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Comprehensive Review of Medical Cyber-Physical Systems with Innovative Technologies, Difficulties, and Expectations

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Abstract:

As a result of technology's incorporation into healthcare systems, Medical Cyber-Physical Systems (MCPS) represent a paradigm that blends medical operations with cutting-edge computing, communication, and control technologies. This evaluation examines the current situation of MCPS, highlighting its development, key elements, challenges, and prospects. Real-time monitoring, analysis, and management of medical processes are made possible by the seamless integration of physical and cyber components that forms the basis of MCPS. This integration makes it possible to provide patients with better treatment, use resources more effectively, and make decisions quickly. The growing use of connected medical equipment in the industry has led to a widespread application of cyber-physical systems (CPS) to provide high-quality patient care in difficult clinical situations. In this work, we primarily focus on gaining a thorough understanding of the many studies conducted in the field of Medical Cyber-Physical Systems (MCPS). We lay forth an MCPS conceptual framework to give a concrete example of our research. In addition, we discuss the applicability and feasibility of different security measures in designing safe MCPS architectures. This initiative charts a path toward adopting state-of-the-art research endeavours to strengthen the security of MCPS and acts as a foundational step toward identifying the various security concerns that MCPS faces.

Keywords: *MCPS, HRS, IOT,* CYBER PHYSICAL SYSTEMS and HOMECARE ROBOTIC SYSTEMS (HRS)

Introduction: Recent years have seen the emergence of innovative paradigms that are revolutionizing the healthcare industry as a result of the convergence of medical sciences and cutting-edge technologies. The innovative approach known as Medical Cyber-Physical

Systems (MCPS) blends potent computer, communication, and control technologies with physical processes in a seamless manner. As the healthcare industry struggles to meet the demands of an ageing population MCPS emerges as a promising solution with the potential to transform patient outcomes, streamline healthcare delivery, and optimize resource utilization. As the name implies, cyber-physical systems (CPSs) combine the cyber and physical worlds to serve healthcare, automotive, cloud computing, IoT, and distributed networks. It is the unique amalgamation of physical systems, communication, and control [3]. Their operation must ensure the following metrics, known as S3: 1) Security, 2) Protection, and 3) Long-term viability. The embedded systems govern physical processes and deliver computational results via feedback loops. Recent advancements in wireless sensor networks (WSN), medical sensors, and cloud computing have made CPS a strong contender for healthcare applications such as in-hospital and at-home patient care. The need for in-home care services Homecare Robotic Systems (HRS) are replacing human-centric systems as the need for services rises as a result of the ageing population. Cyber-physical systems are now used in healthcare Systems (CPS) to smoothly integrate digital and analog communication with the actual environment; they were first utilized in manufacturing [5]. The capabilities to remotely check on patients and take action no matter where they are in the world are made possible by CPS developments. Considerable study is being done on medical sensors at the patient's site. Such vital patient data as health statistics can be gathered by these sensors. The collected data is transmitted to a gateway over the wireless communication means. Patient data is legally and ethically sensitive, thus security is a top priority. So, while designing CPS architecture for healthcare applications, special attentions need to be paid to ensure data security [9]. Network interfaces within these devices connect them in patient treatments and electronic health record systems. CPS, a major research topic since 2008, faces challenges in system dependability, assurance, autonomy, security, and privacy in healthcare [10]. On the other hand, it improves patient empowerment and professional coordination, both of which are essential for the provision of healthcare system services. The rapid development of digitization technology in the healthcare sectors has made medical CPS more inter- and intra-connected, but many of the employed resources are not [11]. Concepts and Facilitating Technology. One example of this revolution is the emergence of new generation homecare robotic systems (HRS) that are based on cyber-physical systems (CPS) and have superior speed and intelligent execution [12]. Modelled after Industry 4.0, Healthcare 4.0 refers to the incremental adoption of a growing number of manufacturing-industry-established technologies, including Cyber Physical Systems (CPS). Artificial intelligence (AI), intelligent sensing and fluctuation, automatic control, robotics, the

Internet of Things (IoT), big data analytics, fog and cloud computing, autonomous robotics, and robotics are just a few of the enabling technologies and methodologies that these CPS are accountable for. .As the computational foundation of CPS, the current research in this field aims to improve the system's scalability and facilitate real-time data processing by utilizing state-of-the-art Cloud Computing technology [13]. Cloud computing is another name for computing infrastructure that any consumer company or individual can access from anywhere in the world at any time. The following is a discussion of the survey's motivation for the above topic:

(1)It is imperative that distinct components of CPS for healthcare be used and demarcated clearly, as this is a viable and developing field [14].

