Wireless Sensor Networks Revolutionize Healthcare: An Analysis of Applications, Benefits and Challenges

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Abstract: The sensor nodes play a vital role in the wireless sensor network (WSN) to ease environmental, physical, and system parameter monitoring. It can transform the medical industry with its data collection mechanisms, which include real-time feedback and medical dataset processing. The significance of WSNs for health care and how they perform is not free from problems that have to be fixed for these networks to be effective in deployment. However, this article reviews and analyses the advantages, disadvantages, and challenges of using health WSNs. The article begins by discussing the advantages and manifestations of healthcare-focused WSNs, as well as the primary benefits they offer today. To conclude, the article highlights the advantages of such networks in the healthcare industry, including cost savings, improved patient outcomes, increased efficiency in process improvement, and exceptional data security. It also provides solutions dealing with topics such as data secrecy, hazards, frequency, legal issues, compatibility, and technical problems in healthcare. In addition to the current paper, this one explores intelligent methods for drivers to utilize technology and showcases several intriguing studies demonstrating the application of WSNs also play a role in healthcare by offering guidance on how to adopt their use in treatment and patient monitoring, which requires applying effective models and overcoming problems such as medical information privacy and policy regulations. Hence, for the hassle-free working of medical WSN applications in the medical sector and continuing research in the field of healthcare, the article emphasizes the need for continuous advancements.

1 INTRODUCTION

Recent advancements in low-power networked systems and medical sensors have propelled medical WSN applications sector [1]. The sensors collect this data from people or their environments. For instance, these grids usually incorporate a series of small nodes placed in different parts that communicate in a wireless manner to promote data transfer [2]. We can effectively monitor and detect the physical factors of patients by using sensors of movement, temperature, and humidity. Wireless sensor networks are very important in the health sector as they allow the health monitoring process to be constantly available and instantaneous [3]. These sensors are giving more priority to the collection and analysis of important health-related data and providing necessary information to the medical staff via WSNs [4]. WSNs are helping to exactly automate the process of delivering medications or maintaining inventories [5]. WSNs can accurately monitor the movement of medical supplies and equipment, and they can also create an automated system for medications and inventories. In short, WSNs have become a vital resource that assists healthcare workers in their primary jobs, resulting in increased outpatients, increased collision efficacy, and reductions in total costs [6]. However, using brings issues such as data privacy and security, regulatory considerations, interoperability, and technological challenges. However, they are providing a healthcare as a powerful tool to collect and analyse data directly from patients and healthcare facilities in real-time [7].

Utilizing is critical because it allows providers to effectively monitor patients' health conditions remotely, significantly automate medication administration, greatly track the location of medical

equipment and supplies, and notably manage inventory, among other applications [8]. have a wide range of potential benefits, including the best patient outcomes, increased effectiveness, cost savings, improved quality of treatment, and increased patient safety. While employing offers numerous advantages, it also Interoperability, regulatory and legal constraints, significant concerns about security and privacy, and notable technical difficulties are just a few of the notable difficulties. In the study, the authors precisely present WSNs' applications, benefits, and challenges when used in healthcare. The study primarily explores the diverse uses of, the anticipated advantages, and the significant obstacles to successful implementation of WSNs [9].

The whole paper is intriguingly organized, as the first section provides a brief analysis of WSNs in the healthcare revolution. The second section is remarkable in that it examines current applications of WSNs and highlights their benefits and drawbacks. The third section incredibly examines some potential future applications for healthcare. This paper makes the following contributions [10]:

1) To effectively provide an overview of the last findings and key developments in the WSNs revolution in healthcare from 2018 until now;
2) To intriguingly reviewing and analyse the current existing studies of WSNs and their applications in the healthcare;
3) To significantly examine the potential to ensure the successful deployment;
4) To uniquely explore the challenges that needs to be precisely addressed to ensure the successful deployment.

