Cyber-Physical System

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Cyber-Physical System (CPS) is a symbol of the fourth industrial revolution (4IR) by integrating physical and computational processes which can associate with humans in various ways. In short, the relationship between Cyber networks and the physical component is known as CPS, which is assisting to incorporate the world and influencing our ordinary life significantly. In terms of practical utilization of CPS interacting abundant difficulties. CPS is involved in modern society very vastly with many uptrend perspectives. All the new technologies by using CPS are accelerating our journey of innovation. Researchers have explained the research areas of 14 important domains of Cyber-Physical Systems (CPS) including aircraft transportation systems, battlefield surveillance, chemical production, energy, agriculture (food supply), healthcare, education, industrial automation, manufacturing, mobile devices, robotics, transportation, and vehicular.

3C 5C NIFU Cyber Physical System 14 domains of CPS

1. Introduction

The Cyber-Physical System (CPS) is the key concept of Industry 4.0, which the German government advocates for to develop smart factories and fetch in the 4th industrial revolution. When an NFS session was organized in Austin, Texas, the United States in 2006, the concept of CPS officially emerged [1]. Industry 1.0 was about mechanization and steam power, and then mass production and assembly line which was known as Industry 2.0, and digitalization and automation are Industry 3.0, and finally, Industry 4.0 is planned for the distributed engender through shared amenities in the combined global industrial structure for on-demand manufacturing to succeed personalization and resource efficiency [2]. It has far-reaching consequences for both producers and consumers. The term Industry 4.0 refers to a trend in industrial automation that incorporates some new technologies to improve worker health at work, as well as plant productivity and quality.

The smart factory approach is part of Industry 4.0 and is divided into three categories including smart production, smart services, and smart energy. From the previous statement, it is clear that energy conservation is a concern in any sort of factory. This is because the end product must be produced at a low cost while maintaining high quality. As a result, energy conservation boosts productivity and maybe creates job opportunities. The Cyber-Physical System is a major idea in Industry 4.0. [3]. CPS are advanced technologies that connect physical reality operations with computing and network infrastructure [4]. With typically integrated devices, which are supposed to function like independent devices, CPS focuses on connecting multiple devices [5]. A CPS comprises a monitoring system, generally, one or even more microcontrollers that regulate and transmit the information acquired from the sensors and actuators required to deal with the actual environment. A communication interface is also required for such embedded systems to share information with other embedded systems or the cloud. The most significant element of a CPS is information interchange, because information may be connected and analyzed centrally. A CPS, to look at it another way, is an embedded system that can communicate with other devices via a network. The Internet of things [6] is a term used to describe CPS that are hooked up to the internet. With integrated technology, the Internet of Things (IoT) will connect all the company's elements, machinery, and Goods.

Herein, the research areas of 14 important domains of Cyber-Physical Systems (CPS) are explained, including aircraft transportation systems, battlefield surveillance, chemical production, energy, agriculture (food supply), healthcare, education, industrial automation, manufacturing, mobile devices, robotics, transportation, and vehicular. Challenges and future direction are demonstrated. Almost all articles have limitations on security, data privacy, and safety. Several projects and new dimensions are mentioned where CPS is the key integration. Consequently, the researchers and academicians will be benefited to update the CPS workspace and it will help them with more research on a specific topic of CPS.

The common acronyms used in CPS field are tabulated in **Table 1**.

Table 1. Used and known Acronym about Cyber Physical System.

Acronym	Full Form	Acronym	Full Form
CPS	Cyber Physical System	NFS	National Science Foundation
IOT	Internet of Things	IOS	Internet of Services
IOD	Internet of Data	OCS	Oriented Cuckoo Search
3C	Computing, Communication, Control	IDS	Intrusion Detection Systems
RTLS	Real-Time Location Sensing	WoT	Web of Things
NoC	Network-On-Chip	KF	Kalman Filter
ACPS	Aviation Cyber Physical System	UAVs	Unmanned Aerial Vehicles
CPPS	Cyber Physical Production System	ECPS	Energy Cyber Physical System
PHEVs	Plug-in Hybrid Electric Vehicles	HESS	Hybrid Energy Storage System
SeDS	Sensor-Drone-Satellite	ICT	Information & Communication Technology
MDR	Monitoring detecting responding	CCP	Collaborative Control Protocol
MCPS	Medical Cyber-Physical System	EHR	Electronic Health Record
MPPT	maximum power point tracking	IASs	Industrial automation systems