(2) Before developing CPS for healthcare applications, a comprehensive analysis of related CPS in healthcare systems established to date is necessary because there is currently no CPS standard.

(3) To the best of our knowledge, no review article exists on cyber-physical systems in healthcare or in the Medical Cyber-Physical system, despite the availability of various review papers on cyber-physical systems [15].

(4)The provides a Comprehensive Outline on Home care Robotic System .

(5) It explores current developments in pertinent research fields.

(6) It makes an attempt to predict possible obstacles and future research directions. The essay discusses the efficient delivery of healthcare services, particularly for the elderly, with a focus on homecare applications, a developing field within health engineering

With a focus on the interconnected fields of AI, cloud computing, communication, and control systems, the paper adopts a multidisciplinary approach [16]. The foundation for cyber-physical interaction is examined, including data processing analysis, transmission modules, interfaces, and control modules [17]. The ultimate goal for the revolution's envisioned transformational loop is to use cyberinfrastructure to intelligently and autonomously regulate the dynamics of homecare robotic systems from cyber to physical and monitor their behaviour from physical to cyber [18].

The article offers a multidisciplinary perspective, focusing on the interconnected AI, Cloud Computing, Communication, and Control System arenas. The cyber-physical interaction framework includes data processing, transmission, interfacing, and control components. For the revolution's envisioned transformative circle. Our goal is to use cyberinfrastructure to monitor and manage homecare robotic devices from both a physical and cyber perspective.

Contributions:

Contributions in this work are discussed as follows:

(1)An exploration of existing Cyber-Physical Systems for healthcare applications using robotics

(2)A representation of the MCPS situation in terms of fundamental components such as application architecture, sensor, communication, security, control, actuation and embedded technologies;

(3)Research-related hindrance difficulties to CPS deployment in healthcare. This study surveys CPS for healthcare applications, identifying key components and problems. In Section 1, the research investigates the evolution and effect of Cyber-Physical Systems in the healthcare industry. Section 2 of the study depicts the evolution and ramifications of the Cyber-Physical system. In Section 3, architectural view of MCPS and new technologies. In Section 4, the paper looks into Empowering CPS in Embedded Computing Technologies. In Section 5, the paper depicts autonomous systems using CPS. In Section 6 investigates collaborative teleoperation, whereas In Section 7 investigates Revolutionizing Elderly Health Care. In Section 8, the report examines the application of advanced CPS and MCPS in the health arena.

Finally, the study discusses future research directions and challenges in Medical Cyber-Physical Systems.

Evolution and Ramification of CPS in Healthcare

Helen Gill, who works for the National Science Foundation in the United States, coined the term "cyber-physical system" in 2006. This concept combines sensors, which operate as data collectors for factors such as temperature, pressure, and activity time, with both physical and digital domains. "Cyber" refers to logical processing, networking, and control, whereas "physical systems" refer to natural and artificial systems that follow physics rules and function as intended. A cyber-physical system integrates computation with physical processes via a computer network. The CPS concept involves embedding intelligence in everyday objects and services to accomplish critical operations. It combines physical equipment such as sensors and cameras with cyber components to build an analytical system that responds intelligently to dynamic changes in real-world situations. CPS has various uses, including smart medical technologies, power systems, control systems, and traffic management. Wearable devices and smart meters are examples of intelligent gadgets that can sense and network. The Internet of Things (IoT) includes gadgets that continuously perceive, monitor and analyze their environment. The convergence of IoT and social networks has huge implications for future computing and communication infrastructure. IoT is typically used to monitor and control small devices that are not connected to a shared network.