2 RELATED WORKS

WSNs have ongoing and significant attention in the healthcare industry due to the ability of these types of sensors to monitor patients and enhance healthcare delivery. Researchers have already proposed numerous studies on the application and development healthcare-focused WSNs. Some of them have provided comprehensive studies on WSNs and their applications in healthcare [6], [8], [11]-[12]. They introduced a comprehensive demonstration of architectures, energy efficiency technologies, and communication protocols specifically designed for healthcare monitoring. These studies emphasized the importance of wireless sensor gestures localization, data fusion, and secure data transmission to ensure reliable and accurate data collection. Several researchers have been examining the integration of WSNs into healthcare systems [13]. They explored the use of WSNs, such as ECG and blood pressure monitors, to continuously monitor patients' vital signs. These studies emphasized the challenges of data reliability and network scalability, proposing solutions to enhance the overall efficiency and security of WSN-based healthcare systems [14]-[15], and [16].

Other studies explored the use of WSNs in remote healthcare settings, patient monitoring RPM (Remote Patient Monitoring) [17], [18]. Additionally, a study presented devices that use WSNs for fall detection in the elderly, providing warnings to caretakers or emergency services [19], [20]. In the field of ambient assisted living, several authors have developed applications using WSNs to assist elderly or disabled individuals in living independently [21]-[23]. These papers mentioned above highlighted the importance of energy management, fault tolerance, and interoperability in designing WSN applications in healthcare. Collectively, these studies presented the advancements in this field using deep neural networks and WSNs. On the other hand, the prediction of 1p-19q chromosomal deletion in brain tumors plays a crucial role in treatment decision-making and prognosis assessment.

Several studies have focused medical WSN applications. In 2019, Zhang et al. presented a WSN-based framework that involved the collection of multi-omics data, including genetic and imaging data [24]. In 2021, Wang et al. also showed a system that used WSNs to predict 1p/19q chromosomal deletion in people with oligodendroglioma. This study used WSNs to get genetic and epigenetic information from brain tumor tissues. It was very good at predicting 1p/19q chromosomal deletion in people with oligodendroglioma [25].

Chen et al. also demonstrated how to combine the WSNs system with advanced imaging techniques, such as magnetic resonance imaging (MRI), to predict chromosomal 1p/19q deletions. Patients use this system to collect MRI data [26]. Also, it addresses critical challenges, namely feature extraction, system optimization, and real-time data analysis. However, further studies are required to improve the scalability, energy efficiency, and interoperability aspects of brain tumor classification using WSNs [27–28]. Furthermore, the accurate and timely diagnosis of respiratory diseases, such as viral pneumonia and COVID-19, using WSNs plays a crucial role in effective patient management and healthcare. Recently, several studies have proposed combining WSNs with X-ray imaging techniques. These studies have demonstrated the use of WSNs to

capture X-ray images of patients, thereby improving the speed and ease of disease diagnosis [29] and [30].

This study presents various explanations and analyses of similar areas in the literature. It covers a broader range of applications, benefits, and challenges, providing a balanced analysis of both the potential and limitations of this technology. It also takes a forward-looking approach, discussing future directions for WSNs and healthcare development, such as integration with other technologies, the development of new applications, and handling challenges such as privacy, security, and scalability. In general, it makes contributions by providing comprehensive studies and insightful analyses of the current state, emerging trends, and practical implications of WSNs in healthcare, thereby offering valuable guidance for researchers, practitioners, and policymakers.

3 WSN-HEALTHCARE APPLICATIONS

Healthcare applications are increasingly using WSNs due to their ability to wirelessly acquire and transmit data from multiple sensors [13], [14].

Table 1 illustrates four significant applications of: remote patient monitoring (RPM), real-time location systems (RTLS), telemedicine, and environmental assisted living (AAL) [15].

