Wireless Body Sensor Networks for Real-Time Healthcare Monitoring: A Cost-Effective and Energy-Efficient Approach

Yuvaraja M [1*], R. Ramesh [2], R. Priya [3], J. Dhanasekar [4]

Abstract

Background: The continuous and accurate monitoring of physiological signals is critical for timely medical interventions, particularly in the context of chronic disease management and elderly care. The advent of Wireless Body Sensor Networks (WBSN) and Patient Health Monitoring Systems (PHMS) promises to revolutionize healthcare by integrating real-time data collection with advanced processing and communication technologies, enabling proactive medical responses through the Internet of Things (IoT). Methods: In this study, a WBSN-PHMS framework is proposed, leveraging a network of biomedical sensors to continuously monitor vital signs such as temperature and heart rate. The system includes a gateway node that wirelessly transmits sensor data to a cloud-based storage and processing system. Physiological data are processed in real-time using advanced algorithms to detect anomalies and trigger alerts. The health status is modeled using a function g(v,w(v),∅−1(v(w))−∂i(v,∂))g(v, w(v), \varnothing^{-1}(v(w)) - \partial_i(v, \partial))g(v,w(v),∅−1(v(w))−∂i(v,∂)), which integrates patient-specific factors and real-time physiological states. The processed data are communicated efficiently through IoT platforms, ensuring that healthcare professionals receive timely alerts via mobile applications and specialized dashboards. Results: The WBSN-PHMS demonstrated high accuracy in detecting abnormal temperature and heart rate patterns, achieving detection rates of 98.61% and 99.43%, respectively. Additionally, the system improved overall patient health monitoring by 98.42%, offering a significant advancement in patient safety and healthcare efficiency. The cost-effectiveness of the system was established with a 96.21% improvement, while energy consumption was reduced by 23%, underscoring the sustainability of the technology. Conclusion: The WBSN-PHMS proves to be a reliable and efficient healthcare monitoring system that enhances patient outcomes through real-time data analysis and rapid medical responses. The system's ability to continuously monitor and analyze physiological signals in a non-intrusive manner positions it as a vital tool in modern medical practice, with the potential to revolutionize remote patient care and monitoring.

Keywords: Wireless Body Sensor Networks (WBSN), Healthcare Monitoring, Internet of Things (IoT) Energy Efficiency, Real-Time Data Transmission

Significance | This study enhances healthcare with WBSN-PHMS, enabling continuous, real-time monitoring and early detection while optimizing energy use.

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1. Introduction

The rapid advancement of computer technologies and wireless communications has largely supplanted older office-based systems with home-based digital electronics networks (Ettyem et al., 2023).

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Today, real-time applications based on home networks have become essential, especially in areas such as remote monitoring and control (Adarsh & Kumar, 2020). Recent developments in wireless sensor networks (WSNs) enable real-time monitoring and alarms within healthcare environments (Chakraborty, Mali, & Chatterjee, 2021). To optimize resource use and enhance patient care, medical centers increasingly integrate medical sensors, microcontrollers, and smartphones into embedded systems that offer continuous patient monitoring (Adeniyi, Ogundokun, & Awotunde, 2021). These networks are particularly useful for detecting unusual symptoms in individuals with chronic conditions (Chakraborty & Kishor, 2022). Innovations like the Wireless Body Sensor Network-based Personal Health Monitoring System (WBSN-PHMS) have been developed to improve health facility monitoring and early disease detection (Subasini, Karuppiah, Sheeba, & Padmakala, 2021).

A notable example is a mobile phone-based healthcare monitoring system that measures vital signs such as blood pressure and electrocardiograms, analyzing data in real-time on a mobile device and transmitting it via a wireless sensor network (Ivanov, Markova, & Ganchev, 2020). Such systems are poised to play a critical role in advancing healthcare technologies in this century (Salunke, Singh, & Jadhav, 2022). The WBSN-PHMS is integral to ongoing efforts to continuously monitor health through sensing, cognitive computing, and wireless networking (Rajan Jeyaraj & Nadar, 2022). Constant monitoring of biological signals is essential for patients with heart conditions, enabling healthcare professionals to track heart function effectively (Nayak & Barman, 2022). Online monitoring systems require software capable of transmitting health signals over the internet for effective patient management (Jain, Panesar, Talwar, & Sah, 2021). The ubiquity of wireless technologies means that health data can be monitored and transmitted from virtually any location (Chandra, Chandra, & Gupta, 2021). Additionally, hospitals favor wireless biomedical systems due to their cost-effectiveness and ability to meet patient needs without the expense of extensive cable networks (Lamonaca, Carnì, & Scuro, 2021).

