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SURVEY

Patient Monitoring System Based on Internet of Things: A Review and Related Challenges With Open Research Issues

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ABSTRACT The unexpectedly high number of deaths caused by inadequate medical care is, to date, considered as a serious problem. Moreover, the ratio of elderly people who require continuous care is rising. Therefore, a patient monitoring system (PMS) also known as remote patient monitoring (RPM) using the latest Internet of Things (IoT) technology becomes a viable solution that can provide efficient healthcare from a remote distance. PMS monitors timely physiological signals of a patient's health and can reduce the healthcare costs of treatment significantly. In PMS, different health and vital signs issues such as body temperature, heart rate, sleep monitoring, fall detection, and blood pressure can be checked effectively in real-time. To this end, this paper provides a clear vision of electronic healthcare assistance based on PMS and explores the applications of IoT that allow efficient medical services in healthcare systems. In particular, the objective of this paper is to provide a review of PMS, current research, and the challenges associated with this area. Besides, the essential services that can be offered by PMS for monitoring human activities are also discussed. Furthermore, the communication networks and protocols that are required to endure efficient healthcare systems are explained. Finally, this paper discusses several research challenges and open issues that can be investigated for further work. Overall, this paper offers valuable insights for both industry professionals and academic researchers, exploring potential avenues for new research directions.

INDEX TERMS Edge computing, healthcare, IoT, microcontrollers, patient monitoring system (PMS), remote diagnosis, remote monitoring, sensors, wearable devices.

I. INTRODUCTION

The Internet of Things (IoT) is utilized in many essential fields and has become one of the most important technologies worldwide. IoT is a revolutionary technology, which is able to connect multiple devices, collect heterogeneous information/data from multiple sources and devices, and transmit and process this information and data in real-time. IoT is defined as a network of things, comprising different physical things, encompassing embedded devices integrated with various software and technologies [1], [2]. IoT allows different types and sizes of things such as cameras, vehicles, phones, home appliances, buildings, industrial systems, and people to communicate with each other and share information in real-time, hence, achieving intelligent systems [3]. The primary function of IoT revolves

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around facilitating communication and data transmission via the Internet, thereby enabling seamless connectivity and interaction between these interconnected physical things. In IoT, the term ''Internet'' denotes a worldwide network comprising billions of computers and diverse electronic devices. Through the Internet, users can access the desired information and connect with other people from anywhere and at any time through standard protocols. On the other hand, the term ''things'' refers to any object that can be associated with a particular connectivity. IoT is used to connect anything and get the desired service [4]. Besides, the escalation in data transmission and repository size has increased the demand for big data transfer, so the IoT has become very essential in data exchange. IoT represents a groundbreaking paradigm in which objects possessing distinct identities can seamlessly integrate into an interconnected information network to provide intelligent services [5].

In recent years, there have been considerable advancements in sensing technologies, wearable/implantable devices, and wireless communication technologies. The development of network technology and sensors such as laser sensors, radar sensors, and camera devices, has allowed a smart environment to be achieved with homogeneous and heterogeneous devices. IoT networks leverage a range of monitoring systems that harness the benefits of data processing and analytics, utilizing the power of the Internet to enable informed decision-making in real-time [6]. IoT networks have evolved in many applications such as patient monitoring system (PMS) [7], [8], [9], intelligent energy management [10], smart city [11], smart home monitoring [12], [13], industrial application [14], vehicle monitoring system [15]. The integration of IoT applications and engineering technologies has demonstrated significant value in the biomedical domain, enhancing the efficiency of medical practitioners and optimizing treatment processes. The convergence of IoT with medical devices has expedited medical interventions, streamlined diagnostic procedures, and improved the management of chronic illnesses. From the technological perspective, IoT involves some popular technologies such as wireless-body-area-networks (WBANs) to transfer the collected information from the devices to the centralized cloud for analyzing and extracting meaningful information for efficient decision-making.

The rapid growth of IoT devices brings innumerable advantages. According to Statista, there will be more than 75 billion IoT-devices connected to the Internet by 2025, resulting in an enormous data output [16]. Moreover, IoT is growing on an everyday basis with many potential innovative technologies [17]. To this end, IoT is expected to have a potential economic impact of $3-6 trillion, and the largest fraction, $1-2.5 trillion, of this economic impact comes from smart healthcare applications [18].

The projected global market size for IoT in healthcare was valued at USD 180 billion in 2022 and is anticipated to grow to approximately USD 962.21 billion by 2032, reflecting a compound annual growth rate (CAGR) of 18.3%

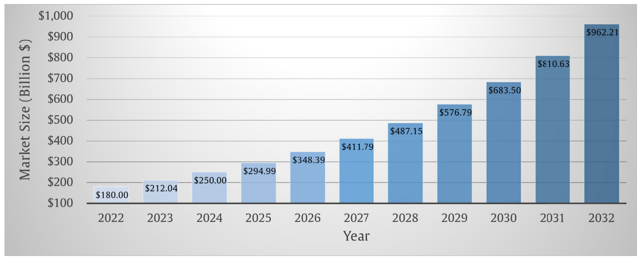

FIGURE 1. The estimated IoT in healthcare market sizes, 2022 to 2032 (USD Billion) [19].

from 2023 to 2032, as shown in FIGURE 1 [19]. The predicted market share of VR/AR by 2021 is 54.6 billion USD, up from 2.5 billion USD in 2016 [17]. Consequently, the bandwidth consumption by this industry is also increased. The connected devices in different healthcare institutes and the utilization of IoT systems are considered the most important parameters related to market growth.

Therefore, leveraging IoT within healthcare is highly advantageous. IoT-driven healthcare minimizes human error by networking all vital sign monitoring devices to a decision support system, empowering physicians to deliver more precise and timely diagnoses [20]. One of the most important applications of IoT in the healthcare field is PMS [21], [22]. The Internet of Medical Things (IoMT) represents the convergence of medical devices with the Internet of Things (IoT) [23]. IoMT leads the future of healthcare systems, envisaging a scenario where every medical device is interconnected and remotely monitored by healthcare professionals via the Internet [24]. In the medical sector, the importance of IoT technologies is highlighted by IoMT, which is a collection of medical and fitness devices with various applications that are connected to the systems of healthcare through online computer networks. IoMT has several advantages such as improving drug management, decreasing healthcare costs, enhancing patient experience, improving diagnosis and treatment, improving disease management and most effectively achieving efficient PMS for chronic diseases [25]. This paradigm shift promises faster and more cost-effective healthcare delivery as it continues to evolve. Hence, PMS is considered a major part of IoT, which is related specifically to the concept of the IoMT [21]. In general, the network of IoMT is dedicated to various medical systems such as PMS, disease treatment, anomaly detection, medical nursing and rehabilitation, remote and telemedicine care, conditioning, and screening systems. PMS combines different equipment that constantly monitors patients' health through warning systems of patient vital signs based on the detecting and tracking of the changes in their health condition [26]. The importance of PMS has rapidly increased due to the highly contagious diseases (such as COVID-19) and the increasing number of elderly people who require constant care where the demographic shift toward the aging population [27]. A PMS is useful for all patients suffering from serious illnesses such as diabetes, cardiovascular disease, mental illness, cancer, hypertension, and COVID-19 [28], [29]. In addition, there is a growing incidence of factors that negatively impact the quality of life, such as busy schedules, outbreaks of epidemic diseases, and increasing pollution levels. Recent statistics indicate that over 90% of the population is exposed to polluted environments, exacerbating these challenges [30]. Therefore, PMS appears as an important technology, which enables the medical professionals to monitor the patient's health remotely and quickly in addition to revolving the healthcare systems with lower costs and better patient outcomes. The basic functionalities of PMS are signs detection, monitoring, and tracking. The application of PMS allows specialists to monitor and track patients remotely in a real-time manner based on their convenience at home or office. Besides, PMS allows to warn the caregivers of potential threats to patient health, and hence to take quick action automatically. There are various detection, monitoring, and tracking methods that have been developed for PMS [31].

Generally, the applications of PMS have analogous architecture, which consists of wearable sensors and micro-controllers, wireless communication networks, and cloud computing platforms. The work in [32] and [33] demonstrated that PMS can be implanted in real-time with multi-tier pervasive WBAN. There are many types of sensors that are used to detect vital signs and physiological conditions of the patient. Examples of these physiological parameters are heart rate, body temperature, electrocardiogram (ECG), electroglottography (EGG), electroencephalogram (EEG), blood oxygen saturation level (SpO2), blood pressure, electromyogram (EMG), electrooculogram (EOG), magnetoencephalogram (MEG), breathing rate, mechanomyogram (MMG), photoplethysmogram (PPG), respiration (RESP), and electrodermal activity (EDA) [23], [34]. Sensors send data to the microcontrollers, which then analyze the data and determine the process based on the algorithmic design implemented. For instance, if a temperature body sensor detects a change in the body temperature, the sign will be sent remotely to the specialist to sound an alarm and apply a quick treatment to the patient by the specialist. Hence, efficient communication systems that are able to carry out fast detection to send this essential information in a reliable and secure way are required.

To this end, wireless communication technology has advanced significantly in recent years, which is considered a crucial part of the development of automated and smart healthcare tasks [35], [36], [37]. This advanced development in such technologies allows PMS to provide fast detection of patient conditions in real-time scenarios. Therefore, PMS continues to serve as a cornerstone in driving the evolution of autonomous healthcare services, particularly as wireless communication technology advances. Its ubiquity ensures widespread accessibility to healthcare while minimizing costs and errors, thereby contributing significantly to the advancement of medical care delivery. Moreover, through the employing of efficient cloud computing for PMS, we can get coherent-optimized healthcare systems. Utilizing cloud computing offers several advantages for healthcare systems. These advantages include streamlined processing of health-related issues, simplified management of various diseases, and the capability to access real-time patient information seamlessly and securely. Furthermore, cloud-based systems enable synchronized data sharing across multiple platforms, ensuring scalability to accommodate varying workloads while addressing concerns regarding scalability and security. Besides, employing cloud computing with robust algorithms could ensure that critical information remains readily accessible whenever needed, thereby enhancing the efficiency and effectiveness of healthcare delivery. A medical server refers to a remote computer situated within a healthcare institution, tasked with real-time data monitoring and offering health recommendations to patients. Physicians or a database handle monitoring and post-processing. The medical server plays a crucial role in remotely monitoring patients in telemedicine settings, using a remote computer to collect and transmit vital signs to a telemedicine server for analysis. Subsequently, the medical server assists healthcare professionals by recommending suitable healthcare services for patients remotely based on the analyzed vital signs

A. MOTIVATION AND PAPER CONTRIBUTIONS

During epidemics and disease crises, such as the COVID-19 pandemic, and for individuals managing chronic health conditions like diabetes, as well as for the elderly population, PMS can play a crucial role in addressing the shortcomings of traditional healthcare models. PMS becomes crucial, especially in regions with limited access to healthcare facilities and medical professionals. PMS can facilitate the efficient transmission of patient data to healthcare providers, enabling timely interventions and necessary actions based on real-time information. Given these critical needs and the challenges faced by conventional healthcare systems, there is a compelling necessity to comprehensively study and understand PMS. Noting that, the appropriate PMS architecture and necessary communication technologies were not identified in the earlier review studies. This paper aims to provide a literature review and an in-depth study of recent trends in PMS based on IoT technologies, which are required to achieve efficient healthcare services.

The contribution of this manuscript can be summarized as follows:

- We provide a comprehensive review of the architecture of PMS, discussing its essential technologies and components. This review serves as a foundation for understanding the complexities of PMS and its potential applications in healthcare systems.
- We highlight the importance and urgency of adopting PMS-based IoT in healthcare systems, emphasizing its potential to revolutionize healthcare delivery and improve patient outcomes. By adopting PMS-based IoT, healthcare systems can become more efficient, effective, and patient-centered.

- We analyze various types of existing monitoring and tracking methods in healthcare systems, providing a thorough understanding of the current state-of-the-art approaches. This analysis serves as a basis for identifying areas of improvement and opportunities for innovation.
- We present the relationship between different layers in the architecture of PMS, providing a detailed understanding of how these layers interact and interoperate. This understanding is essential for designing and implementing effective PMS-based systems.
- We identify challenges and provide recommendations for future work, benefiting both academic and industrial sectors in remote healthcare applications. These challenges and recommendations serve as a roadmap for future research and development in the field.
- Finally, this survey paper contributes to improving healthcare delivery, disease surveillance, management, and response strategies during public health emergencies and routine care scenarios. By leveraging the potential of PMS-based IoT, healthcare systems can become more resilient, responsive, and effective in addressing the needs of patients and communities.

B. PAPER ORGANIZATION

The structure of this manuscript is outlined as follows. Section II presents the basic terminologies related to PMS and provides introductory concepts of PMS in healthcare systems. Section III provides a review of remote patient monitoring systems and discusses the architecture used for PMS based on IoT, which is essentially required to achieve effective healthcare systems. Section IV provides a thorough explanation of the sensors' application in PMS. Section V gives a detailed description of the communication technologies required for PMS. Section VI highlights the cloud computing and distribution technologies and their applications in the PMS. Section VIII provides research challenges and discusses the future research direction in PMS based on IoT in healthcare systems. Finally, this paper is concluded in Section IX. FIGURE 2 shows each section and subsection in the paper.

II. BASIC TERMINOLOGIES AND INTRODUCTORY CONCEPTS OF PMS IN HEALTHCARE SYSTEMS

This section discusses the essential terminologies that are commonly used in healthcare monitoring. In addition, the basic concept of PMS systems is introduced.

A. SOME BASIC TERMINOLOGIES IN HEALTH CARING DOMAIN

Over the last few years, the advancement in health technologies has demonstrated a considerable consequence on our quality of life. In particular, the development of these advanced technologies has a considerable impact on enhancing patient care and diagnostics, which helps in providing better and quicker treatment. In conventional healthcare systems, doctors need to visit patients physically and required the use of traditional tools for diagnosing their cases [38]. The traditional methods are considered to be cost-effective, leading to delayed diagnosis, especially for remote distances, which leads to serious consequences. Therefore, one of the most important goals of advanced technologies is to build smart and efficient healthcare models that are able to close the gap between caregivers and patients to improve patients' well being [39]. Specifically, with the advancements of mobile technologies and smart medical devices and sensors, health experts become able to make a great improvement on healthcare systems. Furthermore, m-health and e-health, supported by Information and Communication Technology (ICT), enable the efficient delivery of healthcare services to multiple patients, aiding in their health improvement. Besides, the emergence of IoT presents even more advantages by connecting diverse devices to the Internet, thereby providing caregivers with real-time updates on patients' conditions [7]. In the epicenter of advanced healthcare technologies, PMS is considered in the advancement of a medical stream. PMS has different types of equipment such as microcontrollers and sensors, which are used to collect the information of the patients and give the required process using IoT. PMS is very helpful in remote monitoring patients, especially in the conditions of elderly and chronically ill patients and those who have chronic diseases such as heart disease, diabetes, hypertension, and pressure. This remote monitoring capability offered by PMS proves particularly beneficial for ensuring timely intervention and personalized care for elderly individuals and those managing chronic conditions. By enabling continuous monitoring and early detection of health issues, PMS plays a pivotal role in improving the quality of life for patients, allowing healthcare providers to intervene proactively and mitigate potential complications. The following are some basic terminologies that are used for PMS.