CPSs focus on monitoring and managing physical systems through internet. Platforms for sensing, processing, and communication can be integrated into physical processes to offer real-time monitoring and feedback control. MCPS, a type of healthcare system with both computational and physical components, aim to improve healthcare by integrating with pervasive health monitoring systems. It allows for distributed computing with wireless devices.

Wireless body area networks (WBANs) have re-emerged as the dominant technology for smart healthcare, offering ubiquitous healthcare services and real-time health monitoring. MCPS stands out for its high integrity, physical resource limits, cross-domain transmission, multi-domain networking, complex space domains, dynamic reorganization, high automation, reliability, and CPS security.

The medical domain includes information about national health, electronic medical records (EMR), patient care, and operating room procedures. Further research and development are needed in areas such as security, reliability, stability, embedded systems, abstract computing, model building, security authentication, and data traceability.

A strong healthcare system is essential for smart cities, especially during pandemics. Research employing MCPs in the health sector has led to improved proficiency and additional research directions, with positive consequences. The table illustrates research contributions.

Reference	**Title of the paper**	**Methodology used**	**Accuracy/Achievement**
1	A Survey on Recent Advanced Research of Security	This paper investigates CCF (Common Control Framework) for CPS security concerns.	Here Global CPS security trends are recognized and classed based on dimensions to improve understanding of global CPS.

2	Medical Cyber-Physical Systems: A Solution to Smart Health and the State of the Art	Methodologies for safeguarding Medical Cyber-Physical Systems (MCPS) include a four-layer architecture for data control, encryption schemes for privacy threat modelling, and blockchain integration for safety and security	Achievements include blockchain-based EMR architecture, secure eHealth systems, and smart contract-based X.509 certificate standards. Enhanced authentication technologies such as biometric analysis, lightweight authentication for Wireless Body Area Networks, and blockchain-based authentication help to ensure secure transmission. Image forgery detection, cooperative learning for intrusion detection, and specification-based bad behaviour detection enhance MCPS security
3	PHAROS-Physical Assistant Robot System	PHAROS, an elderly assistance robot, has a two-module structure: Recommender and Human Exercise Recognizer. It uses Pepperrobot for real-time exercise monitoring and recommendations using a dynamic Glicko2 algorithm.	PHAROS actively monitors and proposes tailored exercises based on individuals' changing health statuses. Its Glicko2-based evaluation system increases interest while reducing repetition and enables caretakers to track users' abilities with time. PHAROS is designed to be welcoming and intuitive in order to increase acceptance
4	Smart City Healthcare Cyber Physical System: Characteristics, Technologies and Challenges	CPS and the integration of various devices and services in the smart city healthcare ecosystem	Achievements include effective energy management using smart sensors and a successful CPS installation aided by the Smart Grid. Integration requires handling device heterogeneity and varied data formats, as well as utilizing third party service .

5	Health Care in the Cyberspace: Medical Cyber-Physical System and Digital Twin Challenges	Medical cyber-physical systems (MCPS) use networking protocols and embedded software to connect medical devices. They use sensors in medical equipment and wearables to communicate real-time data for monitoring purposes. Wireless sensor networks (WSN) and other wireless technologies are used for communication. Electronic Health Records (EHR) are stored and accessed efficiently via cloud computing. MCPS decision-support devices send alarms for aberrant health behavior.	MCPS supports remote health monitoring, preventive treatment programs, and real-time decision support for caregivers. Wireless Body Area Networks (WBANs) use wearable or implanted biomedical sensors for continuous monitoring. Cardiovascular monitoring, body temperature measurement, blood glucose monitoring, stress monitoring, and rehabilitation are some examples of applications. Challenges include ensuring regulatory compliance, software certification, and addressing potential threats to patient health and data privacy.
6	Simulation Integration Platforms for Cyber-Physical Systems	The paper describes the creation of a conceptual integration architecture across three platforms over several years. It covers difficulties related to time management, distributed object management, and more.	The framework for Cyber-Physical Systems emphasizes interoperability and usability while integrating heterogeneous simulations and automating experimentation.