Patient-doctor communication benefits from wireless transmission of data from various sensors installed throughout healthcare facilities (Ahmad et al., 2022). The integration of medical sensors with wireless technology enables significant improvements in monitoring patients' health status during daily activities (Bhandari, Seo, & Cho, 2020). Each patient acts as a node in a wireless sensor network connected to a central hub at a healthcare facility via the internet. This setup includes a small, handheld medical device equipped with a microprocessor and sensors (Uddin & Koo, 2024). Healthcare applications leveraging computers, smartphones, and wireless technologies offer numerous advantages, including faster diagnoses, more accurate results, and reduced paperwork, allowing physicians to monitor patients remotely (Vistro et al., 2020). These technologies facilitate continuous monitoring, early detection of issues, guided rehabilitation, and comprehensive information collection, benefiting patients, healthcare providers, and the broader community (Dewangan, Vyas, & Mandal, 2022). Modern smartphones, with their built-in wireless networks, are especially useful for remote medical data sensing and monitoring (Jarial, Dubey, & Dubey, 2024). By combining patients' medical histories with real-time data, this technology supports accurate diagnoses (Zhao & Li, 2020).

The primary contributions of this study are: Development of a monitoring system: This study introduces a system that connects to body-worn wireless sensor nodes to measure vital signs like temperature and heart rate, enabling real-time monitoring and alerting medical experts of anomalies.

Proposed IoT healthcare monitoring system: The research suggests a secure IoT-based system for comprehensive health monitoring, which sends alerts in emergencies (e.g., patient falls) via SMS and uploads data to an IoT server, thereby notifying healthcare providers of critical health events.

Efficient platform creation: The study presents a flexible and cost-effective platform designed to minimize energy consumption and enhance communication and computational efficiency. It utilizes a piezoelectric accelerometer and strategically placed sensors to reduce energy use, making the WBSN-PHMS suitable for widespread application in healthcare settings.

The remainder of this paper is structured as follows: Section 2 reviews related research on wireless sensor networks in healthcare systems. Section 3 details the proposed WBSN-PHMS methodology. Section 4 evaluates and analyzes the efficiency of WBSN-PHMS, and Section 5 concludes with suggestions for future work.

2. Related Work

To continuously monitor patients at large, biomedical sensor network systems provide warning mechanisms for aberrant situations and rich contextual information. To enhance the quality of life using implanted and wearable biomedical sensor networks, this assesses the current state of the art in research and highlights the challenges that need to be overcome. In addition to introducing the open research challenges that will be tackled with the construction of a healthcare environment based on sensor networks, it discusses the advantages that will be obtained and the unresolved research questions.

Machine Learning Algorithms (MLA): Recent studies have demonstrated that machine learning algorithms (MLAs) can effectively analyze, forecast, and categorize health data, significantly enhancing the quality of tele-monitoring and tele-diagnosis. This paper focuses on the application of machine learning techniques for real-time categorization of blood pressure measurements. Data is collected from the human body using a multilayer Wireless Medical Sensors Network architecture (El Attaoui et al., 2021) and analyzed to improve remote monitoring and diagnostics.

Data Mining (DM): Wearable sensors and social media platforms provide innovative methods for gathering patient data, but the sheer volume of data generated presents organizational challenges. Despite advancements, current healthcare monitoring systems struggle with efficiently collecting and analyzing this extensive user-generated healthcare data (Ali et al., 2021).

Cloud Computing (CC): Wireless Body Area Networks (WBANs) leverage clustering and cloud computing to monitor user vitals. These networks measure various internal and external human body characteristics. Given the limited resources of sensor nodes, minimizing energy consumption is a crucial design consideration for WBANs (Behura et al., 2021).

Nano Sensors (NS): This study highlights the capabilities of various nano-sensor technologies in disease diagnosis, focusing on energy efficiency, sensing capabilities, and adaptability to different conditions. The research discusses potential applications and challenges in integrating nano-sensors into healthcare systems (Abedi et al., 2024).

Big Data Technology (BDT): Big data technologies are essential for human health monitoring as medical devices continuously collect and record physiological data. Modern machine learning and big data tools enable the extraction of valuable insights from vast datasets, offering significant potential across various sectors (Bedi et al., 2021).