3.1 Remote Patient Monitoring (RPM)

Adopting applications truly assists in efficiently collecting and transmitting crucial patient data to the healthcare provider from a distant location [1]. A patient's vital signs can be continuously monitored, including blood pressure, heart rate, and even temperature, without requiring frequent visits to a hospital or clinic. A physician can easily transfer this data to assess the patient's condition remotely and take the necessary action [16]. RPM proves to be especially beneficial for patients with chronic conditions like high blood pressure, diabetes, and heart disease. Long-term care institutions, remote patients with limited healthcare access, and post-operative care also benefit from RPM [18]. Many wireless sensors, either attached to the patient's body or located in their surroundings, such as a home or hospital room, make up this application. These nodes have the capability to transmit vital patient sign data wirelessly to a medical physician or monitoring center at a distance. The physician received the acquired data through communication channels such as Bluetooth [19]. RPM offers a number of additional benefits. Improved treatment outcomes may result in higher levels of patient satisfaction and possibly lower medical consumption. It also enables medical professionals to recognize early warning signs of possible medical conditions, take immediate action to avoid hospital readmissions, and reduce the entire healthcare cost. Finally, RPM remains one of the most exciting WSN applications in the healthcare sector. This app empowers users to make healthier decisions by providing the ability to view real-time vital sign updates [20]. RPM may improve patients' health, lower hospital readmission rates, save costs, and increase satisfaction by utilizing real-time data on patients' vital signs [31]. It may affect the efficient administration of medical services [32].

Table 1: Summarized benefits and challenges WSNs applications in healthcare.

Applications	Benefits	Challenges
Remote patient monitoring	Convenient for patients, reduces hospitalization costs, detects health issues early	Need for reliable and secure data transmission, proper management and storage of large amounts of data
Medication adherence monitoring	Improves patient outcomes, reduces hospital readmissions	Ensuring accurate and timely data collection, patient privacy concerns
Fall detection	Early detection of falls, reduces risk of injury	False alarms, privacy concerns
Activity monitoring	Helps manage chronic conditions, encourages physical activity	Standardization in sensor development, interoperability
Infection control	Reduces risk of hospital-acquired infections, improves patient safety	Need for reliable and secure data transmission, patient privacy concerns
Asset tracking	Efficient resource utilization, cost savings	Standardization in sensor development, interoperability

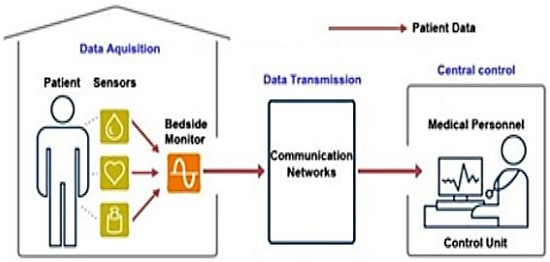

Figure 1: RPM System Architecture [24].

Furthermore, it allows healthcare providers to monitor patients remotely. Frequent reminders and feedback from the physician can increase patient adherence to treatment plans through frequent reminders and feedback from the physician. Moreover, RPM can assist in preventing health issues and hospitalizations, leading to better health outcomes and lower costs [33]. However, there are some significant challenges when implementing the RPM system. Firstly, collecting data on patients should be accurate and reliable, as motion, skin condition, and sensor location are some factors that may affect sensor measurements [34]. This is an example of an RPM system [24], as shown in Figure 1.

Secondly, RPM should have privacy and security, as data transmitted over networks can be vulnerable to hacking or other security breaches. Finally, people need standardized guidelines and protocols for RPM to ensure its safe, effective, and consistent implementation. Examples of RPM applications [35]-[36]:

1) Wearable devices: smartwatches, activity trackers, and other gadgets that can collect information about a patient's vital signs, such as heart rate, blood pressure, and oxygen levels, fall into this category;
2) Remote monitoring systems: these are devices that can be installed in the home of a patient to monitor their health state, such as blood glucose levels in diabetics or medication adherence;
3) Telehealth platforms: these are platforms that allow patients to interact virtually with healthcare practitioners such as doctors, nurses, and therapists;
4) Patient portals: these are online portals that allow patients to access their health information, connect with their healthcare professionals, and arrange appointments.

RPM apps can help patients by giving them proactive, individualized care, which has the potential to enhance patient outcomes, decrease hospital readmissions, and cut healthcare costs [14].

