taking place, and a variety of flexible tools will help meet the growing challenges of urbanisation over the next few decades. One of the tools of digital transformation is cyber-physical systems.

Cyber-physical systems (CPS) are a set of infrastructure and production systems that combine computing (cyber) technologies integrated into the physical environment with human interaction.

CPS are being introduced into almost all areas of everyday life in smart cities. At the same time, CPS is one of the four fundamental approaches to designing the Industry 4.0 industrial revolution. CPS form the next generation of complex interdisciplinary engineering systems that include cybernetic entities integrated into the physical world. They use computing, communication management, information technology and physical processes. As a result, CPS opens up a wide range of perspectives and possible applications. This paper provides an overview focusing on current information technology concepts and their real-world applications. A number of challenges and opportunities for CPS are listed. Ideas, strategies and innovative trends for future technological solutions are discussed. The paper also highlights the relationship between CPS and the Internet of Things (IoT). As these information technology solutions will play an important role and have a significant impact on the formation of smart cities.

Keywords 1

Cyber-physical system, Industry 4.0, Internet of Things, smart city, information technology, intelligent systems

1. Introduction

Thanks to advances in information technology and the development of networking technologies, the computing and communication functions of devices are integrated into physical systems. Which interact with each other and respond to the environment.

There is no doubt that information technology will be integrated into almost all innovations of the future. At the same time, humans will become one of the entities of the expanded digital world [1].

The field of cyber-physical systems is interdisciplinary by nature. It is based on complex information technology systems.

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Cyber-physical systems are constructed systems in which functionality and basic properties are formed through the network interaction of computing and physical components. CPS are aimed at creating the processes, information technologies and networks necessary to integrate cyber and physical components [2].

According to [3], A CPS is a type of complex engineering system that combines physical, computational, and actuating elements. CPSs contain a computing and communication core that is necessary to perform computing and control, provide monitoring processes and integrate into physical systems.

At the same time, CPSs are intelligent systems created using low-power wireless network sensors. They are interfaces between the physical world, control systems and cyberspace [4]. The emergence of the Internet of Things (IoT) and cloud computing has significantly expanded the capabilities of CPS. Thanks to the integration of cloud storage and data processing processes.

CPS is an important element of the fourth industrial revolution. These systems are formed through the integration of production, based on the concept of sustainable development and processes to meet the needs of citizens. The CPS consists of Internet-connected devices, machinery, robots and industrial environments. It allows all industrial network infrastructures and applications to take advantage of simultaneous network connectivity at all levels. At the same time, it provides the ability to process and analyze much larger information flows in production and intra-system processes [5-6].

CPS forms a cyberspace that contains intelligent systems, physical methods of perception, means of observation, manipulation and interaction with physical space. CPS is used in various industries, including manufacturing, transport, smart grids, and medical care. The innovative paradigm of CPS is the IoT concept, which is also the basis for creating smart cities [7]. For example, automobiles, medical devices, energy meters and intelligent transport systems contain a wide range of specialised applications.

The physical network consists of:

- physical environment;
- interface between the physical and the digital entities;
- cyberspace formed on the basis of network equipment.

Physical space is the physical elements that need to be physically controlled or monitored in a physical environment. Cyberspace are embedded devices consisting of sensors that process information and interact with their distributed environment through actuators. The interface is realized through smarter sensors or actuators that are used to convert energy forms into electricity. Thanks to recent technological advances, the computing and communication functions of devices are being transferred to physical systems that interact and respond to stimuli from the environment. This is due to the rapid development of networked computing technologies. These embedded technologies have created cyber-physical systems.

Measuring, monitoring, and controlling the dynamics of networked physical systems requires advanced computing capabilities for real-time decision making, deployment of appropriate feedback systems, and integration of computers and networks The synergy achieved through this integration will fundamentally change the way people interact with engineering systems in the future. CPS can initiate a revolution in smart devices and key strategies for shaping our cities [8-9].