Table 1: Methodology used /Accuracy/Achievement

A thorough analysis of the MCPS architecture and new technologies.

This section provides an overview of the Medical Cyber-Physical System's architecture. Over the past few decades, there has been significant advancement in the ability to adopt new equipment for health monitoring. Medical cyberphysical systems are embedded network systems that include medical equipment for drug delivery and sensors for monitoring patients [10]. An Electronic Health Record (EHR) is a report that tracks patient treatment over time. They can forecast patient health and warn custodians accordingly. The MCPS design includes three layers: Data Collection, Data Management, and Application Service (Fig 1).

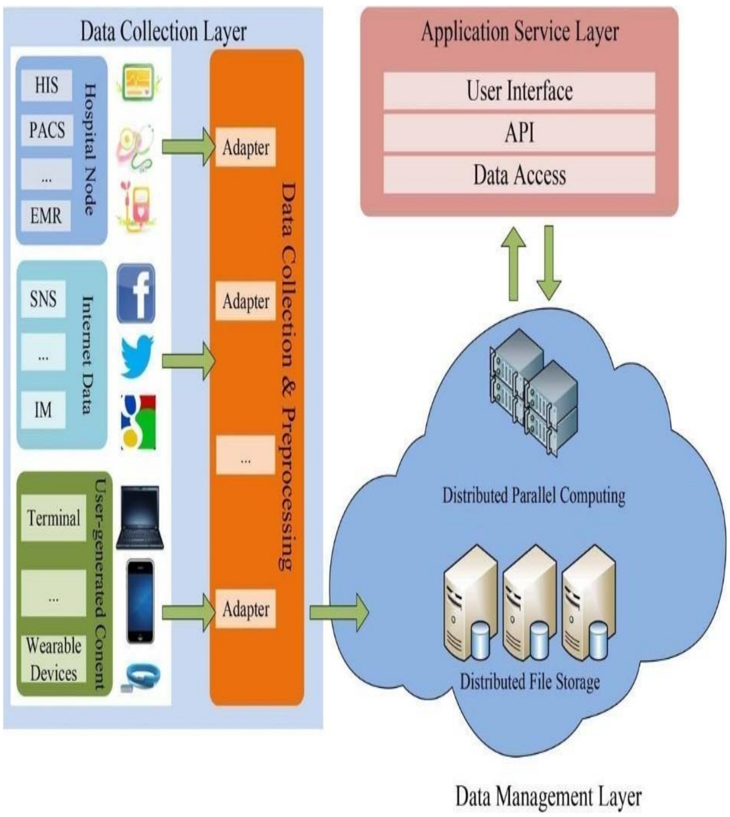

Fig 1: Architecture Of Medical Cyber-Physical System

Data Collection Layer: It is made up of data nodes and adapters, and provides a consistent system access interface for diverse data sources such as hospitals, the internet, and user-generated information. An adapter can pre-process various types and formats of raw data, ensuring its availability and security during transmission to the data management layer.

Data Management Layer: This layer consists of two modules: Distributed File Storage and Distributed Parallel Computing (DPC). DFS improves healthcare system performance by providing efficient storage and I/O for diverse healthcare data, utilizing big-data technology. DPC processes and analyzes data based on its timeliness and significance.

Application Layer: Consumers can view the basic visual data analysis results on this tier. The platform provides an open API for developers to design user-centric applications that provide individualized healthcare services.