- Conventional healthcare system: This refers to a traditional healthcare practices, where a doctor visits patients with the required traditional tools, that are not essentially related to information and communication technology (ICT) [38].
- Medical emergency: This refers to the manual call to the hospital in emergency situations. This call should constitute some critical information such as the location, the medical problem nature, and a valid available contact until the ambulance arrives. Once the patient reaches the hospital, the caregiver records the vital parameters such as blood pressure, breath rate, heartbeat, etc., to proceed with the required treatment.
- The Internet of Medical Things (IoMT), also known as the Internet of Health Things (IoHT), represents a significant advancement in healthcare, leveraging IoT technologies to enhance patient care and healthcare services [8]. IoMT encompasses various medical devices connected to the Internet, including wearable sensors and implantable devices like smartwatches

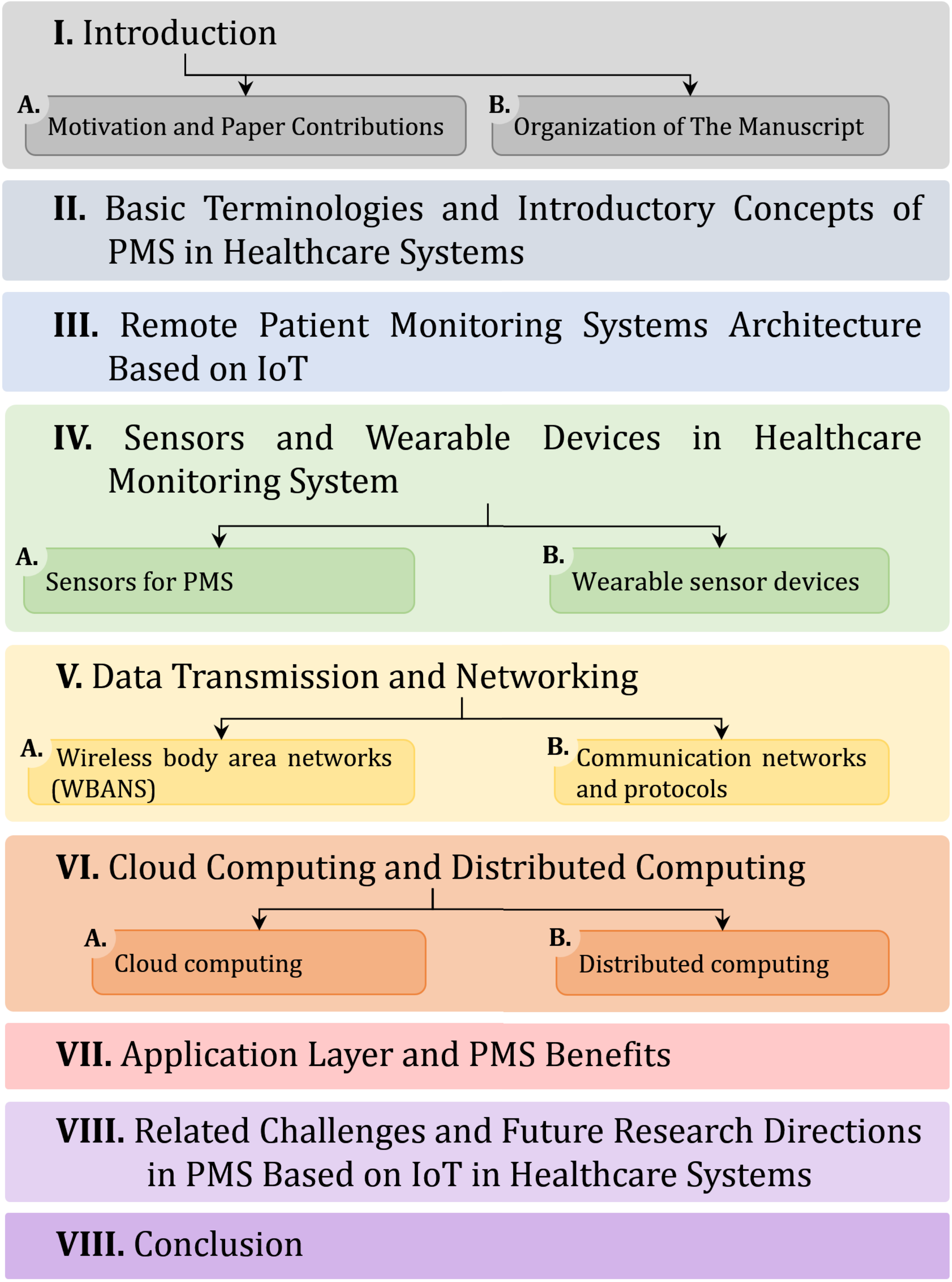

FIGURE 2. Structure of the PMS review paper.

and smartphones, facilitating the analysis of patient data [39], [40].

- Telemedicine: This term is defined as an integrated system that has bidirectional remote contact among patients and medical professionals. Telemedicine utilizes the emergence of ICT to provide clinical healthcare and to exchange health information in remote locations. This strategy is especially beneficial for remote areas with limited access to healthcare services, as it overcomes geographical barriers and enhances medical care accessibility. Telemedicine is crucial for delivering urgent care during emergencies, potentially saving lives in critical scenarios. Additionally, telemedicine plays a role in monitoring patients at home, facilitating quicker, more efficient, and cost-effective patient mobilization and rehabilitation [41].

- Remote Patient Monitoring system (RPM): This term is a standard for healthcare delivery that enables caregivers to monitor patients remotely using smart body sensors and build upon modern connectivity standards [8]. RPM performs certain specific tests on the patient's body, which is essential in healthcare, especially for the elderly and chronically ill. PMS term is similar to Remote Health Monitoring System (RHMS), Mobile Health Monitoring System (MHMS), and Wearable Health Monitoring System (WHMS), each denoting similar systems that serve similar purposes just with different names across literature [22].
- Sensors and wearable devices: This refers to technology-enabled tools that are able to monitor physiological parameters and activity levels for many patients, facilitating continuous health monitoring and tracking and personalized care interventions. Typically, sensors receive their input signals from the physical surroundings and produce a response action based on the received signals. After the vital signs or signals are received by sensors, they transmit them wirelessly to the Body Area Networks (BAN) control unit. By monitoring vital signs like body temperature, blood pressure, body temperature, serum cholesterol, glucose level, arterial oxygen saturation, and breath rate, wearable sensors provide enormous potential for the early detection of diseases. Noting that wearable devices are typically attached to the human body, or they are integrated into elastic bands, textile fiber, or patient clothes. Wearable devices are used to measure the physiological signals of the patients and their activity. Moreover, wireless medical sensors are used to transmit vital signs to a remote server for diagnostic purposes.
- Smart health system: This concept has been given multiple definitions with different interpretations [39]. Smart health can be defined as an integration of advanced technologies, data analytics, and digital communication tools to optimize health management, improve medical service, enhance patient outcomes, and improve healthcare delivery.
- Pervasive health: This concept aims to deliver healthcare services to patients anytime and anywhere, as reducing institutionalization being a tool to face healthcare costs while increasing both the coverage and the quality of healthcare [39]. Based on the given definition, the concept of pervasiveness emphasizes the broader societal impact of healthcare accessibility to all, rather than solely focusing on technological elements. Pervasive healthcare also encompasses the usage of pervasive computing principles, such as IoT, to deliver medical services directly to homes or anywhere. Additionally, it involves remote data collection through mobile devices and sensor networks, often resulting in large volumes of data in diverse formats and with high frequency.
- Vital patients' signs: The human body contains different health signs that reflect the critical health status and can be effectively used to help in disease detection. These signs are defined as the important indicators that are used to monitor the condition of a patient by allowing the specialized to know the body functions and find if there is any delay in the patient's recovery. Checking these patient signs is one of the most common interventions being practiced in healthcare settings. The most common types of these signs are heart rate, body temperature, ECG, EGG, EEG, SpO2, blood pressure, EMG, EOG, MEG, breathing rate, MMG, PPG, RESP, and EDA [23], [34].

FIGURE 3. A generic PMS system with BSN, local switch, PMS server, and dashboard for PMS visualization with medical staff.

Health monitoring based on IoT is considered as an advanced platform to provide us with a remarkable service in contemporary medicine. Recent advances in cloud computing, mobile technologies, and wireless sensor networking give a great possibility for efficient remote patient monitoring. FIGURE 3 demonstrates a generic PMS system with body-sensor-network (BSN), local switch, PMS server, and dashboard for PMS visualization with medical staff. The applications of IoT in the medical sector seem to be endless, but the most promising ones are represented by monitoring and tracking patient health using PMS. To this end, PMS is able to perform various functions with an aim to achieve different objectives, which can be listed as follows:

- Affordability and automating healthcare: Affordability in healthcare can be significantly enhanced by PMS through measures such as reducing hospital readmissions and administrative costs, ultimately lowering overall healthcare expenses. Additionally, PMS contributes to automating healthcare processes, optimizing tasks such as data collection, appointment scheduling, and treatment reminders, thereby improving efficiency and quality of care delivery.
- Improve work productivity and accuracy: Monitoring patients through PMS will likely improve the accuracy of the diagnosis and provide a fast decision in medication management and productivity [42]. PMS has the ability to simplify healthcare workflows and reduce administrative burdens on healthcare professionals, hence allowing them to focus more on patient care and improve overall work productivity.
- Real-time patient tracking: The majority of PMS provides portable, high reliability, and wireless low-cost tracking of patient health metrics and activities, hence facilitating prompt decision-making and interventions based on current patient conditions. In the sophisticated technologies of real-time patient location monitoring, the location of the patients is tracked then an alarm is raised based on specific incidents. Such activity should be performed in real-time, and hence, effective rescue and immediate operations should be guaranteed.
- Security of data access: PMS can offer the security and reliability requirements for healthcare systems, which is important to protect the data and prevent unauthorized access by a secure communication framework. Besides, PMS ensures the privacy and confidentiality of patient information by using robust encryption and access control measures, safeguarding sensitive medical information from unauthorized access, and following industry standards and regulations. The main criteria for security and privacy of a cloud-based healthcare approach are authorization, non-repudiation, authentication, integrity, and confidentiality.
- Speed up data management: in PMS, patient's vital parameters can be transmitted faster in real-time to health professionals such as doctors, nurses, or laboratories regardless of the geographic location of patients. Therefore, the rapid availability of patient information allows rapid data analysis and provides predictive insights into the patient's condition with appropriate management and treatment. In addition, PMS accelerates the processing and organization of patient data, allowing healthcare providers to access critical information efficiently.
- Remote monitoring and medical assistance: One of the main objective of PMS is to allow healthcare professionals to monitor patients' vital signs remotely in real-time, hence enabling timely intervention and medical assistance, especially for those in remote or inaccessible areas.
- Prevention of disease spread: By enabling remote monitoring and minimizing in-person interactions, PMS helps prevent the spread of infectious diseases, especially during pandemics or outbreaks, by reducing the need for patients to visit hospitals and doctors.
- Reduction of care costs and patient expenses: PMS can play an essential role in lowering healthcare costs. This can be achieved by detecting health issues in an early stage, proactive management, and reduced hospitalizations, and hence, beneficial for both providers and patients, resulting in decreased overall expenses [43].
- Patient self-management: PMS enables patients to participate in their own healthcare by providing tools and resources for self-monitoring and management of their health conditions. By promoting self-management, healthcare providers can enhance patient engagement, improve health outcomes, and optimize the efficient use of healthcare resources.
- Boosts caregiver connectivity: PMS enhances communication and collaboration among caregivers, enabling seamless coordination of patient care plans, sharing of medical information, and providing support to patients and their families.

The aforementioned functions and applications are illustrated in FIGURE 4.

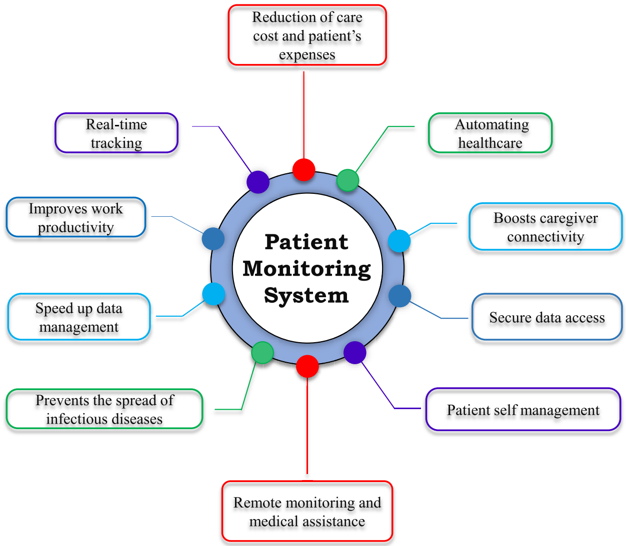

FIGURE 4. The significant functions and applications of PMS in healthcare systems.

III. REMOTE PATIENT MONITORING SYSTEMS ARCHITECTURE BASED ON IoT

Currently, one of the most critical global challenges revolves around ensuring that healthcare services are available, accessible, and affordable for everyone. PMS is, in particular, one of the most essential health systems that has a great effect in health services by providing faster monitoring, diagnosis, and treatment for people who need continuous and/or urgent healthcare. PMS is a revolution in the digitalization of healthcare, and it uses a combination of software and hardware to provide a fast and effective decision-making process. We aim to build a healthcare system that are able to allow individuals to take an active role in the management of their health conditions, which can effectively improve patient engagement and enhance overall health outcomes. This engagement impacts individuals and communities profoundly, influencing health outcomes and overall well-being. Thus, by enabling people to actively engage in their healthcare decisions and treatment plans, patient self-management plays a critical role in tackling health concerns. By fostering patient engagement and responsibility, healthcare providers can enhance the effectiveness of care delivery and the distribution of healthcare services, leading to improved health outcomes and a more sustainable healthcare system [44].

One of the main objectives of using IoT and remote health monitoring is to transfer medical services from hospitals and extend them to convenient homes. IoT comprises a network of interconnected electrical and wireless devices that collaborate to collect and share patient data for diagnostic and analytical purposes, as well as for securely storing patient information. This technology has revolutionized healthcare by allowing real-time health monitoring, and personalized treatments that could significantly improve patient healthcare [45]. Various sensors and devices can be used in PMS to collect patient data. PMS-based IoT is an advancement in the medical stream for monitoring patients' conditions. For instance, the movement of comma patients' bodies should be recognized and checked continuously using temperature measuring devices, IoTs accelerometer (devices and sensors for measuring body movement), and eye blinkers [22]. The elderly and people with chronic illnesses can benefit from these remote monitoring devices [46].

The design and implementation of PMS architectures aim to optimize patient care by ensuring accurate data collection, efficient data processing, and timely communication of relevant information to healthcare providers. To this end, several research works have considered the real-world applications of PMS based on IoT in healthcare systems. For example, the work in [47] provided a comprehensive survey discussing edge computing solutions for IoT applications, covering applications and highlighted the benefits of edge computing over cloud computing in healthcare domains. The work in [48] investigated the impact of IoT intervention in a hospital unit and provided empirical evidence on the effects of smart technologies on patient safety particularly (patient falls and hand hygiene compliance rate) and staff experiences. The work in [49] considered the detection and monitoring of cardiovascular autonomic neuropathy in diabetes patients. The work in [50] provided an empirical investigation of how wearable IoT devices would bring about a revolution in the healthcare industry. The work in [51] developed a system that tracks blood pressure using the Keep In Touch (KIT) method and integrated closed-loop healthcare services. The KIT device is connected to a JAVA-based mobile phone via near-field communication, which operates on principles of magnetic and inductive coupling, effective only at short distances. Upon touching the KIT, data is transmitted to the mobile phone. In the closed-loop system, this data is then securely sent from the mobile phone to a designated website, allowing for remote monitoring of the patient's blood pressure. The work in [52] proposed a method to monitor a patient's ECG waves from any location globally using the IOIO-OTG Microcontroller. An Android application was developed specifically for ECG monitoring, where the IOIO-OTG microcontroller connects to the Android phone via USB cable or Bluetooth. After data collection, the ECG waves are transmitted to the Android app, which allows for both monitoring and storage of the ECG data. The work in [53] concentrated on monitoring body temperature using a Raspberry Pi board within a cloud-based system. Their approach involves using the Raspberry Pi to monitor body temperature, with the data being transmitted through wireless sensor networks (WSN) to a cloud-based platform, where it can be accessed for temperature monitoring. The work in [54] introduced a system for monitoring body temperature using an LM35 temperature sensor connected to an Arduino Uno board. A website in SQL database format was created and linked to the Arduino Uno, enabling sensor output to be sent directly to the website. Through this platform, users can log in and monitor body temperature remotely. The work in [55] explored the monitoring of ECG, respiration rate, heart rate, and body temperature using a system where various sensors are connected to a PIC16F887A microcontroller. After gathering data from the sensors, the information is uploaded manually. To facilitate monitoring, an application, and a webpage were developed for health status tracking. The work in [56] discussed a system that monitors temperature, blood pressure, and heart rate of patients. In this setup, sensors are connected to a microcontroller, which is also linked to a GSM module. Once data is collected, an SMS is sent to the doctor if any values are concerning. The work in [57] described a method for monitoring ECG waves using an AT Mega 16L microcontroller. The system employs a Zigbee module to transfer ECG data to the nearest connected system for further analysis. The work in [58] developed a system for controlling and monitoring home appliances via an Android-based smartphone. An Arduino Uno board is connected to home appliances like lights and fans. An Android application was created for this smart home system, enabling users to control and monitor appliances remotely from anywhere in the world using the internet. The work in [59] focused on monitoring body temperature and heart rate using a C8051F020 microcontroller. Wearable sensors collect data, which is then transmitted to the microcontroller. A Zigbee module connected to the microcontroller transmits the data to the nearest receiver.