The emergence of CPS is expected to enable, redesign and create many new approaches in resource management, intelligent transportation system, enterprise management, energy management (intelligent grid management system), education, commerce, industry, smart manufacturing and environmental monitoring, to name just a few. By seamlessly integrating the various complex interdependencies of intelligent computing and common physical processes, CPS promises to transform the transportation industry [10-11].

However, despite significant progress in the development of CPS, reliability, automated operation, efficiency, and maintenance of the systems remain a subject of research as networked systems become increasingly popular. CPSs are effective because of their powerful systems. However, the security of the new cyber world is a significant challenge [12].

2. Conceptual characteristics and definitions of CPS

The term "cyber-physical system" arose from the integration of physical and network systems and processes.

A more detailed definition given in [13] defines CPS as: "a system with embedded software (consisting of equipment, buildings, vehicles, production systems, medical processes, logistics processes, coordination processes, and control processes). It is designed to collect data through sensors and influence physical processes, evaluate and document recorded data, and interact in real time with the physical and digital world through digital communication networks (wireless or wired, local or global), in a series of specialized multimodal human-machine interfaces."

The process of designing reliable cyber-physical systems (CPS) involves many different disciplines. Design parameters located in a development chain that supports cross-functionality, complexity and scale management, co-modeling, simulation, testing and deployment.

3. CPS in IoT: Challenges and opportunities

Related to CPS is the IoT, which is a wide network of various interconnected objects. Devices include various sensors, actuators, smart devices, RFID-enabled devices, and intelligent mobile devices that interact via protocols. IoT is developing as a technology used to create a system that consists of intelligent autonomous physical and digital objects that interact with each other, supplemented by sensors and actuators. In addition, appropriate processing, storage, and networking capabilities are also available in IoT systems [14]. IoT architecture is the basis for successful CPS design and implementation. These IoT infrastructures include protocols and APIs used to facilitate the collection, management, and processing of large amounts of data. Deployments can be local or global, facilitating connectivity through technologies such as Wi-Fi, fiber, cellular, and 5G. In large-scale IoT-based CPSs, cloud infrastructure and platforms can be effectively used to provide flexible cloud computing capacity. These infrastructures also provide virtualization and high-capacity storage for sensor-generated data. Another enabling factor is big data and analytics, which is considered the brain of the IoT. This system processes the data sent by sensors and actuators, correlates this data with other sources of information, and generates intelligent data that can be traced back to actions in the physical space.

The Internet of Things (IoT) efficiently manages procurement, development, production, sales and logistics through software services and enhances new business models for hybrid products. Given the challenges of a version-based architecture approach for a true enterprise network, CPS makes it possible to significantly simplify the manipulation of physical world objects in software systems and services in organizations. IoT environment. The service architecture for software services on CPS will empower business users instead of managing them by improving their approach. Software services should include attributes that differentiate them from current business applications.

They should be understandable so that business users can develop them according to their needs without the help of IT specialists [15]. Creating a CPS architecture that delivers software and service-based services in a simple way that allows business users to design collaboration easily and quickly is not an easy challenge. Hypothetically, a unified data model is needed to allow users to focus on common intelligent objects and services according to their individual needs in the IoT space [16]. Possibilities include software-defined industries that require timely processing, production, and delivery of innovative products, goods, and services, often for a single batch of a certain size. Programmable objects create individual products, as opposed to the bulk of products in the production process [17]. Highly optimized and customized manufacturing plants and supply chains will be able to adapt to fluctuations and respond effectively to customer needs. In this model, production relies on measuring actual demand and reconfiguring production methods in software through CPS instead of traditional long-term forecasting and foresight modules [18]. Static lean manufacturing will cease to exist. Instead, manufacturing companies must be more "flexible. This means continuously monitoring and analyzing the amount of data related to production systems, inventory, and supply chains, while effectively eliminating or reducing waste [19].