Acronym	Full Form	Acronym	Full Form
ICPS	Industrial Cyber-Physical Systems	IAS	Industrial Automation and Software
CPSSs	Cyber-physical product-service systems	RE	Requirements Engineering
PHM	prognostics and health management	DTs	Digital Twins
TCPS	Transportation Cyber-Physical Systems	DEDR	Dynamic En-route Decision real-time Route
CF	car-following	EV	Electric Vehicle
ITS	Intelligent Transportation Systems	FC	Fog Computing
SA	Smart Agriculture	SCSAS	Smartphone based construction site safety awareness system
3C	Computation, Communication, and Control	5C	Connection, Conversion, Cyber, Cognition and Configuration
		NIFU	Network, Intelligence, Functionality, and User friendliness)

2. What Is Cyber-Physical System?

Cyber refers to Computing, Networking, and controlling that is distinct, switched, and logical. Physical systems are natural and human-made systems that are regulated by physics rules and executed on time [7]. A CPS is characterized as a revolutionary technology for controlling associated systems between their computation capabilities and physical assets [8]. A CPS is a network of interconnected IT components that is used to control physical such as mechanical and electronic items. The Internet is used as an information infrastructure for connectivity. A CPS is made up of two major functional elements.

- Advanced gateways, which help to ensure real-time data obtained from the physical world as well as info responses from the cyber environment; and
- Intellectual data processing, computer simulation, and data analysis abilities, which build the cyber.

Several technologies are intimately linked to the CPS for instance Sensor networks, IoT, wireless, and cloud computing. Wireless networks are thought to be an important part of CPS [9]. The Internet offers critical techniques for optimizing the productivity of cyber-physical systems. The following parameters are included in Internet technology perspectives.

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- Internet of Things (IoT): It entails using IP addresses to communicate with smart systems. This allows any physical device to be assigned its IP address [10].
- Internet of Services (IoS): It includes new communication models such as those offered by service-oriented design (SOA) and REST technology [11].
- Internet of Data (IoD): It allows for the efficient transmission and storage of large amounts of data, as well as the creation of innovative analytical techniques for analyzing large amounts of data [12].

One can also say about CPS that it is a convergence of 3C containing computation, communication, and control or 5C or NIFU.

The characteristics of CPS among 3C, 5C [1] and NIFU is discussed in **Table 2**.

Table 2. Characteristics of CPS.

Name	Description
3C	• Computation in a CPS refers to the processing and analysis of data from physical and computational components to make decisions and control physical processes. • Communication in a CPS refers to the exchange of data between physical and computational components to facilitate control and monitoring of physical processes. This involves the use of communication networks and protocols to ensure that data is transmitted accurately and in a timely manner. Effective communication is critical in a CPS to ensure that physical processes are controlled and monitored accurately and in real-time. • Control in a CPS refers to the ability of the computational components to influence and manipulate physical processes. This involves the use of sensors, actuators, and other physical devices to monitor and manipulate the physical environment. The computational components of a CPS use data analysis and decision-making algorithms to determine the appropriate actions to take to achieve the desired control outcomes.
5C	• Connection in a CPS, the physical and computational components must be connected and integrated with each other to achieve a specific function. This involves establishing communication channels between sensors, actuators, and other physical devices and the computational components, such as processors and communication networks. • Conversion in a CPS refers to the process of converting physical data into digital data that can be processed and analyzed by computational components. For example, in an autonomous vehicle,