Typically, PMS architectures consist of either three or four layers, depending on the system design. These layers share common concepts across different PMS implementations. The PMS architecture refers to the organizational structure that defines how the system operates and how different IoT components interact with each other. This architecture typically consists of multiple layers, each serving specific functions and contributing to the overall operation of the healthcare system. PMS architecture can be categorized into different layers which are physical, logical, and application layers. The physical layer includes a number of different sensor nodes that are operating within a wireless network. Then, the logical layer comes to processes the data collected from the sensors in the physical layer. Finally, the logic layer deals with media access control and mind-to-mind communication. The application layer is responsible for determining the decisions based on the data processed in the logic layer. The work in [44] defined the PMS by using a three-layer architecture, which involves BSN, wide-area-network (WAN) and personal-sensor-networks (PANs). Physiological parameter sensing is the responsibility of BSN, while the final layer addresses the interrelated medical services. PSNs, or personal surveillance networks, are made to record and process contextual information about people and their environment. Through personal service applications that function as a gateway layer, PSNs are important in facilitating integration between the first and third layers. The work in [60] divided the architecture of the residential environment in an e-healthcare system into four layers. In this architecture, layer 1 refers to the BAN layer, which includes different types of sensor nodes operating within wireless networks. Layer 2 comes to have user interaction devices. This layer works as an access-point layer to represent the user interaction interface. The medical information is gathered from layer 2 and transferred to layer 3 to prepare for the final destination using home networking possibilities. The role of Layer 3 is to filter and analyze the data collected, which is automatically connected to the Internet. Finally, Layer 4 provides the required healthcare to the patient based on delivered analyzed data. Another approach PMS architectures is proposed in [61]. In this PMS architecture, four layers are proposed which are: sensors, data acquisition, transmission, and database layer. In the proposed architecture, the Wi-Fi communication technique was used to connect the sensors to the smartphones, while 5G technology was used to connect smartphones to a cellular network, which in turn sent the data to the database. Besides, machine learning (ML) algorithms are proposed to classify the data for diagnostic purposes. The first layer was used to connect sensors and interface them wirelessly to layer 2. Layer 2 is represented by the patient's smartphone. Using a mobile application, the collected data is sent to the base station via the 5G network through layer 3, which is the transmission layer. The final layer, which is the database layer 4 was utilized as a processing unit that stores, processes, and classifies the data using machine learning (ML) algorithms. Furthermore, several works have investigated different PMS architectures, see. e.g., [40], [62], [63], [64], [65], [66], [67].

In this paper, we propose to use five 5 layers PMS architecture. FIGURE 5 illustrates the proposed general architecture for remote PMS, which is composed of a sensing layer, wireless communication layer, edge/fog computing layer, cloud computing layer, and application/action layer that involves a user interface and medical server layer. As shown in FIGURE 5, the data is obtained by different types of sensors and wearable devices, then it is transmitted using a short-range communication protocol to the nearest gateway, such as a display, a smartphone, or a computer. After that, the processed signal is transmitted to a remote server that is used by the healthcare specialized person, which is usually placed in a health institution. End users are the one benefit from the PMS, which could be patients, medical staff, hospitals, doctors, government organizations, clinical research institutes, and manufacturing companies. The general architecture of PMS can be summarised as follows:

- Things layer (sensing layer): This layer is the lowest level of the architecture where data is captured from sensors and devices attached to the patient. Specifically, this layer involves collecting of the patient's vital signs by using interoperable wearable medical devices, such as wearable sensors, EMG, ECG, SpO2, heart rate monitors, temperature sensors, ambient sensors, blood pressure sensors, and many other sensors and devices. The sensing layer collects real-time health-related data from patients and transmits it wirelessly to the higher layer.
- Communication/Networking layer: This layer acts as a gateway layer where the data collected from sensors and wearable devices is processed and aggregated locally before being forwarded to a higher-level layer or the cloud. This layer can manage device connectivity. It might also facilitate the transmission of processed data to higher-level systems or healthcare professionals. This layer involves networking protocols to ensure that healthcare data is transmitted securely and efficiently. In particular, the communication and networking layer often communicates with devices using short-range wireless protocols like Bluetooth, Zigbee, and Wi-Fi. Then, the data is forwarded to the cloud using Wi-Fi or cellular networks.
- Edge/Fog computing: This layer serves as an intermediate hub that can pre-process the data, and perform basic analytics. Edge computing can be used to enable programmable decentralized networks, and

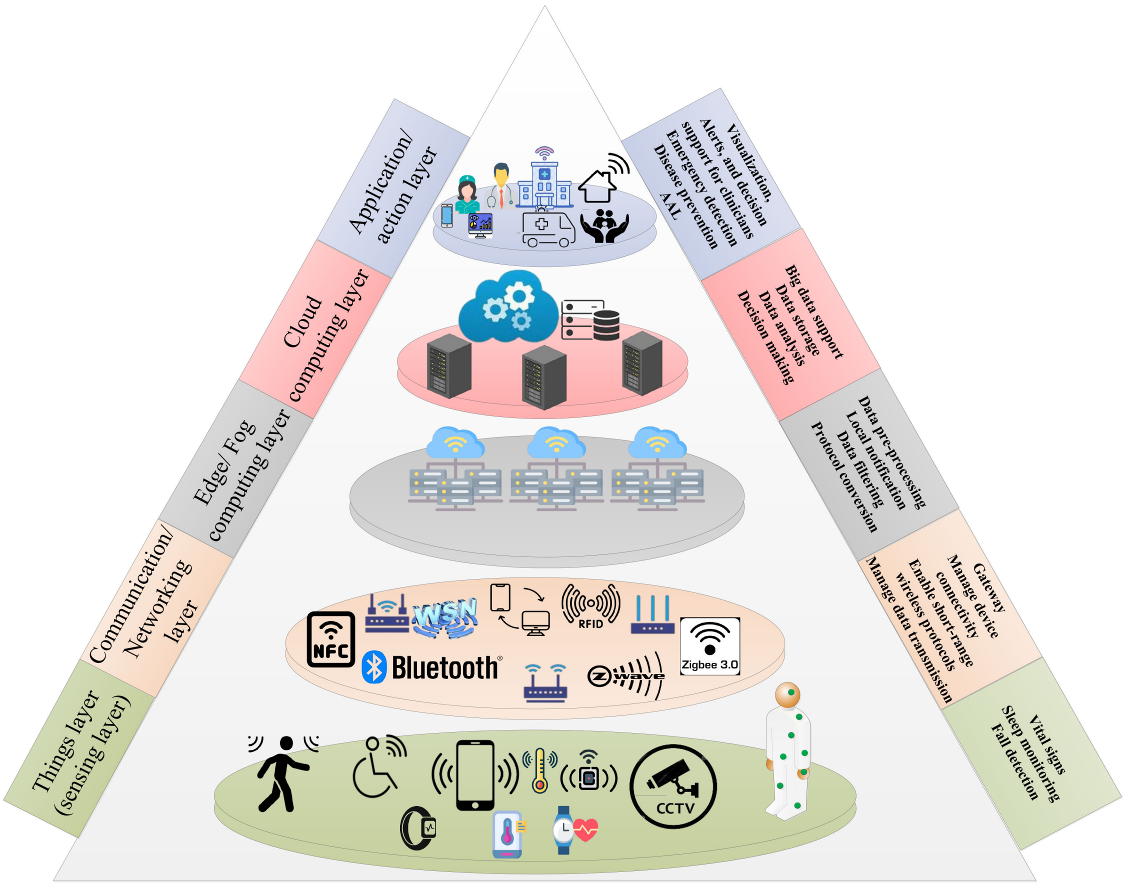

FIGURE 5. The general multi-layer architecture of PMS in healthcare systems.

hence, facilitating effective processing and management of data at the network's edge rather than at the centralized cloud. This is particularly useful for delay-sensitive applications such as PMS. Noting that fog computing is an edge computing technology that brings cloud computing closer to the locations where data is generated and collected by extending its capabilities to the network's edge. Such distributed computing technique enables the processing and analysis of data to be performed closer to the data source, hence reducing latency, conserving bandwidth, and improving overall system efficiency.

- Cloud computing layer: IoT utilizes a distributed platform to process and store data. Data can be obtained from the communication/gateway layer. Alternatively, data from sensors and wearable devices can be sent directly to the cloud layer for processing, storage, and analysis. Cloud-based platforms provide scalability, flexibility, and accessibility, allowing for centralized data management and advanced analytics. The devices typically communicate with the cloud using WiFi, cellular networks, or other long-range wireless technologies. In the cloud layer, the raw data is processed and analyzed. Algorithms may be applied to detect patterns, anomalies, or specific health parameters.
- Application/action layer (medical server): The processed data is presented to healthcare providers or integrated with electronic health records (EHR) systems. This layer enables visualization, alerts, and decision support tools for clinicians. This layer may involve self-management, active assisted living (AAL), activities behaviors, emergency detection, disease prevention, and mobile health (m-Health) [68] or electronic health (e-Health) [69].

A complete review on the significant components used in PMS architecture is provided in the following section. This would reflect each point in architecture provided previously.

IV. SENSORS AND WEARABLE DEVICES IN HEALTHCARE SYSTEM

This section discusses the application of sensors, which is considered the most essential part in PMS healthcare architecture. Then, a description of the wearable devices and their use in PMS.

A. SENSORS FOR PMS

Typically, the first layer in PMS healthcare architecture is represented by sensor nodes. Sensors are made to be implanted beneath the skin (in-body), sewn into clothing (wearable), or applied to the human body as tiny patches (on-body) [60].

In general, sensor is a device that receives signals and responds to a stimulus. An electrical value is translated from a nonelectrical value via a sensor [70]. A sensor is defined as a computing device that can be installed on people, animals, and objects. Sensors are ubiquitous, with applications spanning homes, offices, shopping centers, and automobiles, embodying a fundamental component of the modern world. Sensors can sense, transmit, process information, and perform different works such as motion detection, image sensing, voice control, environment perception, physiological signal monitoring, and gesture recognition.

In PMS, various sources are used for data acquisition and gather information related to the patient, environment, activities, and behaviors. Sensors are the most important part in the PMS, which are used to collect information on the patient's condition. They are smaller in size, faster in process and gathering information, and cost-efficient [66]. It is important to mention that sensors are considered as the core element or fundamental component of any wearable device [71]. Hence, it is essential to delve into the specifics of sensors and explore their fundamental types.

In wearable technology, sensors play a pivotal role in capturing various physiological and environmental data that are essential for monitoring health parameters or activity levels. Different types of sensors, such as accelerometers, heart rate sensors, temperature sensors, and ECG sensors, are integrated into wearable devices to collect specific data points. Understanding the characteristics and capabilities of these sensors is essential for optimizing the accuracy and effectiveness of wearable devices in healthcare applications. Studying sensor technology within wearables not only enhances our comprehension of device functionality but also guides decisions on device choice, data analysis, and the creation of modern healthcare innovations. Hence, this review paper provides an explanation of the different types of sensors to provide researchers with the important information they need.

The emergence of the first thermostat in 1883 is often regarded as the inception of modern sensor technology. Since then, sensors have evolved significantly, adopting various principles and forms. Early sensors were relatively straightforward, measuring specific quantities and generating mechanical, electrical, or optical signals in response. However, over the past decade, the landscape of sensor technology has been revolutionized by advancements such as computing power, pervasive communication networks, internet connectivity, mobile smart devices, and integration with cloud computing. These developments have greatly enhanced the capabilities of sensors, enabling sophisticated applications in healthcare, wellness monitoring, and environmental sensing [72]. The evolution of sensor technologies into pervasive sensing environments poses fascinating not merely through integration them into sensing networks but through the way of adapted these technologies to operate in diverse collective sensing applications. Network technologies allow sensors to be connected and integrated into home infrastructure. Every sensor is performing one or more tasks concurrently [73].

Sensors have several forms of properties of the input signals and electrical output signals. They can detect any small change in the sensed quantity of the input and produce a change in the electrical output using their measuring capabilities. It is important to distinguish between sensors and transducers. The transducer converts any type of energy into another, while the sensor converts any type of energy into electrical energy. For example, a loudspeaker is a transducer that receives the electrical signal and converts it into acoustic waves. Sometimes, a Transducer can be used as an actuator in different applications, which converts electrical signals into nonelectrical energy (the opposite of a sensor). An electric motor that transforms electrical energy into mechanical action is an example of an actuator [74].

Sensors can be classified into different types and can be made based on different aspects such as uses, applications, and material, and based on their characteristics such as accuracy, range, and cost. In general, the data generated by sensors has also different formats. This format is classified as numerical, categorical, graphics, and video. Therefore, PMS can be categorised into two partitions. One partition called vision-based approach and the other called sensor-based approach, which is related to the formats and sensor types as discussed in [73]. Different types of sensors with their applications are presented in [72]. Besides, Table 1 presents a comparison of the most common types of sensors [75], [76], [77]. Noting that sensors such as sound, light, smoke, color, and seismic sensors are typically employed in various innovative ways to capture physiological data by monitoring changes in the environment that correlate with specific bodily functions. For example, sound sensors can be used to detect breathing patterns or heartbeats by capturing the acoustic signals generated by these activities [78]. On the other hand, light sensors can measure changes in skin tone or detect blood flow by monitoring variations in light absorption, often used in pulse oximetry [79], [80], [81]. Smoke sensors, though more commonly associated with detecting fire, can be adapted to monitor respiratory functions by sensing changes in air quality or exhaled gases, indicative of metabolic processes [82]. Color sensors are instrumental in analyzing changes in skin color, which can reveal information about oxygenation levels or emotional states. Seismic sensors, traditionally used for detecting vibrations, can be finely tuned to monitor subtle movements such as those caused by heartbeats or muscle contractions [83]. By leveraging the sensitivity of these sensors, physiological data can be gathered with high precision, allowing for continuous and non-invasive monitoring of vital signs.

Sensors can be divided into passive and active. A method of using passive and active sensors in road extraction is presented in [84]. The passive-type sensor does not require an additional energy source. It is able to generate an

TABLE 1. Different types of sensors.

Sensors	Action	Advantages	Disadvantages
Temperature sensor	Detect thermal parameters and record signal temperature changes.	• No need to use a reference temperature. • Large response time and easy display.	Error of self-heating from applied power and challenging to adjust.
Position sensor	Detect the position of an object.	• Accurate and predictable measurement. • Higher switching rate and susceptibility to noise.	The target object's metal kind determines the range.
Sound sensor	Detect the intensity of the sound and sound pressure waves.	Real-time sound manipulation is simple and doesn't require cabling.	Sound files require more memory size and have limited coverage area.
Light sensor	Transforms detected photons of light energy into electrons for use in devices like photodiodes and resistors.	Requires lower power, available in different shapes and Sizes., quick response time, and low cost.	Nonlinear characteristics, temperature sensitive, and vulnerable to surges and spikes.
Accelerometer	Detects the acceleration of an object, senses the acceleration of gravity, and calculates the object's direction.	Good response at higher frequencies, resists high temperature, and has a small size.	Sensitive to high frequency and requires external power.
Infrared sensor	An infrared (IR) sensor consists of two packs. Transmitters transmit the rays in the infrared spectrum and the receiver receives the IR spectrum range.	Operates with low power, strong noise immunity, and detects presence or absence of light.	Requires line-of-sight Deployment and has Limited range. Affected by environmental conditions.
Pressure sensor	Assign signals to the inputs of control and display devices based on the measurement of gas or liquid pressure.	Low cost and high output signal level.	High hysteresis, sensitive to vibrations and movable contacts.
Ultrasonic sensor	Sensing and measuring the distance of a particular object.	Greater sensing distance, resistance to dust, rain, snow, and other environmental factors, and the ability to sense all elements in dark situations are its main features.	Sensitive to variation in the Temperature, cannot work in a vacuum and sensing accuracy is affected by soft materials.
Smoke and gas	Utilised to detect the existence and characteristics of various gases and transmit signals in the form of output signals to the controller.	• Simple and low-cost technology. • Wide measurement range. • Increased dependability, sensitivity, and resolution.	Requires air or oxygen to work, narrow or limited temperature range.
Humidity sensor	Determine the amount of water present in the surroundings and translate these findings into signals suitable for input stimulation.	• Does not require much maintenance. • Flexibility to use. No aging effects.	• Sensitive to dewing and Substances. limited accuracy and measurement range.
Color sensors	Uses a receiver to pick up light reflected off the detecting item after light is emitted from a transmitter.	Simple to implement and easy to adjust configurations without even reprogramming the sensor device.	Sensing range affected by color and reflectivity of target.
Chemical sensors	Transmits chemical information from a chemical reaction.	Linear output, low power requirements and good resolution with excellent repeatability and accuracy.	Narrow or limited temperature Range with short or limited life
Seismic sensor	Records and amplifies minute motions of the earth in addition to measuring them.	Detects lateral and vertical variations in velocity and produces detailed images of the Subsurface.	Data processing is time-consuming and equipment is expensive.