Conducting CPS-IoT research based on real-world cases and solving specific CPS-IoT problems yields certain results. The real world uses sophisticated analyses to understand and evaluate problems. Thorough and industry-relevant empirical research is essential for the future of CPS. Addressing the challenges of CPS-IoT opens up research challenges to bridge the gap between theory and practice, and will provide a driving force for CPS in IoT that will make the results as accessible as possible. CPS must develop and support pre-industrial systems to be attractive to local industries. To understand these systems, existing technologies can serve as a model, and innovative features should be implemented when they are available in CPS. Large-scale integrated CPSs are important for IoT research, the current work of the CPS is an attempt to expand, integrate and focus the areas of research and industry. Currently, the CPS is trying to expand, integrate and focus on different research areas, and is considering different applications and aspects to develop practical and meaningful solutions [20]. Implementation of an open IoT strategy for CPS research should start at an early stage, leveraging existing ecosystems, supporting and accepting open CPS outputs. This develops the open-source community in the IoT. Open source has inspired model and interface development as an exciting new direction. Open models serve as base models for standards, providing easy access to them later [21]. Based on a solid foundation of CPS principles, applications should be in line with technological trends.

4. Smart City using CPS

The concept of a smart city was developed by combining several areas, such as smart building, emergency response, smart transportation, and smart grids. Smart cities are large-scale CPSs with sensors that continuously monitor events in the real and virtual worlds. This, in turn, affects the actuators, changing the urban environment accordingly. These systems are being implemented to improve the lives of cities and towns that are growing at a very fast pace. Urban cities need to redesign and re-equip their urban infrastructure as the growing population puts a strain on existing infrastructure [22]. These challenges include the efficient use of basic resources such as energy, water, and food. Rapid urban growth is an obstacle to sustainable urban development without the necessary infrastructure. In fact, it leads to stagnation of city growth. To make a city "smarter", it needs to be redeveloped and re-equipped, but this is not easy for existing old cities, where some of the existing infrastructure is already outdated and degraded. Redevelopment is not easy because the city itself can have a long history and it is almost impossible to make any changes. One example is the presence of centuries-old buildings and roads that cannot be easily replaced.

The cyber-physical system of a smart city, whose schematic is shown in Figure 1, which includes the following layers, including the role of the Internet of Things, can be implemented as follows:

1. Cyber layer: covers information and communication technologies. They are responsible for collecting, processing, and analyzing data. This layer includes the Internet of Things and, accordingly, sensor networks, surveillance cameras, data collection and processing systems, machine learning systems, and others.
2. Physical layer: includes physical components: buildings, roads, vehicles, critical infrastructure (power supply, water supply). This layer includes sensors that collect data on physical parameters: temperature, humidity, air quality, etc.
3. Real layer: covers real processes and events in the city. For example: movement of people, traffic, provision of certain services. The next step after data collection is analysis to optimize city operations and improve services.
4. Personal layer: includes information about smart city users, such as their health level and service needs. The collected data can be used to provide individualized services that will improve the quality of life.
5. Environment layer: this is the environment in which a smart city develops. This layer includes factors such as weather conditions, pollution, and climate change. Once the relevant data is collected, it can be used to improve environmental sustainability and zero impact on the environment.

In general, a cyber-physical smart city system that includes such layers is capable of collecting and processing a large amount of data that can be used to analyze and optimize various processes in the city, promote sustainable development.