3.2 Real-Time Location System

WSNs can track the location of medical equipment, patients, and personnel in real time, improving hospital efficiency, reducing wait times, and

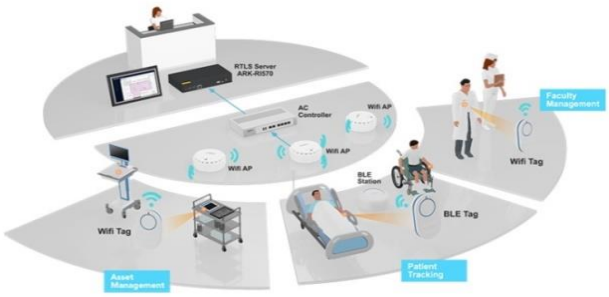

Figure 2: RTL System Using Wi-Fi technology [27].

improving patient safety [37]. Building on the benefits of RPM, another critical application of WSNs is Real-Time Location Systems (RTLS). RTLS is a WSN healthcare application that enables real-time tracking and monitoring of medical equipment, patients, and staff positions. RTLS can assist hospitals and healthcare organizations in increasing operational efficiency, decreasing wait times, and improving patient safety. This application can utilize technologies such as Wi-Fi, ultra-wideband (UWB), infrared (IR), and radio frequency identification (RFID) [38]. RTLS systems gather location data and wirelessly send it to a central database or system using a combination of sensors, tags, and readers (see Fig. 2).

The data can then be used for real-time tracking of assets, people, and patients [38] [39]. Medical devices connect to RFID tags, while RFID readers strategically locate themselves throughout the hospital. When medical equipment moves, the RFID tag sends a signal to the closest reader, which then updates the central database with the equipment's location.

The staff working in the hospital can use the collected data from WSNs to quickly find equipment, reduce wait times, and enhance operational efficiency. Additionally, the hospital utilizes RTLS systems to track the location. Therefore, wearable tags can be attached to patients' or staff bodies, and these tags are tracked in real-

time using RFID or other location-tracking technologies [40] [41]. In the above case, Wi-Fi access points used to track the location of patients and staff using wearable Wi-Fi tags. Wireless transmission of the data to a central database enables real-time tracking of patient and staff movements [40], [41]. By identifying potential hazards like individuals working alone in dangerous spaces or patients wandering into restricted areas, it can enhance safety. RTLS systems can also benefit managers and inventory control assistants [42]. By tracking locations in real time, healthcare providers can maximize utilization and prevent equipment downtime. It can help reduce equipment costs and increase operational efficiency [43], so RTLS is one of WSNs' applications in healthcare that can improve operational efficiency, reduce waiting times, and improve patient safety! Several location-tracking techniques can be used in RTLS applications, such as Wi-Fi, RFID, UWB, and IR. RTLS can assist hospitals and healthcare facilities in enhancing healthcare management, inventory control, and patient care by providing real-time location data [44].

3.3 Telemedicine

Telemedicine is defined as the use of data and communication technology to deliver clinical healthcare remotely [45]. It makes the technology possible for medical professionals to diagnose, monitor, and treat patients virtually, often obviating the need to visit a clinic or hospital. In recent years, telemedicine has gained popularity, especially in rural and underserved areas, due to technological advances and increasing demand for telehealth services. There are several types of telemedicine, namely: online consultations, videoconferencing, and remote monitoring [46]. Healthcare professionals can diagnose and treat a variety of health issues remotely, such as chronic diseases, mental health disorders, and minor injuries. Patients can communicate with healthcare providers using their smartphones, desktop computers, or tablets. Healthcare professionals can also detect potential health issues before they become serious by using remote monitoring devices to track patients' vital signs and other health parameters [47].

Telemedicine has many benefits, including improved access to care, lower healthcare costs, and increased patient engagement. Without having to drive to a medical facility, patients can receive care from their homes, and healthcare providers can reach a broader patient base. While patients can get rapid treatment for non-emergency illnesses without having to leave their homes, telemedicine can help reduce the burden on emergency rooms and urgent care facilities. Telemedicine application examples [48]-[49]:

1) Virtual consultations. Videoconferencing allows medical professionals to remotely consult with patients who live in rural areas. As a result, patients find this application useful due to the difficulty of traveling to the medical center;
2) Remote monitoring. Patients can monitor their glucose or blood pressure at home and then send the data to medical professionals for remote health checks. They can use mobile health applications to monitor their health metrics, get prescription reminders, and communicate with healthcare professionals.