In summary, recent research has shown that Machine Learning Algorithms can effectively analyze, forecast, and categorize health data, enhancing tele-monitoring and tele-diagnosis quality. This work focuses on using MLA for real-time categorization of blood pressure measurements, utilizing a Wireless Medical Sensors Network architecture. Data Mining leverages wearable sensors and social media for patient data collection [26], though challenges in organizing this vast data remain. Cloud Computing in Wireless Body Area Networks addresses energy efficiency in health monitoring. Nano Sensors offer advancements in disease diagnosis and healthcare adaptability. Big Data Technology applies machine learning to large datasets, driving insights and value across multiple sectors.

3. Proposed Method:

To assess a patient's health while they are not in the hospital, a remote patient monitoring system gathers physiological data using biomedical sensors. The goal is to bring healthcare closer to people where they already spend most of their time instead of in sterile hospital facilities. All of the data is sent wirelessly to the doctor so that they can make the right judgments. By use of this kind of tele-health, vital signs including respiration rate, heart rate, blood pressure, temperature, and oxygen saturation levels in the blood may be monitored and sent.

Building an Interconnected Wireless Biomedical Sensor Network for Patient Tracking:

To make better use of the scarce spectrum, a cognitive radio network reduces interference and boosts efficiency. There are two categories of users—primary and secondary—who are used to prioritize who gets to utilize the frequency channel. When it comes to critical data transfers in real time and the allocation of available bandwidth, primary users are given preference over secondary users.

In figure 1, route data based on idle bandwidth, the next step in spectrum sensing is to actually access that capacity. To detect when the spectrum is free, bandwidth access functions work together to update the channel access time of the WBAN. There is an enormous and ever-increasing demand for radio spectrum from applications including mobile telephony, digital video broadcasting (DVB), Wi-Fi, wireless sensor networks, and the Internet of things. In, the contention window-based methodology is investigated, whereas in, the CR-based paradigm is investigated for a routing mechanism. To allow secondary users to access the network without requiring global clock synchronization, a channel-hopping method is developed. The throughput and average time are both improved. One major benefit is that it lets wireless devices take use of available bandwidth to increase their throughput. Cognitive radio networks use intrusion detection to find malicious or unlawful network or computer activity.

$$\{(0,r)\exists[0,\infty)\times D_R(S): g_0^V\partial(r,s,0)cv=0\}$$

(1)

The Equation 1 consistency and steadiness of the tracked signals, this is in line with the $cv=0$. The time and space structure to allow continuous monitoring is shown by the criteria for boundaries $(0,r)$ and realm $D_R(S)$. On the other hand, the data collection is proposed by g_0^V and $(r,s,0)$.

$$\frac{c}{cv}[\emptyset(w(r)+\partial i(r,\partial))]=\partial g(v,w(v),w(v),\partial),\partial\leq 0$$

(2)

The equation 2 is related to the suggested $\frac{c}{cv}$. In the present instance, the physiological signals ($v,w(v),w(v),\partial)$ picked up by the sensors are denoted by $w(r)$ and the alteration in sensor readings over time is shown by $\partial i(r,\partial)$. The network processes and communicates these messages $\partial\leq 0$.

$$w(v)=\partial g(v,w(v),\emptyset^{-1}(v(w))-\partial i(v,\partial),\partial) \quad (3)$$

The equation 3 function g models the health status, $w(v)$ denotes the inverse function that accounts for patient-specific factors, and ∂g may be understood as the real-time physiological state of the patient. Similar to the real-time $\emptyset^{-1}(v(w))$ warnings and notifications ∂ sent by the $\partial i(v,\partial)$ in the event of anomalies.

$$s(q,r) = \left(\frac{1}{S}\int_0^S f(s,r,\emptyset^{-1}(q),0)\emptyset^{-1}(q)\right)$$

(4)

Equation 4 can be associated $s(q,r)$ with the proposed WBSN-PHMS method. The system's $\frac{1}{S}$ ability to continuously monitor and analyze $s, r, \emptyset^{-1}$ health data, guarantee accurate real-time warnings and efficiently communicate over the Internet of Things $\emptyset^{-1}$ allows for prompt medical actions, as shown by this vital average over the period (q).