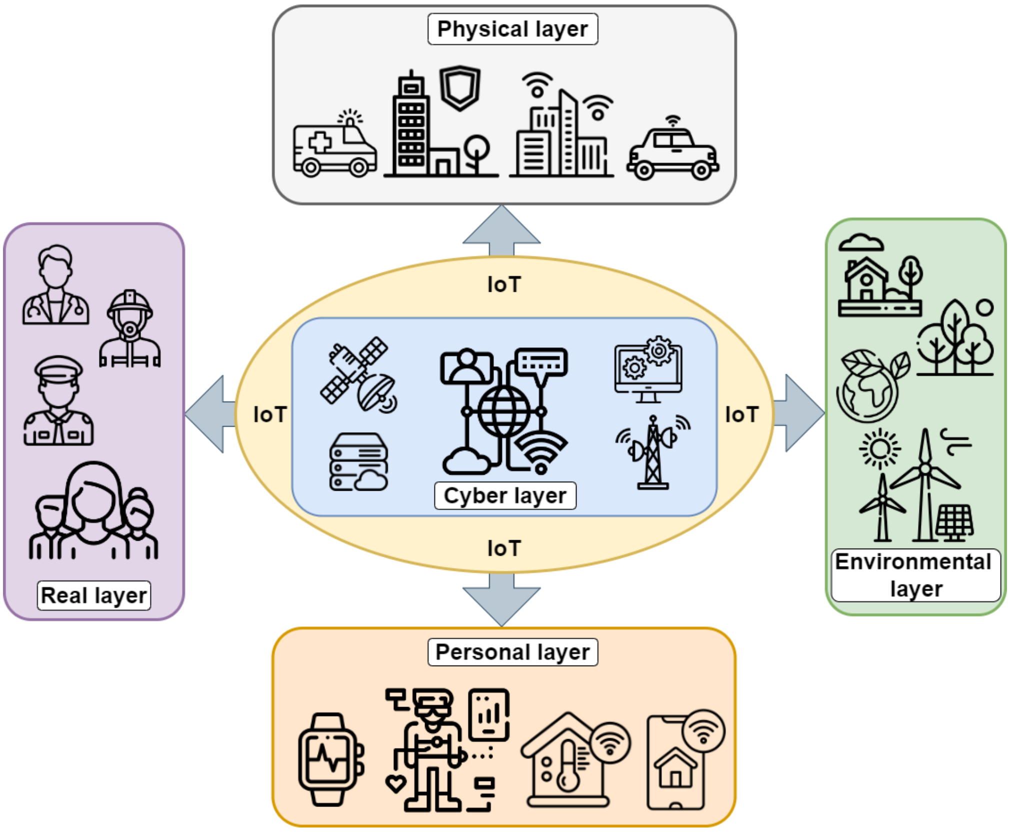

Figure 1: Proposed CPS layers in Smart City

5. Future trends in the use of CPS within the framework of a smart city

CPS is becoming increasingly common in modern society. These systems are used as smart homes, traffic management systems, automotive systems, and energy systems. These types of systems are also used in high-tech sectors such as aviation systems, medical technology, weapons systems, and chip manufacturing and fabrication, among other industries. The following section provides an overview of the various applications of CPS based on their functionality, trends, and within the framework of the smart city concept.

The main future trends of CPS in different areas of smart city identified in various studies and research papers relate to the following points:

5.1. Smart manufacturing

Smart manufacturing is the application of hardware and software integration technology to improve productivity in manufacturing and service delivery. It is considered one of the dominant leadership areas in CPS due to changes in domestic and international marketing, mass production, and economic boom. The feature of smart manufacturing is being realized in the Industry 4.0 revolution with the aim of becoming a pioneer in the manufacturing sector of the future [23].

An intelligent manufacturing system is a system that combines information technology (IT) and operational technology (OT) present in a plant or production unit. The system uses software, ground robots, and automated technology to increase productivity in the production of goods. These CPS systems give rise to Industry 4.0, the manufacturing of the future. In this type of industry, manufacturing technologies will create different workflows in the industry and enhance different forms of collaboration. The goal of Industry 4.0 is to add networked software to machines, which actually offers benefits such as machine-to-machine communication that can reduce human labor and increase efficiency. Another benefit is predictive maintenance of machines and equipment. The status reports generated by these machines can enable predictive maintenance as well as remote repair [24]. The final advantage is user interaction with the system. Users can feed data into the machine system to create new value and further improve the services provided by the system.