Continued on next page

TABLE 1. *(Continued.)* **Different types of sensors.**

Sensors	Action	Advantages	Disadvantages
Touch sensor	Function as switches, and when the sensor's surface is contacted, the circuit's current begins to flow, just like it would in a closed circuit.	Touch interactions are natural and familiar to users accustomed to smartphones and touchscreens and eliminates the need for protruding buttons.	Touchscreens are susceptible to accidental touch and more susceptible to scratches and cracks.
Magnetic sensor	A response by generating a proportionate output to the presence or absence of a magnetic field, including flux, strength, and direction.	Contactless Operation with high-Speed Response and high Resolution.	Limited to conductive materials and higher cost.
Optical sensors	Quantifies biological or chemical reactions, such as variations in colour, scattering, fluorescence, and light absorbance.	Reasonably priced production, visual estimation, simplicity in design, speedy optimisation, and adaptability. elevated sensitivity. corrosion-resistant and suitable for use in challenging conditions.	Dye biocompatibility in fluorescence and colorimetric sensors. Requires bulky UV lamps or fluorescence spectrophotometers and bulky size.
Proximity sensors	Used to find adjacent items without coming into direct contact with them.	It can detect both metallic and non-metallic targets, It has good stability with high speed provided. Low cost and power consumption and useful and can help with many security problems	They are affected by temperature and humidity and difficulties in designing with limited operating range and expensive than inductive and capacitive sensors.
Force sensors	Convert applied mechanical forces such as compressive and tensile forces-into digital signals whose values correspond to the applied force.	Accurately measure the magnitude and direction of applied force and provide real-time data on force variations, enabling adjustments in processes for optimal results.	High-precision force sensors can be expensive and certain environmental factors like temperature fluctuations might affect sensor performance.
Flow sensors	Used to measure a fluid's flow, such as a liquid or gas, and send the controller output signals.	Accurate and reliable data on the rate of fluid movement through a pipe or channe and come in various types suitable for measuring different fluids (liquids and gases), flow rates (low to high), and pipe sizes and can be integrated with data acquisition systems.	The cost of flow sensors can vary depending on the type, accuracy, and features. High-precision or specialized sensors can be expensive and may require periodic maintenance or calibration to maintain accuracy, especially in harsh environments or with continuous use.
Flaw sensors	Used to display irregularities on surfaces or different underlying materials in a variety of manufacturing processes.	• Allow for early detection of defects before they become critical failures, enabling preventative maintenance and avoiding costly downtime or accidents. • Flaw sensors are used in various industries, including aerospace, automotive, construction, and power generation.	• Analyzing sensor data and interpreting results often requires trained personnel with expertise. • Depending on the sensor type, there might be limitations on how deep flaws can be detected within a material
Electro-chemical sensor	Transform the redox reaction's impact on electrode surfaces into electrically readable signals that indicate variations in conductivity, current, and potential.	Low waste fabrication and possibility of large-scale production.	Requires external power sources and requires amplification techniques for highly sensitive signals.
Piezo-electric sensor	Investigated for energy-harvesting solutions and self-powered sensors in biointegrated devices.	Broad sensing range, high-frequency response, and simple construction.	Charge leakage and the only possibility of dynamic sensitivity.

electric signal directly in response to an external stimulus. Examples of passive sensors are thermal, infrared, electric, and chemical. On the other hand, an active sensor type needs an external energy source for their response, (known as an excitation signal). Examples of active sensors are thermistor sensors and resistive strain gauge sensors. The work in [85] provided an extensive review of sensor technologies and their transformative impact on our lives across various fields. The author discussed how sensors are able for detecting changes in the environment and collecting signals, hence enabling a wide range of applications spanning lifestyle, healthcare, fitness, and manufacturing. Specifically, the paper highlighted sensor applications in healthcare, where drug-delivering sensors can be used to aid medication adherence by reminding individuals to take medicine and providing doses at specific times, benefiting older adults, athletes, and at-risk patients. Additionally, the review outlined key industrial trends such as ultrasound, radar, and optoelectronic solutions driving sensor innovation, emphasizing their critical role in modern business operations and everyday activities. The work in [86] explored the diverse and rapidly evolving field of sensors driven by high demand and continuous technological advancements. The authors discussed the electrochemical sensors that is known for their affordability and versatility in detecting various analyses and are extensively employed across industries like agriculture, food, oil, environment, and healthcare. The review highlighted the appeal of electrochemical sensing due to its versatile reporting signals (voltage, current, power output, impedance) and low detection limits attributed to Faradaic and non-Faradaic currents. Additionally, it discusses recent advancements and applications of electrochemical sensors, particularly emphasizing the role of nanomaterials. The work in [87] presented a comprehensive review of advancements in soft sensor design and implementation, focusing on their critical roles in industrial process monitoring, control, and optimization. The author also discussed how new theories, techniques, and information infrastructure have improved soft sensor performance while also how to address some related technical challenges. Furthermore, the author discussed the most recent developments in the soft sensor design, offering insights from a systems and control perspective, to provide up-to-date information related to this research. The work in [88] reviewed the integration of artificial intelligence with health monitoring sensors to improve healthcare capabilities, addressing some technical challenges such as noise, data processing, and feedback control. Besides, this paper explored advances in wearable and implantable sensors for monitoring vital signs, soft electronics for therapy, and volatile organic compound detection. Furthermore, this paper discussed some recent developments in artificial intelligence-enhanced human-machine interfaces and self-sustainable sensor systems, highlighting the potential for more intelligent and secure healthcare services in future biomedical applications.

There are three classes of interconnected networks namely as PSN, BSN, and multimedia devices. Such networks can be deployed within living environments or integrated into various household objects such as sofas, tables, beds, chairs, or floors, all equipped with pressure sensors. By monitoring subjects within their environment and interactions with these objects, PSNs offer valuable insights into the performance levels of daily living activities. The data provided by PSNs enables a deeper understanding of individual behavior and facilitates the development of personalized solutions for healthcare and lifestyle management [73]. Usually, the first layer of PMS architecture is termed BSN. A BSN can be defined as a wireless network obtained by deploying different sensors in and around the human body [89], hence it is a network of wearable sensors that are used for monitoring patients [90]. Miniaturised wearable or implantable wireless sensors have been employed in the introduction of the BSN concept. Imperial College London proposes the BSN node, a BSN hardware development platform, to support BSN research and development. BSN nodes offer a flexible development environment for ubiquitous healthcare applications because of their low power consumption, compact size, and flexible design. The sink node in a BSN gathers data and sends it across the Internet for sharing. Social welfare, emergency treatment systems, diagnosis services, and patient direct care can all benefit from having a BSN [91]. Basically, the identification of the sensor node is defined by a unique ID for each device. For example, in a single BAN, two motion sensors are used: one for tracking hand motion and the other for tracking foot movement [92]. BSNs are moving towards intelligence and multi-technology integration. Despite the existing challenges associated with BSNs, their future holds significant promise as they have the potential to deeply transform human-machine interactions.

The widespread adoption of home appliances integrated with sensors is paving the way for interactive healthcare environments. These integrated appliances are electronic or electrical gadgets that have several uses in the house. Devices such as TV sets, speakers, phones, cameras, and microphones create a platform for data sharing between people and healthcare systems. These devices enhance user engagement with health applications, serving as new sources of contextual data and platforms for guidance and counseling. Multimedia devices, such as cameras and microphones, are central to these approaches, enabling visual and audio sensing for monitoring daily activities [73]. Wireless sensors, including smartphones, smart cameras, and devices like Raspberry Pi with cameras, are instrumental in monitoring chronic disease patients, comatose patients, and newborns for smart caregiving and independent living in smart homes. These sensors facilitate measurements such as respiratory and cardiac rates using air quality sensors, integrated toilet seats with ECG monitors, cardiac and respiratory monitors, and smart beds equipped with sensor-enabled pillows and magnetic switches. Vision-based methods extend further to include posture recognition, human presence detection, movement and fall monitoring, and tracking complex activities. While multimedia-based approaches offer rich contextual insights, they are challenged by computational demands and privacy concerns. Data acquisition methods vary across sensors, and the heterogeneous sensor set provides primarily raw, low-level data that is imperfect, uncertain, and of limited meaning. Thus, further advancements are necessary to develop higher-level approaches for delivering comprehensive healthcare services. Besides, advanced signal processing techniques such as those presented in [93], [94], [95], [96], and [97] can be used to obtain efficient healthcare systems.

When it comes to creating and retrieving raw sensor data-that is, information about the patient and their surroundings-physical sensors are thought to be the most often employed type of sensors [73]. The common types of sensors used for the purpose of health sign activity monitoring, which are generally attached to human body, are provided as follows [98], [99]. Electrocardiogram (ECG) sensor is used for heart rate monitor. Electromyography (EMG) sensor is used to track muscle contraction. EEG (electroencephalography) sensor is used for brain electrical activity monitoring. Glucose sensor is used for measuring and monitoring glucose levels in the body. Pulse oximeter (SPO2) is used to measure oxygen saturation of blood. Body temperature is used to track temperature sensor. Respiration sensor is used for detecting and measuring respiratory parameters such as breathing rate, volume, or patterns to monitor respiratory function and provide insights into respiratory health. Finally, motion sensors (accelerometers) used to estimate user's activity.

B. WEARABLE SENSOR DEVICES

Data acquisition plays a crucial role in PMS by utilizing smart health devices, primarily wireless sensors and wearable devices, which gather comprehensive patient data. Wearable devices like digital watches, smart clothing, and fitness tracker bands collect a diverse range of health information, enabling continuous PMS and data collection for wearable health monitoring systems) and general health monitoring systems. Specialized devices like smart vests are used for non-invasive physiological monitoring, including ECG, galvanic skin response, body temperature, and blood pressure assessment. Such data acquisition methods not only enhance athlete performance and support disabled individuals but also enable personalized healthcare interventions based on real-time patient data.

Since Steve Mann, who is recognised as the father of wearable computing, unveiled the first Linux-based wristwatch at the 2000 IEEE International Solid-State Circuits Conference, the number of wearables has increased dramatically over the past ten years [100]. The first wearable sensor was called Holter monitoring, which was developed in the late 1940s and used in clinical settings in the 1960s. It is a portable gadget that tracks the central nervous system's electrical activity continually. The field of wearable sensors has advanced during the last ten years, having begun to take shape in the first part of the 20th century. Wearable devices have been introduced as key enabling of IoT-based healthcare systems, which attracted much attention due to their various functionalities. Besides, the wearable devices become available in the market at an acceptable price [101]. Wearable devices have many advantages and are becoming more and more popular because they make life easier. Wearable devices have been used in different applications such as environmental detection, physiological signal monitoring, human activity recognition, and most importantly healthcare monitoring. An example of wearable devices are smartwatches, smart glasses, and fitness trackers. Particularly, these devices integrate low-power sensors to detect movement and other physiological signals. As a result, research and commercialization are now focused on wearable sensors as functional parts of wearable technologies [71]. With the recent advancements in IoT and artificial intelligent technologies, wearable sensors have been developed and employed widely in the scientific and industrial communities and receiving significant attention in sophisticated scenarios such as navigation systems, biomedical applications, Google Glass, consumer goods and smart clothing. The combination of IoT, augmented reality, and wearables can create new paradigms that may potentially change the way people experience the world [102]. Proactive personal health management involves monitoring patients outside of the hospital setting, often using wearable sensor devices. This approach allows individuals to actively track and manage their health status remotely.

The wearable devices can be placed on-body biosensors, which should unobtrusively measure significant physiological signals like blood pressure, body movement, heart rate, skin, and body temperature [60]. Wearables can be worn on the body itself, concealed in clothing, or housed in semi-rigid objects like headgear, gloves, insoles, and smart watches. In PMS, wearable devices cover a wide and important range of applications. The working and characteristics of wearable devices in healthcare fields are mainly based on the observation of physiological data from the user's body [71]. These wearable devices in PMS are considered simple in use, low-cost, independent devices targeting personal use without the need for medical professionals. These properties make wearables devices widely deployed, and in turn, has led research attention at a much faster pace to this field [103].

Typically, wearable devices can be divided into three groups according to the position of wearing: hand-worn, limb-worn, and head-worn. Different considerations and requirements of such devices should be taken into account such as the cost, portability, usability, wearability, intelligence, and performance. TThe development of wearable sensors grew quickly as a result of the growing need for telehealth and real-time health monitoring, with a compound annual growth rate of 18.3% from 327.6 million in 2021 to 1,487 million in 2030 [29]. The statistics predict that by 2025, there will be multibillion wearable sensors, where over 30% of them are considered as new types of sensors that are just beginning to emerge [104]. There is a greater exchange of data across medical equipment when wearables are used. The ecosystem addresses these issues in wearables interoperability & intelligence by including different points. Standards developers, payers, providers, healthcare delivery

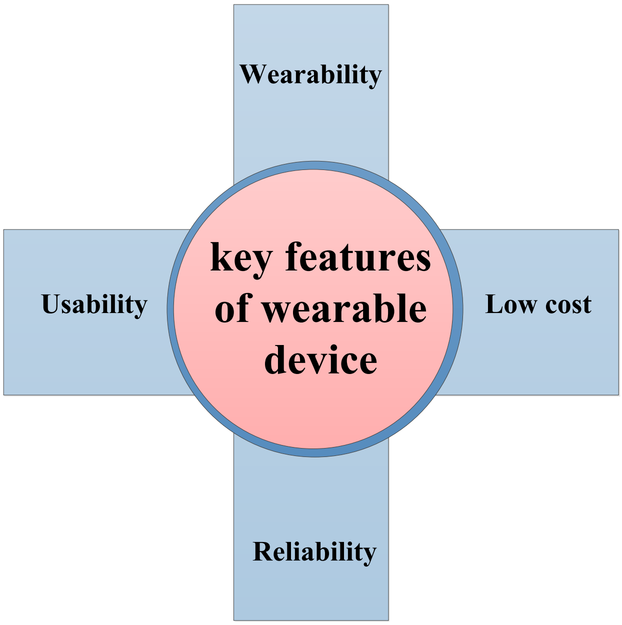

FIGURE 6. Key features of wearable devices in PMS.

organisations, network service providers, and manufacturers of IT and medical device hardware, firmware, software, and services [105]. Nevertheless, there are a number of issues with wearables and medical IoT connectivity and intelligence, including the possibility of wearable and implantable hacking.

In general, the two key challenges that face wearables devices are security issues and power efficiency [40]. Practically, wearable monitoring equipment is very efficient for patients enabling him/her to monitor his/her own health status anywhere. Wearable medical technology is expected to keep expanding, particularly in rural areas. Additionally, the vast economic market helps to fuel the quick growth of these gadgets [106]. Therefore, the commercially available wearable devices and prototypes for medical IoT need to be classified to distinguish the best devices for each patient status that is monitored [103]. It is worth mentioning that wearable sensors with other diagnostic platforms such as point-of-care devices and lab-on-a-chip systems are integrated with biosensors. In order to monitor the concentration of different analytes in biological fluids including blood, saliva, and urine, biosensors are widely employed in medical diagnostics. Wearable biosensors, or devices with built-in biosensors, can save healthcare expenditures [107]. Additionally, wearable biosensors are a useful tool for identifying bacteria, spotting dangerous compounds in the environment, and diagnosing ailments in people. The following are some of the key features of wearable devices [108], [109], [110]. FIGURE 6 summarizes the key features of wearable devices in PMS.