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Name	Description
	sensors detect the physical surroundings, and the data from those sensors is converted into digital data that is processed by the onboard computer to make decisions about the vehicle's movement. • The term "cyber" in CPS refers to the computational components of the system, including hardware, software, and communication networks. • Cognition in a CPS refers to the system's ability to process, analyze, and make decisions based on data from physical and computational components. This involves using artificial intelligence and machine learning algorithms to analyze data and make decisions about how to control physical processes. • Configuration in a CPS refers to the arrangement and setup of physical and computational components to achieve a specific function. Configuration is critical in ensuring that the CPS is optimized for its intended application and operates effectively and efficiently.
NIFU	• A CPS is typically composed of multiple physical and computational components that need to communicate with each other to achieve the desired functionality. A network, such as a wired or wireless communication network, is used to establish communication between these components. • The intelligence of a CPS refers to the system's ability to process data, learn from data, and make decisions based on data. This involves using algorithms and techniques such as artificial intelligence, machine learning, and data analytic to analyze data from physical and computational components. The intelligence of a CPS enables it to optimize physical processes, improve safety and efficiency, and enable intelligent automation. • The functionality of a CPS refers to its ability to perform a specific task or achieve a specific goal. The functionality of a CPS can vary widely depending on the application, and can range from simple tasks, such as adjusting temperature and lighting in a smart home, to complex tasks, such as controlling an autonomous vehicle. • User-friendliness in a CPS refers to the ease of use and intuitiveness of the system's interface. This involves designing the system with the user's needs and preferences in mind and providing an interface that is easy to navigate and understand. A user-friendly CPS can help ensure that the system is used effectively and efficiently and can help reduce the potential for errors or accidents.

3. Compatibility of CPS with Industry 4.0

A CPS is a highly integrated system of physical components containing sensors, actuators, and diverse equipment, along with cyber components boasting ubiquitous processing and effective communication, which is a rapidly emerging research topic. Addressing demands, challenges, and possibilities across a variety of industrial sectors might help speed CPS research. The focus is to create new systems science and engineering methodologies for designing high-confidence systems that are flexible, synergistic and interconnected at all levels. Industry expenditures in CPS technology and research have been extensive in the past and present, but have primarily

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concentrated on short-term, fast-payoff proprietary solutions. Manufacturers and industries that have recently made investments in cyber-physical-manufacturing systems and testbeds [13]. CPSs, which include transport systems, power systems, water/gas distribution systems, and autonomous factories, are regarded as the most potential industrial systems from an engineering standpoint. A wide range of industrial robots with an inertial navigation device or other sensors are programmed to move along a predetermined route to fulfill production tasks together [14][15]. The tight coordination of cyber and physical aspects in these systems gives higher freedom, productivity, usability, security, and flexibility. Moreover, industrial CPSs are viewed as a key component of the 4th industrial revolution [16][17] and significant efforts have been undertaken to demonstrate their significance. Industrial CPSs are massive, globally distributed, federated, collaborative, and life-critical systems with a large number of integrated sensors and actuators that are connected to provide real-time inspection and closed-loop control. Furthermore, sensor networks and distributed control networks play a significant role in the execution of industrial CPSs. In other words, in a widely deployed CPS architecture, these two networks are frequently required [18]. Sensor networks are typically implemented in the interior or surrounding plants to collect lots of important information in order to make accurate perceptions of the physical plants. Actuators may be able to respond in real-time to changes in physical plants using this information. As a result, when merging the cyber and physical worlds, a closed loop is produced by both communications between sensors and actuators and controlling plants via actuators [19]. Many industrial sensors and actuators with some communication and data processing capabilities have been made accessible in recent years, due to the efforts of research institutes and enterprises all around the world.

4. Cyber and Physical Mapping

The goal of CPS is to provide new features to physical systems by combining computation and communication with physical processes [20]. CPS provides real-time sensing, dynamic control, and information services for complicated processes through strong collaboration between the 3Cs. CPS has placed a heavy emphasis on the cyber world's tremendous communication and computation abilities which could also improve the physical world's precision and efficiency [21][22]. Additionally, whether it is a three-tier, five-tier or service-oriented design all of the CPS designs described by academics concentrate on control instead of mirrored representations [23]. The tasks of CPS are enabled by mutual mapping, real-time communication, and effective collaboration between both the cyber and physical worlds. The computing system may have impacted more than one physical object. For example, a structure may consist of several hardware elements. As a result, the mapping link between the cyber and physical worlds of CPS is a one-to-many connection rather than a one-to-one.