Service robotics is the introduction of intelligent robots that perform services for the benefit of humans in a fully automated, semi-autonomous or remotely controlled manner. Robots can be used, for example, in defense, environmental research and monitoring, logistics, life support, etc. Since next-generation robots will physically interact closely with humans, it has become important for robots to interpret and learn from human activities [25].

Building automation is the implementation of actuators, sensors, and control systems that provide automation and optimal control of ventilation, heating, air conditioning, fire protection, firefighting, lighting, and security systems in smart buildings [26].

5.2. Emergency response

Security and emergency response is one of the main issues in the smart city environment. A citywide video surveillance network that combines resources from public and private organizations will be combined with automation to detect and monitor threats and incidents in real time.

Emergency response, responding to threats to public safety, health and welfare while protecting the security and integrity of natural resources, infrastructure and valuable assets. CPS can develop and implement rapid emergency response through various sensor nodes in many areas, ready to respond to natural or man-made disasters [27].

Emergency response occurs when the health and safety of the population is threatened by natural or man-made disasters and when a system exists to address these issues. A CPS-enabled emergency response system is a system that can perform unmanned search and recovery in an adverse environment. Most CPS robots are automatic, self-learning, or remotely controlled by a controller [28]. These systems provide rapid response to emergencies through the use of low-power distributed sensors with dedicated control and communication space. These systems require nodes to collect information so that they can assess the situation and communicate with emergency teams. These situations are usually fluid and constantly changing. Therefore, the system must be reliable, efficient, adaptive, and make effective use of all the resources at its disposal.

5.3. Critical infrastructure

Critical infrastructure is a set of valuable assets and public infrastructure that are essential to the well-being and survival of a society, often the norm between countries. The smart grid is a lucrative application in the critical infrastructure sector. It utilizes industrial and central power plants, renewable energy sources, energy storage and transmission facilities, as well as energy management and distribution facilities in homes and buildings [29].

This category is an important critical infrastructure necessary for the existence of a country. The deployment of smart grids makes it possible to transform an ordinary grid into a real system. The efficiency and reliability of existing power grids can be improved by introducing smart grids. These systems have features that support automated monitoring, diagnostics, energy demand response, and advanced communications [30]. The system consists of power plants that generate energy, storage facilities for storing this energy, and transmission facilities for transferring energy to the end user. This system also includes self-renewable energy sources such as wind turbine and solar panel fields. It also includes energy management and distribution facilities in smart homes and smart buildings. A smart grid is actually a distributed, collaborative and interactive network that is used to monitor usage in real time in terms of loads, to understand energy distribution, efficiency and thus plan energy usage levels for consumers [31]. This is possible because there is a two-way information flow between the consumer and the utility provider. Through this interaction, decisions can be made to switch between the many energy sources present in the grid, leading to a better understanding of the grid's condition, monitoring of power quality, and prevention of outages. In addition, part of the smart grid is the water distribution system, which includes monitoring water quality for hardness and impurities. Water pressure detection and water distribution are also involved in this system, which contributes to better leakage detection. An important component for creating a smart grid is the smart meter, which is used to create an automatic meter reading system. These devices collect detailed data on electricity consumption and transmit it wirelessly to playback devices. Real-time system monitoring can allow utilities to better respond to changes in demand.

5.4. Health and medicine

Healthcare will benefit from faster response to emergencies, as well as from personalized health data provided by wearables, telemedicine, and artificial intelligence. Another important factor is energy; smart cities respond flexibly and instinctively to fluctuations in energy demand, the availability of alternative energy sources, and infrastructure breakdowns. This improves efficiency, reduces costs, cuts greenhouse gas emissions, and benefits the interconnected infrastructure itself.

Healthcare - refers to many issues related to the physiological state of the patient. Particular attention is paid to the introduction of health into CPS research, which opens up research opportunities [32, 33]. These opportunities may include technologies related to home care, smart medical devices, and smart prescribing [34].