Therefore, these types of applications significantly enhance access to healthcare services by improving patient outcomes and reducing costs, particularly in remote or underserved areas [50]. However, there are several drawbacks to telemedicine, such as the requirement for a stable Internet connection, concerns about privacy and security, and concerns about the quality of care provided remotely. Finally, with any new technology, it is critical to carefully weigh the benefits and risks of existing technologies and develop best practices to ensure their safe and effective implementation [51].

3.4 Ambient Assisted Living

WSNs play an important role in assisting elderly or disabled people who live independently. These advanced networks can detect movement, monitor vital signs, send alarms in cases of emergency, and provide assistance and support to those in need [21]. AAL applications are a collection of technologies, equipment, and services that aim to improve the quality of life and independence of older and disabled people by assisting them in their daily activities [22]. People in their daily environment receive support and care from various types of sensors, communication technologies, and data processing algorithms. AAL application examples [23], [52]:

1) Fall detection and prevention apps. This application uses sensors to detect falls in elderly people, alerting caregivers or emergency services [52]. They can also help prevent falls and slips by identifying possible

hazards in that region and making recommendations on how to mitigate them [53];

2) Remote monitoring telehealth apps. These programs commonly allow medical personnel to conduct virtual consultations and track patients' health from afar. They are ideal for monitoring long-term illnesses such as diabetes and heart disease, as well as detecting early warning signs of health problems [20].

AAL applications have the potential to improve the living conditions and mobility of the elderly and disabled, as well as lessen the strain on caregivers and the healthcare system [19].

4 WSN HEALTH-CARE BENEFITS

One of the main advantages of is their ability to improve patient results, as shown in Table 1. WSNs have revolutionized the medical industry by providing real-time health indicators, patient movement patterns, and environmental information [54]. Continuous monitoring of vital signs such as heart rate, blood pressure, and oxygen saturation enables medical practitioners to identify early signs of deterioration in emergencies [55].

WSNs can monitor a person’s activities, such as walking, sitting, or sleeping [20], [56]. This highlights the continuing benefits of using WSNs in the healthcare sector for risk minimization, improving patient recovery rates, and reducing expenses [57]. WSN could help eliminate human interaction in data input; this will improve healthcare efficiency [58]. This information may show how much a patient moves and provide an early understanding of functional decline [59]. Over and above that, they might as well be employed in environmental monitoring such as temperature, humidity, and air quality, which affect human health [60]. WSNs offer numerous benefits.

Healthcare. By automatically gathering and transferring patient data, WSNs can enhance the precision and promptness of information collection in the medical field. This approach not only saves time and money but also allows medical staff to focus on treatment rather than data management [61] [62].

WSNs could also improve healthcare quality by providing healthcare professionals with more detailed and precise data. WSNs are associated with multiple healthcare advantages. They save time and reduce costs, allowing for more opportunities for doctors to take care of their patients rather than wasting hours dealing with files [62]. Additionally, WSNs can improve care quality by providing healthcare professionals with more detailed and exact information. By collecting data from multiple sensors and merging it with other sources such as patients' electronic health records and medical imaging, healthcare experts can have a complete understanding of the patients’ physical conditions, thereby making treatment plans that are unique for them [63]. In addition to hat, real-time monitoring of vital signs, patients' movements, and their surrounding environment has changed this area in health WSNs, leading to numerous advantages like better patient outcomes, efficient healthcare services, and quality of care [64]. WSNs transform traditional healthcare by enabling on-demand patient monitoring, remote diagnostics, and personalized treatment plans."

5 APPLICATIONS CHALLENGES

WSNs transform traditional healthcare by enabling on-demand patient monitoring, remote diagnostics, and personalized treatment plans.