- Wearability: This characteristic is mostly dependent on the size of the sensors, the power supply specifications, and the reduction of on-body hardware. Future developments could address the used hardware by incorporating the parts into e-textiles. Textiles' special qualities of being lightweight, pliable, and comfortable to wear make them ideal for wearable technology.
- Low cost for various applications: The cost-effectiveness considering the initial investment, training, and maintenance will surely influence the integration of the wearable devices into PMS.
- Usability: The functionality of these devices such as data collection, transient information collection, and user-friendly interface are required to satisfy the specific clinical need and measure the important signs of the patient.
- Power consumption and ease of fabrication: These are major challenges in the design of wearable devices as long-term maintenance-free operation is required. Hence, advanced methods for low-power processors are essential.
- Performance and reliability: Verification in real-life scenarios provides essential information based on its usefulness and reliability. Wearable devices should demonstrate specific tolerances for patient activity in the environment to contribute the reliability through the identification of mistakes, avoiding misleading the collected data.

Wearable device innovation is being propelled by advancements in wireless communication, energy harvesting, and sensor networks, in addition to the previously mentioned factors. In [103], the commercial wearable existing products were classified under three categories: 1) Accessories, 2) E-Textiles, and 3) E-Patches. A summary of commercial products and research prototypes are surveyed.

Medical sensors operating in PMS might have varying principles depending on factors like photoelectric, hall, and piezoelectric effects. The sensors attain the physiological parameters of the patients and normally consist of sensitive and conversion elements [106]. In the design of wearable devices, the significant issue is based on the sensors that are embedded within the wearable devices. Different types of sensors are used for this purpose such as pulse oximeter, EEG, breathing sensor, heart rate monitor or ECG, respiration rate, movement sensor, EDA, SpO2, and blood pressure [111], [112]. Besides, several historical examples of wearable sensors are provided in [113]. Traditional sensors measured the heart rate alone, where this sign is considered the most important and almost all medical sensor nodes support it, then the photoplethysmography appears to measure the SpO2 besides the heart rate [114]. Chemical and biological materials are integrated with optical systems, microfluidics, electronics, and micro-machines to create wearable technology-comfortable, wireless, battery-operated systems that can provide data on a regular basis [115], [116]. The human body can serve as a transmission channel for wearable devices, or they can connect with one another via a particular transmission medium like Wi-Fi, BLE, Zigbee, and other previously covered communication protocols. They are able to gather, sort, and store the subject's long-term physiological and activity data [117]. In essence, there are two main strategies for implementing wearable technology: using wireless technology and electronic textile solutions, as covered in [92]. Several research works have investigated wearable devices and their applications highlighting their advanced technologies, significance, industrial communities, materials, target analytes, and design issues, see, e.g., [114], [117], [118], [119], [120], [121]. FIGURE 7 presents the most common types of wearable devices.

V. DATA TRANSMISSION AND NETWORKING

A paradigm change has occurred in recent years that makes it possible to virtualize and softwarize networks, or create programmable decentralised networks [122]. By segmenting the network into several communication layers, this can be accomplished. These layers can help mitigate the delay sensitivity of IoT applications by bridging the lengthy propagation distance between the end-user and the cloud centre. As was already indicated, patient data and their physical activity can also be recorded using wearable technology and fitness watches. At the beginning, wearables and sensors are used to collect patient health data, and connected devices exchange data with other devices while transmitting healthcare information. IoT devices that are worn inside the body gather medical data, including blood pressure, glucose levels, pulse rate, ECG, and cholesterol.

It is occasionally possible to perform data preparation, which entails removing noise and missing values. Thus, removing noise from data cleaning results in a higher diagnosis process detection rate. The median studentized residual approach, which thoroughly analyses the relationships within the dataset, can be used to filter out undesirable data. This method leads to improved detection rates in the diagnostic process. Initially, missing data is addressed by replacing them with median values across rows and columns. Subsequently, data normalization is performed to scale values between 0 and 1, reducing complexity in the diagnostic process. This normalization involves adjusting data using various distribution techniques.

It is necessary to send the data that sensors capture from the patient to the closest data collection or processing node. Wireless Body Area Networks (WBANs) are one technology that is helpful for moving data from the sensors to the nearest processing node [123]. WBSNS will be discussed in the next subsection.

A. WIRELESS BODY AREA NETWORKS (WBANs)

Various components work together in the IoT architecture to enable different solutions for the end user. An IoT-enabled network of linked devices that perceive critical data in real-time makes up the PMS-based healthcare application. In particular, PMS makes it possible to regulate end-user applications through analytics, device connectivity, data transfers, and real-time data collecting. WBANs are among the technologies that enable data flow from sensors and drive communication to the closest processing node in an IoT architecture [124]. The most prominent application area of WBAN is PMS [124]. Because WBANs measure physiological activity in humans, which varies more periodically, the application data streams show rather constant rates [39]. The tiny, samrt wireless sensors that make up BANs are in charge of collecting and relaying to carers the vital indicators of a patient [125]. WBAN can be used in transfer the information of the patients into a wide communication ranges. It should be noted that the terms WBAN, WBASN, and WBSN are used interchangeably in the research based on the work context. AThese terms mean the same type of networks which consist of sensor nodes to check and monitor the human physiological conditions of patients through their remotely accessed signals [126]. IEEE standards like IEEE 802.15.6 and IEEE 802.15.4j, which are especially designed for medical WBANs, are used by WBAN. WBANs provide dependable communication, speed, accuracy, and energy efficiency between sensors and actuators placed inside, on top of, or next to the human body. By leveraging different sensors to monitor patient health vitals, WBANs can contribute to reducing healthcare costs and enhancing the quality of care [123]. Broadband access networks (WBANs) facilitate a range of data rates, from ultra-wideband (15.6 Mbps) to narrowband communication (75.9 Kbps). Wireless Local Area Networks (WLANs), Zigbee, Bluetooth, mobile networks, Wireless Personal Area Networks (WPANs), and Wireless Sensor Networks (WSNs) are among the other wireless technologies with which they are compatible.Sensors that are dispersed geographically are typically used in WSNs to observe, record, and monitor environmental and physical variables. They require an infrastructure made up of relatively small nodes, which are the core components of WSN and are grouped in groups ranging from a few tens to hundreds or thousands of nodes. They are used to collectively transfer observed data via the network to a central location. where one or more sensing devices are installed on each node. The network architecture is the second part of WSN. A vast region is covered by a large number of sensor nodes that are then networked together. There is communication between sensor nodes and with a base station [127]. The development of WSN was first motivated by military purposes such as battlefield surveillance. WSNs are used in different fields like industry and medical applications [127]. Note that WSNs and Wireless Body Area Networks (WBANs) share similarities in wireless communication technology but differ in their specific applications. WSNs are designed for broader environmental monitoring and data collection, while WBANs focus on wearable sensors for health monitoring and medical applications, often integrated into clothing or implanted on the body. In healthcare, WBANs play a crucial role in improving patients' quality of life by enabling continuous monitoring and personalized healthcare interventions. Three categories can be used to describe WBAN: beyond-WBAN communication, intra-WBAN communication, and

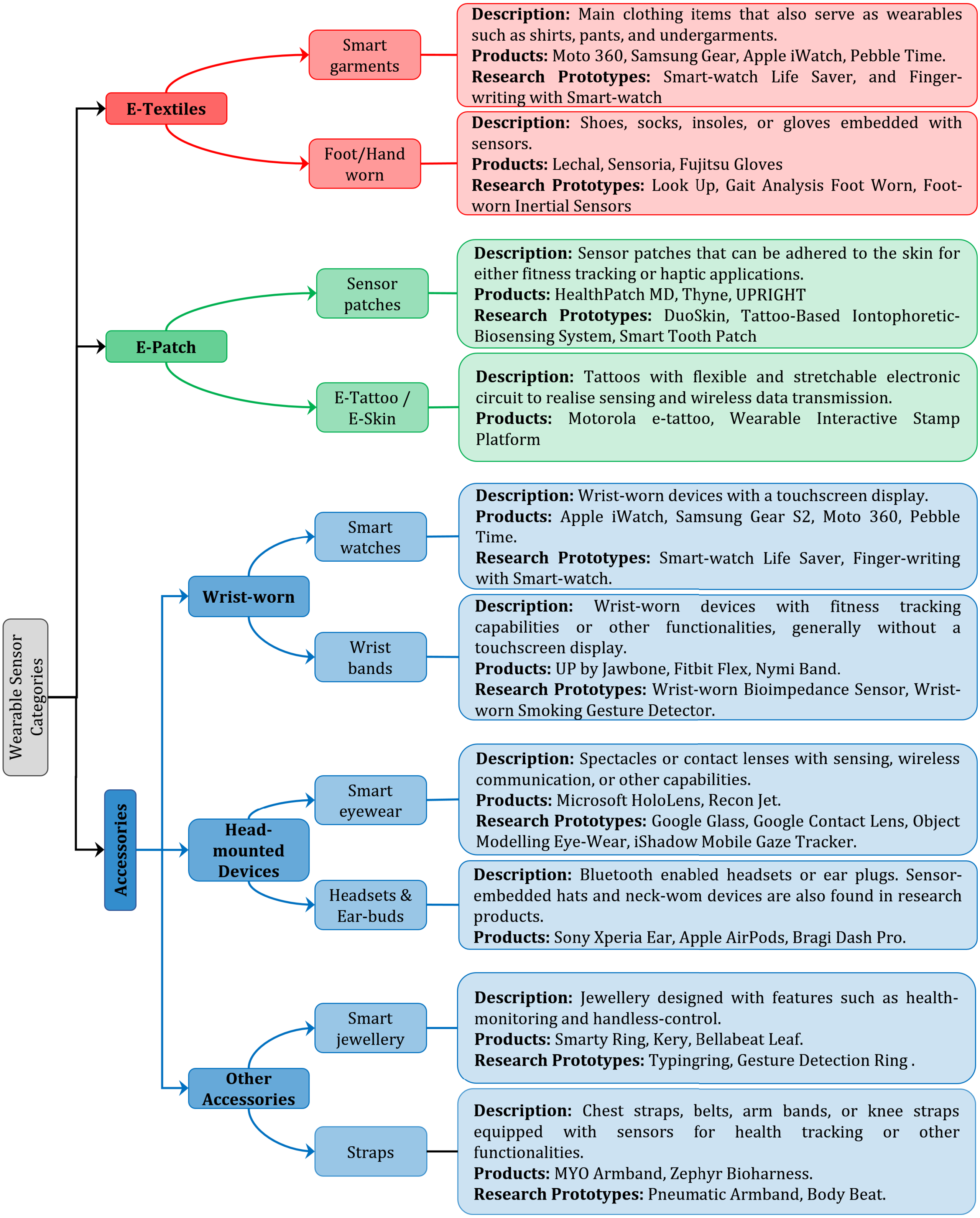

FIGURE 7. Illustration of the the most common types of wearable devices (reproduced from [103]).

inter-WBAN communication [125]. WBANs can be either wearable, i.e., used on the body surface of a human or implantable, i.e., inserted inside the human body [128].

As stated in, a WBAN node is a standalone device with communication capabilities that falls into one of three types according to its capability, implementation, and network role [129]. In terms of functionality, nodes include personal devices, sensors, and actuators. Personal devices gather data from sensors, process it, and can communicate with other devices or individuals through an external gateway or by activating actuators. These personal devices are also referred to as body gateways, sinks, or Body Control Units (BCUs) in certain contexts. Sensors transfer data to the personal device by capturing certain parameters from the human body either internally or outside. Actuators interact with humans based on sensor or personal device data; for example, a physician might send medication instructions via a display actuator after processing sensor data on a personal device. Nodes can be further classified based on implementation into implant nodes, body surface nodes, and external nodes. Based on their network role, nodes are categorized as coordinators, end nodes, or relays. Coordinator nodes act as gateways connecting WBANs to the Internet, and other WBANs, or serving as a central trust point. End nodes are typically sensors without communication capabilities, while relay nodes facilitate message forwarding between sensors and gateways when they are distant. WBSN mainly collects a large amount of real-time data and sends them to the cloud. The cloud, in turn sends and/or saves them in a server and then transmits them to the specialist to be analyzed based on patient statues.

B. COMMUNICATION NETWORKS AND PROTOCOLS

As previously said, PMS is a popular healthcare tool that helps physicians keep an eye on hospitalised patients, elderly individuals receiving home care, and patients with acute or chronic illnesses when they are in remote areas. Wireless network technologies control data transfer and link patient devices and sensors to distant sites. Communication methods such Wi-Fi, Bluetooth, ZigBee, cellular networks 3G/4G/5G, NFC, and satellite are used to convey the patient's signals [130]. By using efficient and reliable wireless networks, the data can be transmitted to several places like the doctors, caregiver. In order to provide data analytics and cloud-based services for biometric data gathered from physical devices and sensors, PMS models may extend big data processing to the cloud. Big data is essential because it facilitates decision-making, data analysis, and the extraction of valuable information [131]. Based on real-time data from connected devices, continuous patient monitoring offers real-time surveillance, feedback, and intervention of patient parameters. The doctor can deal with emergencies cases from a remote location by viewing the patient's report. The integration of intelligent communication technologies that can link diagnostic equipment to distant places has been the subject of some research projects. The appropriateness of every communication technology is contingent upon multiple criteria. These factors are range, data rate, and power consumption [130], [132]. Additionally, the Federal Communications Commission (FCC), a government organisation in charge of overseeing communication technologies in the US, defines sets of standards and guides that can be followed for wireless spectrum, licensing of wireless devices, and ensuring compliance with safety and interference regulations. In the following, we discuss the communication protocols that can be used for PMS.

- Wireless local area networks, or WiFi, are thought to be the most widely utilised wireless technologies in PMS. IEEE 802.11 standards, namely 802.11b-11 Mbps, 802.11g-54 Mbps, 802.11a-54 Mbps, and 802.11n-300 Mbps, provide the foundation of WiFi architecture [133]. WiFi technology allows the devices to access the internet and communicate with each other within a local area range. WiFi technology can operate in bandwidths of 2.4 GHz, 3.5 GHz, and 5 GHz unlicensed Industry, Scientific, and Medical (ISM) frequency bands. WiFi technology is able to support short-range communications with a coverage range of up to 100m. WiFi technology also allows reliable, secure, and high-speed data communications. A network of 45 vital medical devices, including as infusion pumps, defibrillators, lung ventilators, and anaesthesia machines, have been equipped with WiFi technology, demonstrating that WiFi can be utilised safely and successfully for these devices' communication [134].
- Based on IEEE 802.15.4, ZigBee is a wireless personal area network technology. ZigBee is compatible with low data rate networks, which usually require up to 250kbps, because its data rates are far lower than those of other technologies. Long battery life of up to several years is possible using ZigBee [33]. While its power consumption is higher than Bluetooth's, a typical ZigBee transmission range can reach up to 100 metres depending on power output and ambient factors [135]. This distance can be extended up to 1,600m with ZigBee-Pro. Every Zigbee network consists of three types of devices, which are coordinator, router, and end-device [120]. Keys for 128-bit symmetric encryption protect ZigBee networks. It features one channel in the 868MHz Europe band, ten in the 915MHz Australia and US bands, and sixteen in the 2.4GHz ISM band. Moreover, a mesh network architecture utilising ZigBee wireless technology enables higher coverage range and high-reliability communication.
- Bluetooth technology is a wireless personal area network named after King Harald Bluetooth who unified Denmark and Norway and embodies the concept of connecting diverse devices wirelessly. Originally developed by Ericsson in 1994, Bluetooth is based on the IEEE 802.15.1 standard, which is widely used for linking IoT devices, smartphones, and other mobile devices. Bluetooth operates in the 2.4-2.4835 GHz [136] unlicensed ISM band using frequency-hopping spread spectrum (FHSS) and provides a data rate of up to 721 kbps [137]. Bluetooth allows a lower transmission coverage with a coverage distance of up to 100m. Bluetooth is typically used for portable personal devices and to connect between medical devices, sensors, and

smartphones or tablets used by healthcare providers. Bluetooth-enabled devices can transmit vital signs, such as heart rate, blood pressure, and oxygen saturation, directly to monitoring systems, enabling real-time data collection and analysis. Furthermore, Bluetooth is optimised for use in loud situations, covering both the MAC layer and physical access.