The field of healthcare and medicine is used to address issues related to the patient's health. Technologies related to home care, smart operating rooms, and smart medical devices open up a variety of opportunities in this area [35, 36, 37]. These devices support patient health monitoring by increasing the connectivity of medical devices with networked devices, effectively providing continuous patient monitoring. The current trend in this area is the creation of energy-efficient systems that provide real-time visualization of patient data, as well as the ability to seamlessly connect new sensors to other devices with which medical equipment can interact [38, 39, 40]. With the advent of smart wearables that interact with the environment to collect and provide health data, personalized medical care can be provided to improve the quality of life. Thus, these systems contribute to health awareness by actually helping people identify and treat possible diseases in their daily lives and routines [41, 42]. Useful systems and robots can be used to extend and facilitate the lives of older people without assistance, and can also alert external health authorities on the organization's premises, etc. to health emergencies.

5.5. Intelligent transportation

Intelligent traffic: the combination of advanced communication, detection, computing and control technologies in transportation systems to improve traffic coordination, safety and management with real-time information exchange. These technologies accelerate transportation in the air, on land and at sea by implementing information exchange via satellite and planning the communication environment between infrastructure, vehicles and equipment, improving passenger mobility [43].

This industry involves the use of advanced technologies to improve safety, coordination, and services in traffic management. Sensors detect information in real time, which is transmitted to a computer system and then transmitted to actuators to ensure effective traffic management. The system is created by integrating vehicles, sensors, pedestrians, roadside units (RSUs) and a traffic control center. Intelligent traffic allows for real-time traffic monitoring and ensures optimal traffic management and collision avoidance. Implementation through the use of vehicle-to-vehicle (V2V) and vehicle-to-road (V2R) communication. Some of the problems addressed by these systems include reducing traffic accidents, avoiding and reducing congestion, efficient energy use, and improving overall road safety [44]. The presence of intelligent systems, wireless modules, and a large number of sensors in these vehicles are effectively used to create this type of CPS. Other implementations include new solutions that can be applied to autonomous vehicles that can successfully navigate the transportation network. Self-driving vehicles will be equipped with new safety and navigation systems that will integrate with the electronic systems already in today's cars, wirelessly communicate with their manufacturers and service providers, and with third parties via the Internet. These vehicles may have open-source software, which is a challenge because they will have software from many different vendors [45].

Therefore, one of the areas that is likely to undergo a paradigm shift in future smart cities is transportation and the formation of a system such as the "Cyber-Physical Transportation System (TCPS). The evolution of urban structure, function, and prosperity is closely tied to how cities design their mobility infrastructure [46]. Artificial intelligence promises to transform transportation systems around the world by addressing the challenges of extensive data integration, user-centered solutions, real-time decision-making, and usage-based learning. it is used to develop better adaptive solutions [47, 48, 49].

Connected vehicles have already become commonplace, and the world is rapidly moving towards an "always connected" transportation model. We are currently looking for an urban transportation ecosystem that will ensure zero traffic collisions, reduce air pollution and emissions, and provide more predictable commutes. Today's vehicles are more autonomous than ever, smarter, safer, greener, and always connected. Modern roads are no longer just physical infrastructure, they are "equipped" with communication, information.

They can harvest energy, weigh moving vehicles, collect tolls, and more. Leveraging advances in communication networks, the Internet of Things, cloud and edge computing, scalable storage, and data-driven information, they can be called physical transportation network systems (TCPS). It is a new autonomous system of connected vehicles and infrastructure, a shared data-driven mobility model for the future urban environment [50, 51].

In this article, we have identified the following aspects of the cyber-physical transportation system:

- The importance of cyber-physical transportation systems (TCPS) in the context of future smart cities.
- The status of connected and automated vehicles.
- Building a TCPS system for future smart cities.
- TCPS technologies for architecture, reliability, performance, safety and security.
- Wireless networks "media to vehicle" (V2V), "vehicle-infrastructure" (V2I) and "media to everything" (V2X).
- Modern communication standards of the intelligent transportation system (ITS).
- Current and future state of mobility as a service (MaaS) in TCPS.