Architecture	Description
Four Layer MCPS Architecture	-Data Acquisition Layer: Gathers health information from diverse sensor devices. -Preprocessing Layer: Temporarily holds and processes information obtained from the acquisition layer. -Cloud Layer: Delivers extensive-scale data processing and computing services. -Behavior Layer: Furnishes extensive-scale data processing and computing services.
MCPS Architecture based on AI	-Similar to the four-layer architecture but with improved preprocessing capabilities for cognitive decision-making.
OmniPHI Blockchain Architecture	-Client Layer: Deployed on patients' medical and wearable devices. -Server Layer: Distributed across super peers within the blockchain platform. -Utilizes peer-to-peer (P2P) network and structures health records into data blocks. -Creates linked lists and distributes categorized health data.
Blockchain-Based MCPS e-Health	-WSN Layer: Gathers information from WSN nodes and transmits it to the blockchain. -Side Chain Layer: Validates smart contracts and appends a side chain to the primary blockchain. -Smart Contract Layer: Implements smart contracts to create and verify side chains. -Blockchain Layer: The publicly accessible blockchain with restricted entry.
Abdellatif's smart Medical System	- -Patient Data Aggregator (PDA): Sends compiled medical data to the infrastructure. -Mobile/Infrastructure Edge Node (MEN): Conducts interim processing and storage of data. -Edge Cloud: Employed for storing data, monitoring patterns, and analyzing human health data. -Monitoring and Service Providers: Provide healthcare services to patients.

Table 2: Architecture used in MCPS.

Furthermore, Kocabas et al.'s research provides a universal MCPS design divided into four levels, as shown in Fig. 2.

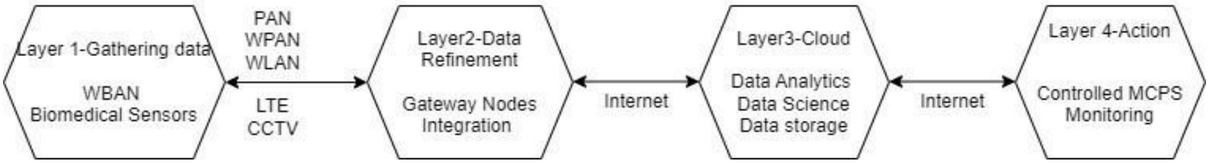

Fig 2: MCPS Architecture with four layers

Data gathering: A Wireless Body Area Network (WBAN) using wireless protocols is commonly used to connect to the Internet via technologies such as ZigBee, WSNs, Bluetooth, Wireless Local Area Networks (WLAN), Wireless Personal Area Networks (WPAN), video surveillance systems, and mobile networks. In healthcare, a wearable body area network (WBAN) involves implanting biomedical sensors under the skin or in specific body locations. This enables real-time monitoring of a patient's health, including blood pressure and temperature.

Data Refinement: Sensors are hardware restricted and have little computational power. To accommodate enormous amounts of data, packets must be transferred to a more modern device before being sent over TCP/IP networks to the Internet. Cloudlets are often configured on a dedicated computer with its own Internet connection.

Cloud System: Patients, physicians, and nurses can all access Personal Health Information (PHI) through the cloud. Data analytics can help prevent catastrophic health conditions by predicting changes based on a patient's status, allowing caregivers to make informed decisions. Cloud computing provides significant advantages for data storage, but accurate diagnosis requires long-term monitoring. Improved cloud storage security mechanisms are needed to safeguard data for extended periods.

Layer of Action: This layer's two basic purposes are to provide "active" and "passive" actions. An actuator is used in the active action to elaborate on MCPS alterations. A physician may approve increasing serum medicine dosage or using robotic arms to assist with procedures.

Developing CPS in Embedded Computing Technology

Modern applications require integrating diverse compute platforms with parallel multi-processor macro-architectures to achieve high throughput while minimizing energy usage. CPS has been successfully integrated into numerous systems for high-performance delivery, timely service augmentation, and increased system security. The integration of the cyber physical environment can result in a smart and cost-effective solution. The physical part of the CPS transfers energy to other parts of the gadget. On the other side, the Cyber system is responsible for gathering, processing, and communicating the information. The embedded system is made up of multiple connected subsystems [13]. It also includes various digital and analog hardware components. The sun's components are tightly connected, allowing for overall control, monitoring, supervision, and troubleshooting of the system. The widespread computing system, also known as the Ubiquitous computing system, excels in integrating information processing and communication. Exploring effective collaboration among subsystems is crucial, with a focus on hardware and software interactions. The CPS can address safety problems in embedded systems by providing security and dependability for overall system operation.