- Z-Wave is a low-power and cost-effective wireless communication technology suitable for short-range applications, particularly in residential and light commercial settings [138]. With a data rate of up to 40 kbps and a coverage distance of about 30m, Z-Wave supports mesh networking, making it suitable for use in PMS. In Australia and North America, Z-Wave uses the 900MHz unlicensed radio frequency range for its operations, providing extended coverage and lower power consumption compared to higher frequency bands like 2.4GHz [139]. Z-Wave immunity to Wi-Fi interference ensures reliable communication alongside other wireless devices, offering a standardized and stable control medium for smart home automation and potentially for WBANs in healthcare applications [126]. Its ability to penetrate walls and solid objects makes Z-Wave a compelling choice for deploying sensors and monitoring devices within healthcare environments, supporting efficient and seamless patient monitoring capabilities.
- IPv6 over low-power Wireless Personal Area Networks is referred to as 6LoWPAN. This networking technology makes it possible for IPv6 packets to travel via short link-layer frames, as those outlined in IEEE 802.15.4, with efficiency. Initially, IEEE 802.15.4 low-power wireless networks operating in the 2.4 GHz range were intended to be supported by 6LoWPAN. Currently, 6LoWPAN is being deployed over low-power RF at sub-1 GHz, among other networking media. Strong AES-128 link layer security as outlined in IEEE 802.15.4 is leveraged by 6LoWPAN. Because of these features, the technology is perfect for a variety of sectors, including smart metering, residential illumination, street light monitoring and control, home automation using sensors and actuators, and general Internet of things applications involving Internet-connected devices. Depending on the benefits of IEEE 802.15.4, which include support for a vast mesh network topology, reliable communication, and extremely low power consumption, 2.4 GHz and sub-1 GHz bands are typically employed. Depending on the frequency, the 802.15.4 standard offers data speeds ranging from 20 to 250 kbps. 6LoWPAN works well over short distances, up to 100 metres. 6LoWPAN allows sensors and local devices to be connected to IP networks in healthcare systems, enabling the connectivity of several sensors [140], [141].
- EnOcean is an energy-harvesting wireless sensor technology that finds applications across diverse sectors including building automation, transportation, environmental monitoring, and health monitoring. It operates without batteries by harnessing energy from ambient sources like light, motion, or pressure, converting them into electrical energy for use in wireless communication. EnOcean devices are designed to be ultra-low power, utilizing micro energy converters and efficient electronics to enable wireless connectivity among sensors, switches, controllers, and gateways. This technology, ratified as an international wireless standard (ISO/IEC 14543-3-10), offers significant advantages in terms of energy efficiency and maintenance-free operation. EnOcean can contribute to the PMS by enabling wireless and battery-less sensors and switches for building, home, or industrial automation applications [60]. EnOcean technology allows a long communication range of up to 300m and low-power consumption, and hence, makes this technology suitable for deploying sensors in various healthcare settings without the need for frequent battery replacements, thus reducing operational costs and simplifying maintenance tasks [142]. EnOcean devices operate at the following transmission frequencies: 902 MHz, 928.35 MHz, 868.3 MHz, and 315 MHz. EnOcean is capable of up to 125 kbps of data rate.
- The bi-directional radio frequency identification system known as radio-frequency identification (RFID) technology comprises of a tag and reader that can be interfaced with personal computers or handheld computers [143], [144]. RFID automatically recognises and tracks tags affixed to items or people using electromagnetic waves. The tag is made up of two parts: an antenna that allows the chip to use radio waves to connect with the tag reader and a chip that stores the object's unique identity. By using the tag's reflected radio waves, the tag reader creates a radio frequency field that allows objects to be identified [130]. RFID makes it easier to follow a patient's movements in real time within a medical facility. RFID adheres to the EPC (electronic product code) standard. RFID is compatible with Wi-Fi and ZigBee, among other technologies. RFID can detect objects within a range of 10 cm to 200 m and operates across a broad range of frequency bands, from 120 kHz to 10 GHz. RFID can help improve inventory control by monitoring the location and use of medical equipment and supplies. RFID technology can deliver up to 4 Mbps of data rate. Because RFID technology enables asset management and patient monitoring capabilities, it is essential to healthcare systems.
- ONE-NET is an open-source wireless networking standard designed specifically for low-power and low-cost control networks, such as those used in sensor applications, home automation, security, and monitoring. Since ONE-NET is not dependent on any particular hardware, it can be built with a variety of commercially available microcontrollers and radio transceivers from companies

including Silicon Labs, Freescale, and Texas Instruments. ONE-NET uses Wideband FSK modulation and operates in frequencies including 433 MHz, 868 MHz, 915 MHz, and 2400 MHz. It can support data rates ranging from 38.4 kb/s to 230 kb/s. With ranges of up to 100 metres indoors and 500 metres outdoors, its adaptable network topologies-peer-to-peer, star, and multi-hop-enable effective connectivity and communication coverage across indoor and outdoor situations. Because of its exceptional low power consumption, this technology can be used in battery-operated gadgets that have a five-year battery life when using AA or AAA Alkaline batteries. Furthermore, ONE-NET integrates strong security protocols, using the expanded tiny encryption algorithm to protect confidentiality and integrity of data in wireless networks [145]. ONE-NET can provide dependable and affordable wireless connectivity for sensors and devices in patient monitoring systems. It provides scalability, energy efficiency, and secure data transmission, improving the capacity for remote patient monitoring in healthcare settings.

- Long Range Wide Area Network (LoRaWAN) is a wireless communication technology well-suited for healthcare systems, particularly in patient monitoring applications. LoRaWAN enables long-range, low-power communication between sensors and gateways, making it ideal for collecting data from remote or distributed patient monitoring devices [146]. LoRaWAN technology supports secure and reliable transmission of vital signs and health data, such as heart rate, blood pressure, oxygen saturation, and body temperature, from patients to healthcare providers or central monitoring stations. LoRaWAN is considered as a robust and scalable transmission technique, which allows for the deployment of sensor nodes in various healthcare settings, including hospitals, nursing homes, and even patients' homes, ensuring continuous and real-time monitoring without the need for frequent battery replacements. By exploiting LoRaWAN technology, healthcare systems can enhance patient care by enabling proactive interventions, timely alerts for critical conditions, and overall improved patient care systems through remote monitoring and management.
- Devices can communicate with one another across a few centimetres' distance thanks to near field communication (NFC), a short-range wireless communication technique [147]. The foundation of NFC is Radio Frequency Identification (RFID) technology, which uses electromagnetic fields to wirelessly transfer data between devices when they are positioned in close proximity to one another. NFC allows for seamless and secure communication between devices in close proximity, making it suitable for healthcare scenarios where quick data exchange and authentication are crucial. Numerous uses are made possible by NFC technology, including contactless payments, access control, and device-to-device data sharing [148]. NFC makes it simple to pair medical devices with smartphones or tablets in PMS, giving medical professionals effective access to real-time patient data.
- Medical Implant Communication Service (MICS) is a specialized wireless communication standard designed for medical implants and devices used in healthcare systems, particularly in patient monitoring applications. MICS operates in the frequency range of 402-405 MHz and enables reliable, low-power communication between medical implants and external devices such as wearable monitors or bedside receivers. MICS ensures secure and efficient communication, allowing healthcare providers to remotely monitor patients' vital signs and device status without the need for invasive procedures or physical connections. Sensor signals can be collected using the MICS band, and data can then be sent to a distant station. This process enables multiple patients to have long-range monitoring at the same time [149].
- Ultra-Wideband (UWB), also known as IEEE 802.15.3a, is a low-power, high-precision wireless communication technology that uses a broad spectrum of frequencies to send data over short distances (about 10 metres) with minimal power consumption. UWB is used in real-time applications in RF-sensitive applications, such as hospitals, and is also used for precise positioning, asset tracking, and short-range data transmission. UWB has been wildly used for healthcare systems with short-distance communication [150], [151], [152], [153]. UWB can achieve a data rate from 20 Mbps up to 1.3 Gbps. UWB is suitable for the physical layer of high data rate PANs.
- IEEE 802.15.6 is standard that is designed for WBANs, has become widely adopted across medical and non-medical wearable devices for communication. This wireless communication standard enables direct sensor-to-device communication, alleviating the need for intermediate relaying or routing devices, which enhances efficiency and reduces complexity in data acquisition processes [154]. With aid of a variety of data rates, low power consumption, and the ability to connect up to 256 wireless devices within a single WBAN, IEEE 802.15.6 effectively meets the communication requirements of wearable devices. With its ability to operate in the Narrow Band, Ultra-Wide Band, and 2.3 GHz to 2.4 GHz frequency bands, this standard supports a wide range of WBAN applications. IEEE 802.15.6 remains highly appealing for wearable and body-worn medical devices, particularly due to its suitability for short-range, low-power, and cost-effective communication services both within and around the human body. This wireless communication standard may allow a significant advancement in facilitating reliable and efficient communication for PMS.

- Sensium is an innovative low-power on-body technology designed for continuous patient health monitoring [155]. Sensium can wirelessly transmit vital sign information to smartphones, mobile phones, laptops, or PCs, allowing seamless communication with medical entities such as doctors or paramedical staff for timely intervention. Sensium sensors operate efficiently by activating only during designated time slots to transmit data, conserving energy through periods of inactivity [126]. This technology has gained widespread adoption as a leading patient health monitoring system, exemplified by its practical application in PMS during the COVID-19 pandemic. The use of Sensium patches, as depicted in the accompanying image, highlights the significance of wearable WBAN devices for remote patient monitoring, underscoring their role in facilitating effective healthcare delivery outside traditional clinical settings [156]. Sensium represents a promising solution for PMS, offering real-time data transmission and enabling proactive healthcare interventions based on continuous monitoring of vital signs.
- RuBee is a wireless protocol considered as an alternative to RFID, utilizing long wave magnetic signals instead of traditional radio frequency signals to transmit and receive data within local networks [60]. RuBee is a low-frequency (131 kHz) device that offers notable power efficiency advantages. It can run on a single lithium button cell battery for up to fifteen years. RuBee is designed based on standard of IEEE 1902.1, emphasizes high security and robustness in harsh environments, offering advantages over RFID in terms of signal reliability and penetration through materials like steel and liquid [60]. Despite its lower data rate compared to technologies like WiFi, Bluetooth, and ZigBee, RuBee's unique characteristics make it well-suited for applications requiring long-lasting, secure, and interference-resistant wireless communication. RuBee represents a robust and reliable technology for specific use cases, particularly in challenging environments where traditional wireless technologies may struggle to perform effectively [157], [158].
- Cellular networks offer a direct and promising avenue for smart wearable WBAN devices to connect without the need for additional bridging mechanisms. While previous network technologies were more oriented toward human communication, they encountered significant challenges when applied to wearable WBAN devices, particularly as applications evolve from basic vital sign monitoring to advanced virtual or augmented reality experiences [159]. These advanced applications demand high data rates in the gigabits per second (Gbps) range, a feat currently supported only by technologies like 802.11ac with a 1Gbps data rate. Cellular networks may involve 2G-Global System for Mobile communication (GSM), Code Division Multiple Access (CDMA), 3G-Universal Mobile Telecommunications System (UMTS), CDMA2000, 4G-Long Term Evolution (LTE-A), and 5G. Due to the imperative of low energy consumption, cellular wireless technology has not yet seen widespread adoption in wearable WBAN devices. However, there is optimism for the future development of cellular technologies that are more suitable for wearable and body-worn WBAN applications, potentially enabling a broader range of advanced healthcare and entertainment experiences on wearable devices. Such cellular networks enable voice and data communication over long distances. Satellite communication could also be used to provide coverage in remote areas or to extend the reach of cellular networks.

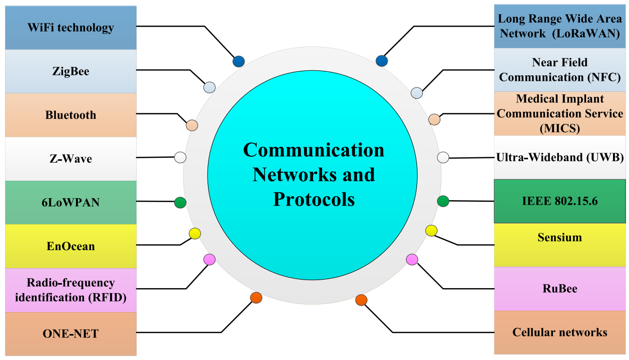

FIGURE 8. The most common types of communication protocols that are used for PMS in healthcare systems.

FIGURE 8 summarizes the most common communication protocols, which can be used for PMS. Table 2 demonstrates the key features of the most common types of communication protocols.

VI. CLOUD COMPUTING AND DISTRIBUTED COMPUTING

Connecting a multitude of physical objects, such as humans, animals, smartphones, and PCs equipped with sensors, and linking them to the Internet generates vast amounts of data known as "big data." Such a big data scale necessitates smart and efficient storage, processing, and retrieval mechanisms. However, traditional hardware and software tools often struggle to handle such immense data volumes within acceptable time slots. In order to accomplish this, the US National Institute of Standards and Technology (NIST) invented cloud computing, which offers a shared programmable network of networks, servers, storage, applications, and services that can be accessed on demand. A longer explanation of cloud computing can be found in the next subsection.

A. CLOUD COMPUTING

A revolutionary concept known as "cloud computing" makes it possible to lease computing resources in real time, such as processing power, storage, and networking, without requiring upfront commitments from customers [123], [160]. With cloud services, people can reliably and economically use and maintain resources from a distance [161].

TABLE 2. Summary of the key features of the most common types of communication protocols.

CP	Standard	Data rate	Spectrum	Data range	Topology	Benefits	Cost
RFID	ISO 18000 6c EPC Class 1 Gen2	424 kbps	135 kHz 13.56 MHz 866-960 MHz 2.4 Ghz	>50 cm >50 cm >3 m >1.5 m	Point to-point Tags and Reader	Non-line-of-sight, Faster rates, durability, improved tracking, enhanced security, and versatility	High
NFC	ISO 14443 ECMA-340 NFC Forum Specifications	100 kbps - 10 Mbps	2.45 GHz	<10 cm	point-to-point	Simple and Secure, Short Range, Versatility	High
ZigBee	IEEE 802.15.4	40 - 250 Kbps	868/915 MHz 2.45 GHz	10-20 m	Mesh, star, and cluster tree	Low power and low cost, reliability, scalability	Low
Bluetooth	IEEE 802.15.1	1 - 24 Mbps	2.4 GHz	8-10 m	Piconet	Convenience	Low
UWB	IEEE 802.15.4z	50 Mbps	Wide range	30 m	Point-to-point and multi-point	High data rates, low power consumption, low latency, Strong Resistance to Interference, and Secure communication	High
WiFi	IEEE 802.11 a/b/c/d/g/n	1 Mbps - 6.75 Gbps	5-60 GHz	20-100 m	Star and point-to-point	Speed, flexibility	High

For healthcare applications based on IoT, which involves numerous embedded devices like sensors and actuators generating big data, cloud computing emerges as an ideal solution for storing and processing this data efficiently. Cloud computing offers a robust platform for storing, managing, and analyzing vast volumes of healthcare data produced by IoT devices [162], [163], [164]. Cloud infrastructure offers the scalability and computational power needed to manage and analyze big data generated by IoT devices, facilitating complex computations to extract actionable insights [165]. Cloud computing utilizes computing resources, networking capabilities, storage, and other essential elements critical for operational efficiency without requiring substantial capital investments. This technology provides rapid elasticity, self-healing, self-configuration, and ubiquitous access, offering significant benefits. Cloud services offer the illusion of infinite computing resources on demand, delivering various services such as Infrastructure as a Service (IaaS), Platform as a Service (PaaS), Database-as-a-Service (DBaaS) and Software as a Service (SaaS). Both public and private clouds can be efficiently used where the public is accessible to the general public and private clouds are dedicated to single organizations, while hybrid solutions integrate both models. Cloud computing in the healthcare sector presents compelling opportunities to contain integration costs, optimize resources, simplify processes, and enhance service quality [166], [167], [168]. Cloud computing serves as a foundational technology for the IoT, enabling efficient processing and analysis of vast amounts of sensor-generated data within the IoT architecture. With the use of cloud based technologies, healthcare systems can address the challenges posed by increasing digital data, improve service outcomes for patients, and streamline health information management. The adoption of cloud computing in healthcare, often referred to as Healthcare as a Service (HaaS) [169], is considered to revolutionize health information technology, benefiting healthcare research and service delivery.