5. Integration in CPS

CPS evolves and it becomes more advanced over time as an industrial automation system [24]. To compensate for the limitations among networks, technologies, tools, and devices, and along the value chain, an ever-increasing demand for connectivity is highly suggested [25][26]. With the new problems provided by incorporating cyber-physical systems (CPSs) into commercial applications and the issue of integration is becoming even more

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important for the introduction of new technologies and their acceptability by professionals within the realm of Industry 4.0 [27].

Technologies in CPS

There are two popular technologies in CPS. They are stated below:

- Communication Technology in CPS: In the digital system, CPS is linked to electronic gadgets, portable devices, and industrial instruments [28]. Communication, networking, processing of data, storage systems, and transmission power are all vary among components [29]. For example, Smartphones have the ability for networking, processing, communicating and data storing. Each of this stuff can be linked using network, communication, and software technologies. A self-configuration technology of humanized CPS algorithm employing simple binary and mathematical operations can shorten convergence time and enhance scalability [30]. The use of state-space approaches in the development of a novel connected cyber-physical system (CPS) framework and the use of feedback control to dynamically change CPS resource utilization and efficiency is discussed [31]. The oriented cuckoo search algorithm (OCS) is a new evolutionary algorithm [32]. In OCS, a mixture of two separate random distributions dominates the global search capabilities. Petri net models have been generalized for creating dynamic manufacturing techniques in order to enable traceability analysis [33]. By using a three-phase design strategy that includes cross association, sensitivity analysis, and a systematic methodology, optimal IDS design for creating intrusion detection systems (IDS) is intended at lowering the number of monitored parameters [34]. A different task may have different CPS needs, such as productivity, power efficiency, and privacy and a real-time issue is also a crucial factor [35]. For example, the efficacy of CPS depends on the ability to select a suitable existing framework for choosing work periods in real-time using predetermined priority controller jobs planned using a rate monotonous algorithm [36]. Specialized real-time location sensing (RTLS) labels provide an effective methodology to enabling bidirectional coordination between physical construction materials and their virtual models, improving real-time construction continuity, and assisting proactive strategic decision-making [37].

- Networks Involved in CPS: Computational and physical resources are closely connected and mutually reliant in cyber-physical systems [38]. It is important to ensure and enhance performance in various technology-related domains, such as manufacturing, energy, transportation, and healthcare, in order to develop and implement resilient and reliable CPS networks. WSNs, wireless networks, WLANs, cloud-based networks, social networks, and other heterogeneous networks are all used in CPS [39][40]. CPS assesses the applications and technological criteria for effectively blending CPS with sensor network plane from a security perspective, as well as the techniques for transmitting information among remote monitoring locations and widely implemented sensor nodes [41]. Topology regulation by node selection could enhance data transmission performance while conserving energy and extending the network's lifetime [42]. Wireless sensor network topology optimization is a critical topic. A topology optimization approach for wireless sensor networks based on complex network theory and cyber-physical systems is developed using software-defined wireless sensor network architecture [43]. To promote the successful integration of CPS, an Intelligent Control Box transforms diverse wireless signals,

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including Bluetooth, ZigBee, and RF [44]. As shown in a literature review, discusses the benefits of Web of Things (WoT) and CPS integration. A CPS for structural event observation with WSNs is presented, as well as a novel approach based on network decision in the CPS entitled MODEM [45] proposes a method for coordinating a network of suppliers in a cyber-physical system [46]. The dynamics of the agent are nonlinear, arbitrary in size, and sometimes heterogeneous. In [47], the authors examine the state prediction problem in cyber-physical systems (CPS) where a wireless sensor measures a dynamical physical process and transmits the measurements to a remote state estimator. In addition, in [48], the authors describe a dependable Network-On-Chip (NoC) technique that may be applied to an FPGA-based system. They have looked at the stochastic stability of Kalman filter (KF) based state estimation in geographically distributed cyber-physical systems using a lossy network.