CPS-enabled Mobile Autonomous Systems

The mobile autonomous system can be integrated with the CPS and has the potential to significantly impact industries such as health, agriculture, manufacturing, and transportation. The system can now control itself without human intervention. Some examples of such systems are drones, autonomous vehicles, and robot-controlled platforms. Computational algorithms enable the merging of the cyber and physical worlds, leading to autonomous effects. The MAS consists of actuators, sensors, and communication devices. CPS serves as a platform for the merging of these components. Integrated systems have important uses in precision agriculture, including autonomous crop harvesting and fertilization. Healthcare robots demonstrates certain efficiency in various surgeries, patient care, and other health-related logistics. Robots can also be employed in manufacturing businesses for monitoring, quality control, and adaptive tasks. CPS integration enhances the safety, dependability, and interoperability of mobile autonomous systems.

Collaborative Robotic teleoperation:

As the population ages, a big challenge will be a lack of in-home caretakers. Teleoperation, which utilizes remote robotic equipment based on the operator's needs, has the ability to address this issue. Robots can complete basic assistance procedures independently. Elders with partial disabilities, who are only partially able to function, can use their remaining powers to teleoperate the robot and encourage self-sufficient life. Teleoperation enables professionals with on-site skills, such as caregivers in healthcare institutions, to deliver in-house senior care. Cobots, also known as collaborative robots, represent the current level of human-robot symbiosis development. It provides secure communication between workers and robots during similar or identical procedures. HRS-CPS will see a growing trend of combining homecare teleoperation with cobots. New applications will emerge to address caretaker shortages and reduce the cost of at-home therapy.

The PHAROS Architectural Innovation is revolutionizing Eldercare.

PHAROS architecture introduces an interactive robot platform to help seniors with daily physical duties at home. It has two major modules: "Recommender" and "Human Exercise Recognizer." [18]. The Human Exercise Recognizer uses cutting-edge AI to rapidly recognize and certify human poses, while the Recommender suggests enjoyable activities. This architectural construct utilizes cutting-edge technology, including sensory settings with embedded smart sensors to monitor senior persons' health. This component uses adaptive illumination to regulate circadian rhythms for better sleep-wake cycles. Small AI-powered assistive robots can be used for telehealth and medication management. The design of telemedicine systems with Regular check-ups and other diagnostics have become an essential feature of the system. The implementation of smart living spaces with IoT devices and voice-activated interfaces has transformed architectural ideas for future benefits. Integrating virtual reality, IoT, and blockchain technology can enhance patient comfort and security when transmitting sensitive information. User-friendly interfaces and tailored treatment plans are significant factors driving the growth of this architecture. The infrastructure has benefited significantly from regulatory compliance, cost savings, training, and support.