Cloud computing offers a valuable infrastructure for storing and managing patient medical data efficiently, especially given the volume of data generated per patient, which can overwhelm traditional storage systems. The use of cloud-based solutions helps address the challenges of handling large-scale healthcare data by leveraging technologies like big data analytics to extract valuable insights and present information in a more accessible format for healthcare professionals [131]. This approach not only improves data management and accessibility but also supports advanced analytics, facilitating more informed decision-making and enhancing patient care. By utilizing cloud-based infrastructure, healthcare providers can efficiently manage and analyze vast amounts of patient data, ultimately leading to improved patient monitoring and personalized treatment strategies. The cloud also act as on on-demand service that is very cost-efficient solution to medical services [22].

Cloud computing offers virtually limitless storage and computing resources in data centers, empowering healthcare stakeholders to derive valuable insights from analyzed and stored data. Physicians can remotely monitor patient health status using data collected from various sensors stored in the cloud, enabling timely interventions and treatment recommendations. Despite its advantages, cloud computing introduces latency challenges due to data transmission over the internet for analysis and retrieval, which may not be suitable for emergency healthcare services. To address latency issues, distributed computing such as fog/edge computing is emerging as complementary solutions in IoT healthcare applications, optimizing data processing and response times at the network edge. The work in [170] presented a net architecture for resource preservation that combines cloud and edge computing, with an emphasis on maximising important performance metrics like average patient waiting time, length of stay for patients, and resource utilisation rate. This framework emphasizes high reliability, efficiency, and security in healthcare systems. By leveraging cloud and edge computing capabilities, the proposed framework aims to model and optimize critical metrics to enhance overall system performance and patient outcomes. The integration of cloud and edge computing allows for efficient resource utilization, improved patient management, and enhanced security measures, contributing to the development of more reliable and effective healthcare systems. Through their work, Oueida et al. highlight the potential of cloud-edge integration in addressing key challenges and optimizing healthcare operations, paving the way for advanced frameworks that prioritize performance, reliability, and security in healthcare environments. In the following subsection, we will discuss fog computing and mobile edge computing (MEC).

B. DISTRIBUTED COMPUTING

Traditional cloud-centric architectures provide a number of issues that call for distributed computing paradigms like fog computing and MEC, especially in the context of healthcare applications. Using centralised cloud resources grows more and more wasteful as the amount of data produced by IoT sensors and devices keeps growing. In particular, conventional cloud architectures may struggle to meet the latency requirements of real-time healthcare applications, where rapid data processing and response times are essential for PMS. Furthermore, the geographic distribution of healthcare services and the expansion of IoT devices raise the demand for enabling distributed computing solutions that can bring computation and data storage closer to the point of data generation. Fog computing and MEC offer decentralized approaches that enable faster data processing, reduced latency, improved scalability, and enhanced privacy and security for healthcare applications [39]. These distributed computing models facilitate efficient utilization of resources, optimize network bandwidth, and support seamless integration with existing healthcare infrastructure, ultimately enhancing the performance and reliability of healthcare systems.

Fog computing has recently been proposed by Cisco [171], [172]. Fog computing, sometimes referred to as cloudlet or edge computing, serves as a link between smart devices and extensive cloud computing and storage services. [130]. Fog computing can be implemented in gateways or edge devices, allowing for real-time data processing, local decision-making, and faster response times. By processing data nearer the site of data production within the network edge, fog computing expands on the idea of cloud computing. This local processing approach reduces data traffic, distance, and latency, which is crucial in latency-sensitive healthcare applications. At the network edge, data is initially gathered through an IoT network and then processed locally using edge devices. Once local processing is complete, the data is forwarded to the cloud for further computational operations and memory storage. Fog computing can utilize various communication protocols such as Wi-Fi, Zigbee, Bluetooth, and many other communication protocols. By enabling customisable decentralised networks, fog computing can help to manage and process data at the network's edge more effectively. For delay-sensitive applications like PMS, where real-time data processing and minimal latency are essential for efficient operation, fog computing is very helpful. Healthcare systems rely heavily on fog computing because it provides substantial benefits for real-time data processing [173], [174], [175]. Data processing may now be done close to sensors thanks to fog computing, which frees it from the cloud. Fog computing specifically makes use of sensors, network gateways, or local nodes to store and perform initial data processing. This would enable doctors and other clinicians to deliver emergency medical care and would allow for a significant reduction in latency.

Data storage within fog nodes allows for data replication or segregation, and security features ensure data confidentiality, integrity, and privacy. Fog computing defines the functionality of edge computing and makes processing, storage, and networking between end devices and cloud data centres easier. It operates at the perception and networking layers of the Internet of Things architecture. Fog nodes empower end-user devices to collaborate in tasks involving storage, management, and network communication, reducing latency by executing these tasks near or at the end user's location. Similar to the cloud, a fog server can store various content types, including health data, videos, audio, and local information like maps and nearby restaurant availability [176]. This architecture, depicted in typical fog computing diagrams, is well-suited for IoT applications, where the proliferation of communication-capable objects and smart devices demands efficient processing at the network's edge. Fog computing enables higher service rates, and better Quality of Service (QoS), and reduces the burden on the cloud, making it an ideal solution for IT convergence scenarios [176].

Fog computing offers several distinctive features that enhance its utility within IoT systems. Positioned between smart objects and cloud data centers, fog resources significantly improve delay performance by reducing the distance data must travel. This architecture is characterized by the deployment of numerous "micro" centers closer to end-users, leveraging their cost-effectiveness compared to expansive cloud data centers. As IoT systems scale with increasing end-users, fog computing allows for seamless scalability through the deployment of additional micro fog centers, a feat not feasible with traditional cloud data centers due to cost constraints. Fog computing also ensures resilient and replicated services, supporting a dense array of devices with mobility. With its proximity to end-users, fog resources facilitate real-time interactive services and enable on-the-fly data analysis by aggregating and processing data before forwarding it to cloud data centers for further refinement, demonstrating interoperability with various cloud providers and offering enhanced performance for critical applications. This decentralized approach to computing optimizes efficiency and responsiveness within IoT ecosystems.

A fog node provides network-wide monitoring, preprocessing, storage, and security features. While preprocessing entails fundamental data analysis required for emergency healthcare services, monitoring capabilities allow the node to track resources and services. To optimize computation and energy usage without compromising functionality, models are developed specifically for edge-dependent healthcare sectors. The fog computing approach is an effective technique that integrates agile computing into PMS. This approach involves distributing computations between the cloud and edge devices using a hierarchical structure, leveraging the advantages of both edge and cloud environments for healthcare data analysis from IoT devices [177]. Healthcare applications that require quick response times can be implemented with the help of edge computing integration, and cloud computing offers plenty of processing and memory capacity. Fog computing and the cloud work together to improve performance in the healthcare industry.

The necessary tasks associated with edge computing can be completed using a virtualized software-based platform that leverages software-defined networks (SDN) and network functions virtualization (NFV) to provide a flexible, scalable, and effective network architecture [178], [179], [180]. With NFV, a single-edge computing server can offer computing services to several mobile devices. This is accomplished by building various virtual computers with the capacity to perform numerous activities at once. Furthermore, network function virtualization (NFV) has promise for managing computer services and improving the scalability, flexibility, and dependability of network services [179].

Mobile edge computing (MEC) is considered a key technology in the 5G network and is defined as an essential form of edge computing, which operates at the edge of cellular networks, enabling rapid processing of large datasets upon reception [181], [182]. MEC involves decentralizing service-specific processing, computing, and data storage from the centralized cloud core network to edge network nodes situated near data sources and end-users [172], [183]. Pushing mobile computing, network control, and storage to the network edges (base stations and access points, for example) is the primary function of MEC. This allows resource-constrained mobile devices to run computation-intensive and latency-critical applications [122]. By hosting compute-intensive apps, handling massive amounts of data before transferring it to the cloud, delivering cloud computing capabilities inside the radio access network (RAN) near mobile users, and providing context-aware services, MEC can maximise the use of mobile resources [184]. MEC has shown to have enormous potential for improving healthcare systems' performance, allowing mobile PMS in those systems. The MEC can provide a number of higher-level functions in these systems, including embedded data mining, local storage, real-time local data processing, and data transfer control [185].

By leveraging a network of servers, MEC can offload intensive computation tasks, contributing to ultra-reliable low-latency communication (URLLC), and traffic optimization [122], [183]. Implementing MEC in PMS promises significant benefits, including increased network capacity, efficient handling of delay-sensitive tasks, and offloading of network-intensive computations to reduce energy consumption and prolong battery life in the devices [186]. MEC plays a vital role in enhancing network capabilities, optimizing services, managing energy and resources efficiently, and reducing the burden on backhaul infrastructure [182]. By providing real-time data processing and analytics at the network edge, MEC integration with PMS may increase overall efficiency in healthcare applications by reducing latency and enabling faster response times.

MEC represents a significant advancement in addressing the challenges associated with managing remote devices, particularly concerning security, reliability, latency, and energy efficiency issues in healthcare systems. Recent research on EdgeCare presented in [187], emphasizes the importance of security in mobile healthcare systems. With strong security features integrated, EdgeCare offers a safe and effective data management solution that handles medical data and enables data trading at edge servers. Similarly, The work in [170] proposed BodyEdge, which introduces innovative body healthcare architectures featuring tiny mobile client modules and edge gateways. The proposed architectures enable the collection and local processing of data from various scenarios, focusing on improving latency and reliability performance within healthcare applications. Additionally, the work in [188] has implemented accurate and lightweight classification mechanisms using edge computing to detect seizures at the network edge based on vital sign information. The research findings demonstrate substantial performance improvements over conventional non-MEC remote monitoring systems, achieving high classification accuracy for seizures, extending battery life, and significantly reducing transmission delays. Through initiatives like EdgeCare and BodyEdge, MEC demonstrates its potential to revolutionize data management and processing, offering secure, efficient, and reliable solutions at the network edge. These advancements highlight the transformative impact of MEC in enabling real-time data processing, reducing latency, and improving overall system responsiveness. As researchers continue to explore the potential of MEC, incorporating security considerations and innovative architectures, the field is poised to advance further, addressing critical challenges in remote device management and facilitating the development of advanced applications with enhanced performance and reliability.

The MEC network can dynamically handle various services thanks to SDN. Additionally, it could separate the control and data planes [189], [190]. For an edge computing network, SDN can offer a logically centralised control platform [191]. By using such a centralised control platform, the network's scalability problem could be addressed, optimal resource allocation could be achieved, overhead could be decreased, dependability could be increased, and most crucially, latency could be decreased.

VII. APPLICATION LAYER AND PMS BENEFITS

The application/action layer in PMS serves as the central hub, typically represented by the medical server. Currently, most IoT services have application and user interfaces. This layer plays a pivotal role in processing and presenting data generated by IoT devices to healthcare providers or integrating it seamlessly into electronic health records (EHR) systems. This layer provides data control services. It can mostly be affected by the type of data traveling through the IoT network [133]. Within this layer, various functionalities are enabled to support visualization, alerts, and decision-making tools for clinicians. Moreover, the application layer extends beyond mere data presentation, incorporating advanced features like self-management, active assisted living (AAL), behavioral analysis, big data analytics, emergency detection, disease prevention strategies, and mobile health (m-Health) initiatives [68]. These aspects collectively enhance the system's capability to provide efficient healthcare services.

Through the application layer, clinicians gain access to intuitive interfaces that facilitate real-time visualization of patient data and enable timely intervention when abnormalities or critical events are detected. This layer also fosters proactive healthcare management through the implementation of self-management tools, empowering patients to monitor and manage their conditions effectively. Additionally, the integration of big data analytics within this layer enables deep insights into patient trends and population health, facilitating targeted interventions and personalized care strategies. Furthermore, the integration of emergency detection and disease prevention mechanisms underscores the proactive nature of modern patient monitoring systems, aiming to mitigate risks and enhance overall patient outcomes. This convergence of technologies underpins the evolution of electronic health (e-Health) and m-Health paradigms [69], reshaping the landscape of healthcare delivery towards more connected, data-driven, and patient-centric models.

The essential task of PMS is to monitor patients in different places such as home, office, hospital, battlefield, and other places. Using PMS can prevent transmissible and infectious diseases, keep the patient's life safer, and provide quick diagnostics and treatment in addition to other health assistance tools. In addition, the economic cost, morbidity, and mortality associated with human beings have been reduced using remote PMS, which appears as a promising solution and can succeed on a large scale. Furthermore, one key area where PMS proves invaluable is in hospital environments. In such environments monitoring patient's vital signs can improve patient safety and enable early detection of deteriorating conditions. In intensive care units (ICUs), PMS plays a crucial role in providing real-time data to healthcare providers, facilitating prompt interventions, and improving patient outcomes. Beyond hospitals, PMS extends its utility to home care settings, allowing patients with chronic illnesses or post-surgery recovery needs to be monitored remotely. This remote monitoring capability promotes patient independence while providing clinicians with vital data for timely interventions. Moreover, PMS aids in the management of elderly patients, ensuring their well-being by tracking vital signs and detecting emergencies. Nurses can benefit significantly from PMS to monitor patients remotely, allowing for proactive interventions and reducing the need for frequent clinic visits. This approach not only improves patient comfort but also optimizes healthcare resource utilization. In emergency situations, PMS enables real-time monitoring of critical patient data, providing crucial information to emergency medical personnel before arrival at the hospital. This capability enhances triage and treatment decisions, potentially saving lives. Additionally, PMS plays a vital role in ensuring the security and integrity of medical data. By employing robust data encryption and secure transmission protocols, PMS can allow safe sensitive health information against unauthorized access or breaches. This aspect is critical in maintaining patient confidentiality and compliance with data protection regulations. Furthermore, PMS supports seamless integration with EHRs, enabling healthcare providers to access comprehensive patient histories and monitor trends over time. This accessibility enhances clinical decision-making and fosters continuity of care across different healthcare settings, ultimately improving healthcare systems.

PMS plays a vital role in ambient assisted living (AAL) environments by enabling continuous remote monitoring of individuals with chronic illnesses or disabilities. In AAL settings, PMS empowers individuals to live independently while providing caregivers and healthcare professionals with real-time data on vital signs and activities. This proactive monitoring allows for early detection of health issues or emergencies, enhancing overall safety and well-being within the home environment. PMS in AAL environments facilitates personalized care plans based on individual health trends and alerts caregivers to potential concerns promptly. By integrating with smart home systems and wearable devices, PMS supports seamless data collection and analysis, contributing to improved health outcomes and quality of life for individuals. Applications for AAL track and assess a range of fundamental daily tasks, such eating, and cleaning. They give the subject suitable assistance involving carers and permit the subject to live independently. Fall detection and movement monitoring systems identify ambulatory behaviours such as unintentional falls, static postures, dynamic activities, and location tracking. Real-time applications are used by physiological PMS to monitor and diagnose vital signs in dependent and chronically unwell people, including those with diabetes, hypertension, and cardiovascular disorders [73].

VIII. RELATED CHALLENGES AND FUTURE RESEARCH DIRECTIONS IN PMS BASED ON IoT IN HEALTHCARE SYSTEMS

Despite the numerous benefits offered by PMS, which were discussed above, there remain several significant challenges that need to be addressed. One key challenge is related to data confidentially, as PMS deals with sensitive medical information that must be protected. Ensuring the confidentiality, integrity, and availability of patient data in PMS is crucial but can be complex due to evolving cybersecurity threats. Several works have been proposed to address this issue in the healthcare domain and PMS networks, see, e.g., [192], [193], [194].

Noting that the interoperability is considered as critical challenge in integrating new IoT-based PMSs with existing healthcare infrastructures, as healthcare facilities often use a variety of monitoring devices that may not seamlessly communicate with each other. As IoT devices generate vast amounts of real-time health data, seamless communication and data exchange between these devices and traditional health systems become essential. However, the lack of standardized protocols and varying data formats across different platforms create significant barriers. Ensuring that IoT-based PMSs can effectively communicate with EHRs and other legacy systems requires overcoming these interoperability issues, which is vital for obtaining an efficient healthcare system.