5.6. Air transportation

Improving safety is a major goal of the air transportation system. Significant progress has been made in many aspects of the air transportation system, but there is still a need for security enhancements to improve tracking functionality and maritime safety. To achieve this goal, distributed control using sophisticated air traffic management systems will be an important part of future systems. This, in turn, will create more challenges, as the interaction between the aircraft and the radar tower will increase significantly, which may inhibit and limit the overall capabilities of the current system. Improvements will include the use of satellite technology over radar towers for air traffic control. Satellite navigation will provide pilots with the exact location of surrounding aircraft. Another implementation is the introduction of unmanned aerial vehicles (UAVs), also known as drones. Technologies used in drones are increasingly being applied to civilian aircraft systems, making them "smarter" [52]. These technologies improve the physical perception of aircraft, and thus will have a significant impact on air traffic and the systems used for air traffic control in the near future. This has led to the emergence of a concept called NextGen Air Transport Systems [53].

6. Security challenges

All CPSs are connected to a system network, a private network, and the Internet. With this in mind, security is considered a key requirement for a CPS. Security can range from physical security to data security in transit and depends on the application and services where the CPS is used. To ensure these security requirements, the necessary security policies and mechanisms must be in place. The main challenges faced by CPS are:

1) Security

2) Integrity
3) Authentication
4) Access control
5) Reliability.

All of these security challenges are applicable to smart cities, where integrated systems are not only used by residents but can also be manipulated by potential hackers [54]. Since CPS are embedded in the city's activities, even small manipulations or hacking of the system can cause serious problems that can even lead to life-threatening situations [55]. For example, autonomous vehicles hitting pedestrians. Hacking of smart grids, leading to power outages throughout the city. Some CPS attacks include phishing attacks, where sensors or controllers send false information, such as incorrect data. The sensors can be compromised physically or comprehended by software. Another attack is a DoS attack, where the system is shut down or slowed down by compromising the communication channel. One of the consequences is that the controller does not receive data from the sensors. Network isolation attacks are also common, where a set of nodes is understood and isolated from the network [56]. This attack can cause packets entering or leaving this area to be dropped. CPS attacks are categorized into short-term and long-term attacks. Short-term attacks are those where the service is immediately disrupted, while long-term attacks do not aim to immediately disrupt the service, but to create a distributed attack that will be launched later. Researchers are working on CPS intrusion detection systems (IDS) to prevent such incidents [57]. Various types of IDS devices are currently being studied, including behavior-based detection, knowledge-based detection, host-based testing, and network-based testing.

7. Conclusion

The analysis conducted in the CPS study confirms their relevance and practical application, including current and future digital infrastructure used in the design of engineering systems applied to current and future technologies. The use of technologies and tools such as the Internet of Things, remote monitoring devices, GPS, artificial intelligence and data analytics, and contact tracking applications provides an additional layer to protect, monitor, and control human life and health.

CPS and IoT are excellent tools for improving the quality of services and, ultimately, the basis of the Industry 4.0 paradigm. CPS is the convergence of many different technologies, including embedded systems, distributed systems, and real-time systems, which help to develop energy-efficient networks using microcontrollers, sensors, and actuators. The CPS as a system must operate reliably, safely, securely, and efficiently, and address security issues such as privacy, security, and availability. The proposed approach to the formation of layers of a cyber-physical system as an information technology platform and the distribution of areas in terms of their functions allows for the active and gradual implementation of scaling of cyber-physical systems using the Internet of Things.The CPS and the concept of a "smart city" within the framework of Industry 4.0 has many advantages for stakeholders if it is reliable, dynamic, and scalable. This review points to the need for further research into the interaction of cyber-physical systems and the Internet of Things in the field of smart cities.

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