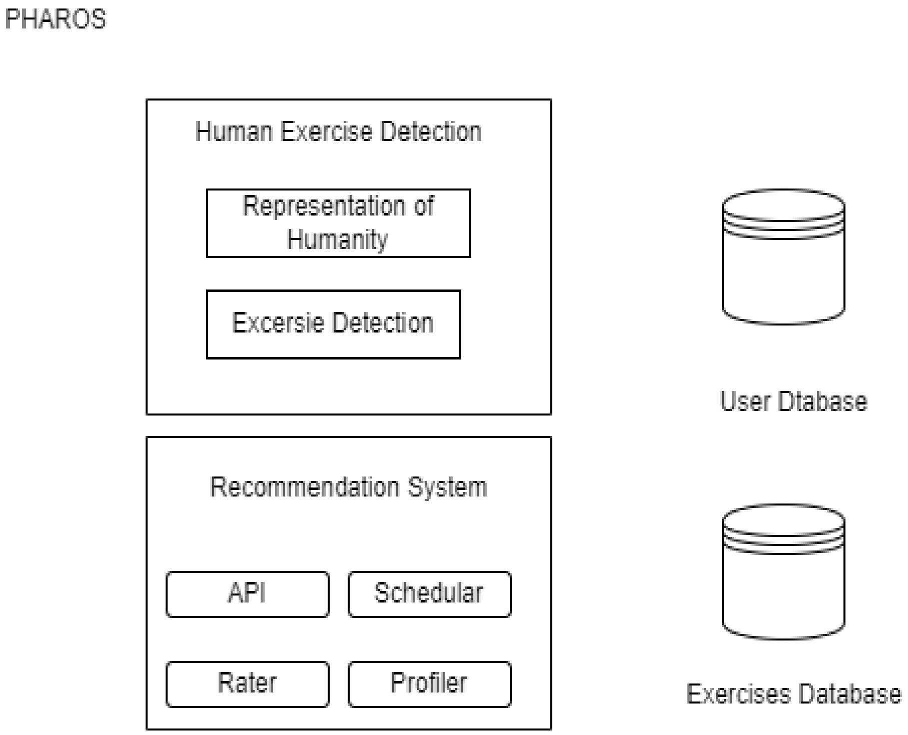

Fig 3: Physical Assistant Robot system

A Comparative Analysis Of Emerging Applications Of Advanced CPS and MCPS in the Healthcare Arena.

Cyber Physical Systems (CPS) and Medical Cyber-Physical Systems (MCPS) play an important role in revolutionizing the healthcare industry by incorporating sophisticated technologies into medical operations. This comparative study examines developing applications of these technologies in healthcare. The CPS system monitors environmental elements, infrastructure, and operations. It also applies to industrial applications such as manufacturing and transportation. The MCPS focuses on real-time monitoring of patients' vital signs, medication adherence, and illness progression. Healthcare systems prioritize timely interventions. Data integration requires consideration of multiple data sources during the optimization process. The system can also provide a full perspective of the patient's health systems. Decision-making systems can ensure efficient resource usage. Personalized treatment and clinical support are significant drivers of technological advancements. This also includes patient safety and other medical rules. Automation and human-machine interaction have facilitated advancements in telemedicine, remote monitoring, and wearable technologies. Improving chronic disease management through efficient medical device and pharmaceutical production is a key focus for technological advancement. Scalability and interoperability are key concerns for MCPs when dealing with large amounts of data. The MCPS has successfully handled sensitive data in the patient care system, yielding positive results. The industry automation revolution will accelerate MCPS advancements.

Future problems and research directions for MCPS in medical devices.

Medical device systems are prime instances of cyber physical systems, with complex treatment algorithms interacting with physical components and patients. Maintaining and improving the security, safety, and dependability of CPS medical devices becomes increasingly challenging as they become more complex and interconnected. Researchers are increasingly interested in social networks, services, and big data analysis and applications .This intriguing technology has recently been used in cyber-physical systems for healthcare purposes. This section discusses how the CPS and MCPS systems have significantly impacted several sections of the health sector. Personalized medicine uses patient-specific data to create tailored treatment regimens. Challenges in securing and protecting sensitive information. The reduction of latency achieved by edge and fog computing has played a significant role in decision making with absolute reliability. The seamless integration of /AI and ML principles into the MCPS has opened up new opportunities. The construction of interoperability in the situation of managing diverse data has become a difficulty for the MCPS. Modern research has addressed the difficulty of relating algorithmic decision-making to system potential. MCPS research focuses on understanding and updating the regulatory landscape. Two key areas to investigate include power management in implantable and wearable devices, as well as biocompatibility difficulties. One challenging research area is merging remote device management with remote patient monitoring systems to improve the efficiency of existing healthcare systems.

Conclusions:

This chapter's detailed examination provides valuable insights into the subject matter and its numerous application fields. The CPS and MCPS have created new prospects in the health industry for future study. This technology's integration with embedded, mobile, and distributed systems has improved security and interoperability, paving the way for significant technological advancements in human society and the healthcare sector. The recent shift in research has created new opportunities to collaborate with other domains. The CPS and MCPS systems facilitate economic development and its impact on related industries. New research methodologies, such as fog and edge computing, have opened up a current research domain, supported by the CPS.

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