Furthermore, the implementation of PMS systems in healthcare presents several significant challenges that must be carefully investigated in future to ensure the successful implementation of PMS in healthcare system. The issues of informed consent and ethical considerations need to considered. To this end, patients must be thoroughly informed about how their health data will be collected, used, and protected, emphasizing the importance of maintaining their autonomy and privacy. This transparency is crucial to build trust between patients and healthcare providers. In addition, integrating PMS systems into existing healthcare workflows requires substantial changes in how hospital staff operate. This transition often demands extensive training and adaptation. The challenge is to seamlessly incorporate PMS technologies without disrupting the delivery of care. Further investigation in this regard is needed. Moreover, the financial aspects cannot be overlooked; the high initial costs associated with implementing PMS systems, coupled with the uncertain landscape of insurance reimbursement, can be significant challenges for healthcare institutions considering adoption. These financial hurdles, along with the need for clear reimbursement policies, add another layer of complexity to the widespread integration of PMS technologies. Healthcare regulators and policymakers need to create clear, consistent reimbursement frameworks for PMS technologies. This includes establishing guidelines that recognize the value of remote monitoring and IoT-based healthcare services, ensuring that these services are reimbursed similarly to traditional in-person care. Besides, educating healthcare providers, patients, and policymakers about the benefits and cost-effectiveness of PMS technologies is essential. Advocacy efforts can help build support for the adoption of these technologies and for the development of reimbursement models that ensure sustainability.

Additionally, scalability and cost-effectiveness pose challenges, particularly for smaller healthcare providers who may struggle to implement and maintain sophisticated PMS solutions. Overcoming these challenges requires concerted efforts in technology development, standardization, and ongoing research works. Moreover, the major components of PMS must be selected carefully. Examples of these components are the types of sensors, processing methods, contact methods, and communication networks. In addition, in large-scale PMS, there is a large amount of data collected from the sensors. In summary, the advancement in wearable devices, which aim to achieve low-cost computing, big storage devices, low power consumption, and the development in communications technologies are paving the way for a low-cost, applicable, and effective PMS. In the following, we provide some of the related challenges in PMS-based IoT in healthcare systems.

- Data and resource management: The IoT-based healthcare systems consist of numerous interconnected devices that generate massive amounts of data, which must be assimilated, stored, and analyzed in order to be analyzed effectively. IoT devices and sensors will generate different types of data; for instance, medical devices generate image data, whereas other devices generate video data. This gives rise to well-known big data issues. High processing power and large data storage capacity are needed to handle this healthcare data. Therefore, PMS based on IoT with healthcare systems will require advanced data-processing mechanisms due to the varying performance requirements for devices and applications. Besides, advanced algorithms for processing the data in edge computing or cloud computing might be helpful in addressing the big data issue. Therefore, further research is needed to investigate data management issues in PMS. Sensor nodes are constrained in terms of store capacity and processing power. Therefore, efficiently managing the resources in PMS PMS-based IoT healthcare systems is essential. Further research regarding the resource management of PMS is required.

- Security and privacy: Due to the critical sensitivity of the data processed in the PMS, it is essential to secure and maintain constant connectivity between medical devices. In addition, patient privacy and security concerns are becoming increasingly important as the number of IoT devices in healthcare systems grows at an exponential rate. In order to handle the plethora of medical assets employed throughout the healthcare system, a number of operational and interoperability difficulties must also be addressed. One such challenge is the integration of varied technologies within the IoT ecosystem. Note that measurement data are gathered from various instruments, sensors, and devices and sent via gateways to an Internet-connected server housing databases. Hence, ensuring reliable communication is essential. Furthermore, security requirements for PMS include availability, confidentiality, integrity, access control, and authentication. These requirements are essential for the medical data shared within hospital networks. Furthermore, as the quantity of IoT devices in healthcare systems increases at an exponential rate, issues about patient privacy and security are becoming more and more significant. Many operational and interoperability challenges need to be resolved in order to manage the abundance of medical assets used across the healthcare system. The IoT ecosystem presents several challenges, one of which is the integration of diverse technologies. Furthermore, the use of wireless technology in healthcare systems without taking security precautions leaves users open to privacy problems. To this end, healthcare providers should consider privacy. Traditional security methods based on existing cryptography solutions face challenges when applied to IoT-based healthcare applications due to resource limitations, specific IoT architecture requirements, and the high-security standards demanded. Physical security, authentication, network security, computer security, and storage security are all included in data security. The utilization of traditional cryptographic approaches becomes impractical within IoT-based healthcare applications. Additionally, IoT gateways often prioritize basic functions over critical security measures like authorization and authentication, highlighting further complexities in ensuring robust security within these systems. We need to design a PMS model that guarantees that only authorized individuals have an access to a patient's medical data. In brief, maintaining security and privacy are essential for PMS, encompassing numerous elements and procedures such as data gathering, communication, sensor and device use. Therefore, to protect sensitive data generated by devices and personal information, advanced technologies are needed. To solve the security and privacy concerns in PMS, more research is required to examine the application of ML and AI approaches.
- Managing heterogeneity in data: Numerous data can be generated by health applications. These data are obtained from a range of heterogeneous sources. Heterogeneity in PMS is mostly encountered in two forms: sensor heterogeneity and data heterogeneity. Multimodal sensors are used to gather data, and they are diverse in terms of organization, format, and meaning. Consequently, datasets are challenging to distribute and reuse since there aren't any official summaries. Despite the efforts has been dedicated to create sensors when describing semantics with data models, it is necessary to standardize the modeling of sensor data to reflect heterogeneous sources of data. Therefore, advanced technologies are required to handle such data heterogeneity. The best possible way to address the data heterogeneity is to make use of advanced artificial intelligence algorithms. Consequently, more study is needed to determine how artificial intelligence and machine learning approaches might be used to manage the variability of PMS data.
- Data integration: Data from multiple sources must be integrated. Scales, social networks, imaging systems, blood pressure monitors, glucose metres, heart rate monitors, fitness equipment, blood oxygen monitors, and many more internet sites are some examples of these sources [195]. Valid and significant results cannot be obtained from the collection of data from diverse sources unless the syntax, structure, and meaning of the sentences are correctly understood. An accurate comprehension can create intelligent applications or a blending procedure. Creating efficient data integration and analytics platforms for clinical decision-making can consolidate disparate data sources into comprehensive and unbiased analyses, offering rapid and insightful solutions that are not achievable through manual processes. Developing such systems for clinical decision support can convert static and offline data-driven guidelines, which are constantly evolving, into dynamic and interactive algorithms accessible online for immediate execution. Integrating patient medical reports into these systems can facilitate the creation of point-of-care decision-making tools. These analytical tools can enhance healthcare response capabilities by enabling epidemic surveillance, geospatial analysis, cluster outbreak reporting, and the development of accurate therapeutic algorithms to address global health challenges, such as pandemics [196]. A heterogeneous network contains a range of sensors with different

sensing techniques or communication spans. Devices from various vendors will be present in a network, and communication between those devices must be guaranteed. Furthermore, interoperability is necessary to ensure that a system can connect to another network that performs different functions. To process the data and make decisions, the data structure must be consistent. Further research investigations to address the aforementioned challenges are required.

- Context-awareness: Applications, interfaces, and services tailored to the user's situation and its changing needs are presented in a relevant, appropriate, and personalised manner by a health context-awareness system. A thorough understanding of a subject's surroundings enables the system to ascertain the subject's actual help needs on the fly. In PMS, obtaining a high-level coherent abstraction of contextual data requires accurate interpretation of data and events. Apart from traditional monitoring methods, it is important to reliably identify emergency scenarios and declines in health. The two main obstacles to the creation of context-aware medical apps are, generally speaking, data acquisition (the amount of information gathered) and data analysis methodologies, which include presenting context-relevant services and information. Context-awareness interpretation and data representation are critical components that impact a health surveillance system's effectiveness. Rapid intervention is made easier by accurate emergency situation identification, which raises the standard of healthcare. Although many current systems fall short of achieving a high degree of contextual awareness, gathering comprehensive and all-encompassing contextual data continues to be a crucial unresolved issue that required further focus. A context-sensitive monitoring system's design must take behavioural, physiological, and environmental factors into account when observing, interpreting, and analysing patient situations. All pertinent context factors, which primarily include place, time, objects, position, frequency, and human activity, must also be considered by the system. System performance is also influenced by historical data, which must be considered. This includes health data (such as diagnoses, illnesses, and treatments), daily behaviour and past changes, and environmental variables (such as humidity and temperature). However, the same context data needs to be accessible across several distribution components that employ various network protocols. This allows different carers to access the contextual data that they require from the infrastructure via the network that is available, which can frequently change in a large setting.
- Power consumption: Another significant challenge that faces sensors in general, particularly in BSN, is energy consumption. The sensors' short battery life may have an adverse effect on the PMS. For monitored subjects, battery replacement and charging in the majority of BAN systems currently in use are inefficient and time-consuming, particularly in architectures with multiple sensors. Any communication device's battery life is typically influenced by its duty cycle, transmission range, and communication channel usage. Sensor nodes can periodically turn On/Off their radio interface with a centrally assigned time slot using the widely used to save energy. Besides, advanced energy harvesting and wireless charging techniques for PMS need to be investigated. Furthermore, low power consumption can also be achieved by applying smart processing algorithms. Consequently, further real-world research is needed to determine how well energy is transferred and harvested in PMS. Additionally, the circuit complexity of the devices may be raised to enable efficient energy harvesting design in PMS. To fully realise the benefits of energy harvesting in PMS, this can also be seen as one of the technological difficulties that need to be resolved.
- Scalability: The healthcare system's scalability is still a problem today. Billions of IoT devices on the network will generate vast amounts of health data. In a similar vein, the amount of data that must be handled and preserved will increase rapidly. This will present a massive data challenge for the healthcare industry. A scalable system is needed to store and analyse this data from IoT devices in order to solve this problem. On the future, data collected from linked IoT devices will need to be stored on the cloud using big data analytics and effective edge computing approaches. Plans for therapy will be improved with the use of this data. In this aspect, more research is necessary. It is imperative that big data analytics be integrated with Internet of Things-based healthcare solutions. Modern medical telematics and informatics have emerged as a result of this convergence, bringing about developments that are highly helpful for PMS sufferers, such as disease diagnosis, remote real-time health monitoring, preventive measures, and medical emergency warning systems. Consequently, further research on big data analytics in the context of healthcare is needed.
- Safety issue: Particularly when carers are absent, PMS should keep offering care services like accident detection and emergency assistance. In a variety of situations, PMS must guarantee the security of participants and carers, including participants with mental illnesses. Simple presence sensors to sophisticated video surveillance systems with real-time alerts and the ability to detect and identify patterns of movement are just a few of the tools that PMS may rely on. Therefore, especially in healthcare facilities, biometric sensors can be utilised to identify aggressive and stressed behaviours. We think that other crucial aspects that must be taken into account are the safety, acceptability, and usability of PMS. Thus, effective video surveillance systems for PMS must be created.

- Data processing: Big data is the massive amount of data generated by a large number of connected IoT devices. Millions of consumer devices have interconnected sensors and actuators that interact, collect, and transmit data. Every gadget generates or detects vast amounts of data that need additional processing. Making sure that these various data types are handled appropriately and effectively will be the main challenge, especially with a limited amount of time, processing power, and computational resources available. It was estimated that by 2020, the amount of data stored would have increased from 80,000 petabytes in 2000 to 35 zettabytes. Due to various data structures, only 20% of these are examined using conventional methods; the remaining 80% are not used in decision-making. It is anticipated that as 6G is evaluated, the amount of data will grow even more. With the aid of artificial intelligence, data-driven techniques can be created to manage big data from numerous IoT devices. Further research investigation is needed.
- Device design issue: The healthcare sector makes use of PMS-based IoT devices, which have tiny sensors, minimal processing power, little storage, and short battery lives. The internet is connected to IoT devices. Wearable technology requires network connectivity in order to offer carers access to health information. Developing IoT devices with more processing power, storage capacity, long battery life, and security that comply with mobility standards remains a research problem to this day. In this area, more research and investigation are needed.
- Monitoring accuracy: Because performing different everyday activities requires a high level of skill, monitoring and evaluating human subjects-especially the elderly-is a challenging endeavour. Subject to subject, the behaviour is arbitrary and varies. The majority of recent research on activity monitoring focuses on short-term, relatively easy tasks that are completed in a lab setting. In the actual world, however, it is evident that managing complicated and long-term tasks in terms of gathering and evaluating pertinent data is more challenging. Activities that involve several subactions can also be completed in various ways and in different sequences. In intelligent homes, long-term monitoring is helpful in identifying actual behavioural patterns. Data related to single-user actions are gathered and processed in an intelligent environment in current research experiments. In actuality, though, several topics can share one space and be completed concurrently with daily tasks. Moreover, the majority of research in this area focuses on activity recognition rather than evaluating the accuracy with which participants carry out these tasks. These issues indicate that the precision and reliability of the outcomes are still somewhat disconnected from the unpredictable and enigmatic real world of human behaviour. We think that further work has to be done to enhance the planning and creation of monitoring systems for senior citizens in intelligent settings. The right sensors must be chosen with care in such systems and solutions in order to collect rich and pertinent data for one or more topics. For the system to successfully comprehend complicated and constantly evolving human behaviour, it must choose the most suitable approaches and strategies. To make sure that these systems are effective in terms of analysis, accuracy, and adaptability to the suggested monitoring, extensive testing is required.
- Trustworthiness: Because healthcare providers utilise data to inform decisions about patient care, data must be thorough, accurate, and consistent in order for it to be considered trustworthy. Specifically, the data produced by sensors and wearable technology is used by carers to inform their decisions and treatment plans. On the other hand, data corruption might result from unapproved exposure and disclosure, which can cause the loss of personal data. Furthermore, malware or viruses could contaminate or corrupt the medical data during transmission. Investigating the dependability of trust management on PMS requires making use of blockchain technology's features, which include integrity, immutability, and trustworthiness. The possible catastrophic repercussions of medical device trustworthiness necessitate prompt and effective resolution of any problems [197]. Traditionally, general-purpose and embedded computer systems have used information security and fault tolerance techniques like cryptography and redundancy. However, because of their significant size and power limitations, they cannot be utilised to many wearable and implantable medical devices [197]. Therefore, creating effective and reliable security methods to ensure trustworthiness is one of the major issues that need to be considered in future research.
- Data transmission delay: A common issue in PMS development is deciding how to transfer sensor data to back-end servers for processing and analysis. Data transmissions in networking are divided into four categories: multicast, broadcast, unicast, and anycast. Multicast or broadcast schemes are frequently used by existing PMS to improve data transmission efficiency and reliability. Both schemes send packets to several recipients at once. As a result, a high volume of network traffic and transmission delay result from frequent transmissions. With the least amount of traffic overhead, the unicast scheme delivers packets to a single recipient; however, additional steps must be taken to locate a backup receiver in the event of a transmission failure. Anycast communication is a brand-new routing protocol the point at which data packets are sent to the closest recipient. This scheme is more dependable than broadcast and multicast and has less traffic overhead. Unicast is used to discover new receivers. But anycast raises the devices' complexity

FIGURE 9. **The research challenges related to PMS in healthcare systems.**

and network routing utilized by the plan. This challenge raises some more general issues. Hence, analyzing the transmission technologies, as well as the quantity of data sent, standard packet size, and transmission frequencies, need to be considered. Therefore, developing new PMS models that take into account the data transmission issue is of interest.

- Availability and reliability: Providing timely access to pertinent health data is another essential challenge for PMS. The dependability of data distribution may have an impact on the accessibility of health information. Numerous factors can affect the reliability of data on wireless networks in health infrastructures. These variables include routing protocols, device or network faults, power availability, network coverage, and device range. Further investigation in this regard is required.

The research challenges presented in this paper can be summarized in FIGURE 9.

IX. CONCLUSION

This paper presented a comprehensive review of PMS in healthcare systems. To this end, an in-depth study of recent trends and the current state-of-the-art research in PMS based on IoT technologies, which are essentially needed to achieve efficient healthcare services, was provided. In particular, this paper provided the effective architecture of PMS and the essential communication technologies that are required for developing a realistic PMS. Moreover, this paper emphasizes the importance and necessity of implementing IoT-based PMS in healthcare systems and discusses different types of current monitoring and tracking systems. The communication networks and protocols that are required to endure efficient healthcare systems were explored. Besides, the key fundamental benefit of PMS has been described. In addition, this report outlined a number of unresolved research issues and suggested fresh lines of inquiry for further investigation. This can benefit both academic and industrial sectors in remote healthcare applications. This paper is essential for understanding the PMS that can be used for enhancing medical services, health management, and response strategies during public health emergencies and routine care scenarios. This paper offered a comprehensive understanding of PMS, which is crucial for business and scholarly academics alike.

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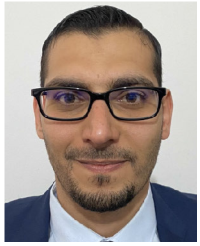

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