Nevertheless, apart from the applications of uptake, advancement has many drawbacks. Combining WSNs with existing healthcare systems, like a medical information system and a patient monitoring system, is another prominent aspect of this technology. This necessitates a substantial capital infusion into hardware manufacturing, software development, and staff training [65]. Another challenge facing the use of WSN apps in healthcare is ensuring reliable and secure data collection [66].

Another ethical issue arises when the use of WSNs reveals who owns a patient's data and who ultimately, standardizing WSN technology plays a vital role in ensuring various devices function seamlessly, provided they maintain interoperability [67]-[68]. WSNs' crowning task is probably continuous data collection of sensitive patient data. However, the potential for interception or contamination can significantly impact privacy [69]. WSNs encounter the same issue, necessitating their construction with robust security features such as access control, strong encryption, and authentication to effectively address the challenge [70].

Dissimilarities can accumulate to the point of losing crucial patient information or incorrectly capturing critical data. This could be detrimental to

the patient's health. Moreover, the robust implementation of WAN relies on effective communication protocols, redundant sensors, and fail-safe mechanisms that form the foundation of the infrastructure. Furthermore, it's crucial to consider the precise integration with the outdated healthcare IT system, which often lacks sufficient development, effective communication, and simplicity. Dealing with the vast amount of data acquired through WSNs presents a significant challenge [71].

These issues may include providing information about health data security, ensuring WSN reliability, and seamlessly integrating WSNs into the current healthcare ecosystem [54].

The main problems one can come across are information security and confidentiality, network dependability, and integrating wireless sensor networks into conventional healthcare systems. In this area, healthcare providers face issues such as patient data privacy and security, WSN reliability, and seamless integration of WSNs with modern healthcare systems.

Such complications include providing patient data confidentiality and privacy, ensuring WSN dependability, and finally, completely integrating WSNs with existing healthcare systems. These issues have a significant impact on the successful resolution of WHSNS's challenges [71].

6 CONCLUSIONS

Healthcare-based WSNs have made an enormous impact on healthcare services as they have developed a highly functioning and efficient infrastructure to take care of illnesses. Providing health services distinguishes the doctor from the patient and raises awareness about health and disease trends without the need for surgery or permanent hospitalization. In some aspects, WSNs have proven to be beneficial to not only patients but also healthcare professionals. The patients taking advantage of the remote monitoring devices enjoy the convenience of being able to keep their own pace, but they still get the necessary treatment. WSNs can also reduce the risk of hospital-acquired infections, enabling prompt diagnosis, early detection, and improved outcomes. They achieve the same health outcomes by providing patient-centered care, cutting costs, and assisting healthcare providers with resource management. Healthcare requires the use of WSNs, despite their potential criticality. WSNs have formed systems that now serve as a valuable source of reliable and effective protocols for patient treatment. As a result, the healthcare system has greatly improved. Therefore, the operations are minimally disturbing, and the duration of hospitalization rarely exceeds the standard. We use the latest monitoring technologies to monitor vital signs, including the patient's movement activity and drug regime, among other parameters. The vast community of networks specifically identified numerous benefits shared by both patients and healthcare professionals. Patients no longer need to travel long distances for routine assessments, which can disrupt their daily routines, as Patient Analytics with Mini-implants provides 24/7 healthcare from a remote location. Hospitals would experience a decrease in hospital-acquired infections due to the authority that WSN would provide, enabling them to stem disease trends at an early stage and enhance the speedy treatment of ill patients. Moreover, these tools ensure the strategic allocation of caregiver funds for optimal utilization, efficiency, and economy.

7 FUTURE WORK

Indeed, the applicability of presents some challenges. IoT primarily focuses on data processing and storage, ensuring its efficiency and security. WSNs transform traditional healthcare by enabling on-demand patient monitoring, remote diagnostics, and personalized treatment plans. WSN is one of the demanding needs in the today's time due to its ubiquitous nature. In the near future, WSNs can be deployed as underwater acoustic sensor systems, cognitive sensing and spectrum management, and security and privacy management. More trends for the next decade are more patients, more technology and more information.

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