A complex design is used by the WBSN to guarantee faultless patient health monitoring. Continuous monitoring of vital signs like temperature and heart rate is achieved by use of a network of sensor nodes that are affixed to the bodies of patients. A gateway node acts as a go-between, receiving data wirelessly from these nodes and sending it on to a storage and processing system in the cloud. Data travels via encrypted processing, storage, and real-time pattern and anomaly detection on the cloud. After processing, the data is used for real-time monitoring, with warnings and alarms delivered to healthcare practitioners via a mobile app for patients and specialized dashboards for physicians and nurses. This method is designed to make sure that any unusual health patterns are reported quickly so that medical help may be given right away. Improved health outcomes, less stress for healthcare workers, and higher quality patient care are all results of the WBSN-PHMS's proactive approach to healthcare management made possible by the IoT is shown in figure 2.

$$\aleph := \{(0,q,r)\varepsilon[0,\infty) \times D_R(S \times T): u(q,r) = 0\}$$

(5)

The equation 5 inside the domain $(0,q,r)$ where the function $\aleph :=$ equals zero. The expression can be seen as determining $\varepsilon[0,\infty)$ the particular states or conditions q and r in the Bluetooth biological sensors Network-based. The person's health management system $D_R(S \times T)$ where the system cannot identify any alterations in a patient's physiological signals.

$$\left\{(0,r)\exists[0,\infty) \times D_R(S): \int_0^R g(s,r,0,0)fh = 0\right\}$$

(6)

Equation 6 may be linked to the suggested WBSN-PHMS technique. Functions representing $0, r$ the physiological condition $\exists[0,\infty)$ are represented by f and h, whereas $g(s,r,0,0)$ could describe the signal transmission between sensor nodes. Timely diagnosis of problems is ensured by constantly tracking within a specific range, as shown by the whole number between$D_R(S)$.

$$v_r + v_{yyyyr} - v_{yy} + v_y + vv_y = 0$$

(7)

The equation 7 may be linked v_r to the suggested WBSN-PHMS technique. With the addition of components for information v_{yyyyr} propagation, dissemination, and quadratic interactions, this quadratic partial v_{yy} differential might explain the spatial and temporal variation of a physiological variable $vv_y = 0$.

$$\emptyset(v,w)_j = \frac{1}{3}\left[v_j \nabla_y w_j + \nabla_y (vw)_j\right] 1 \geq j \geq N$$

(8)

The equation 8 processing and transmission of physiological signals $(\emptyset(v,w)_j)$ maybe connected to this expression $\frac{1}{3}$ within the framework of thev_j. It displays how the system analyses ∇_y and reacts to alterations w_j in a patient's state, making ∇_y sure that the cordless physiological $(vw)_j$ networks of sensors communicate and monitor efficiently $1 \geq j \geq N$ in real-time.

Biomedical sensors were used to track, identify, and forecast individuals' well-being, with the objective of enhancing their health, especially as they grow older. Consequently, this technology will merge the real and virtual worlds. By identifying and notifying employees of potentially concerning changes in conditions in a tenth of a second, the system further decreased the end-to-end latency. Additionally, the system would benefit from a validation and test in a real-world setting.

Implementing Safe IoT Healthcare Monitoring:

An explanation of the structure, levels, and interconnections of RPMS may be found in its architecture. There is a lot of disorder and problems with the RPMS design when it comes to human existence. To start, which brands of sensors are most suited for collecting trustworthy data from patients. Finally, need to know whether the medical community and patients are on board with the notion, and secondly, which processing techniques and communication protocols are most suited for this system.

Figure 3 illustrates the potential impact on the design of the number of developed layers. Type of sensor, Mobile Control Unit, and wireless connection are the subtopics that will be covered in this part. In a remote patient monitoring system, Tier 1 is usually used for the collecting and processing of psychological data. Step one involves using biomedical sensors to gather physical biomedical data, which is then processed, stored, and made available for viewing or distribution to healthcare practitioners. From the literature, this study examines at least three kinds of sensor nodes used in the RPM system. One kind of sensor may be connected to an external CPU either wirelessly or via a wired connection. The data is processed by the processor, who then sends it to the hospital via an internet relaying node.

$$N_{qblue}(v) = \complement + \sum_{k=1}^{Q} u_h(o+1) + \sum_{h=1}^{l}(mn - mq)^{2qz} + kl \quad (9)$$

Equation 9 could reflect the system's network quality or efficiency measure. Several characteristics N_{qblue} of physiological signals (v), interactions between sensor nodes, and external $\complement$ variables might be accounted $u_h(o+1)$ for by the terms $h = 1$ included $mn - mq$ in the summations. Which demonstrate the $2qz$ intricacy and integration kl of various factors that impact the system's performance.

$$G^{L+1} \leq (1 + d\sigma)G^{l} + \sigma h^{l}\; L = 0,1,2,3, \ldots..$$
(10)

This Equation 10 could stand for the iterative enhancement of the observing precision or signal processing efficiency $1 + d\sigma$ in the recommended Wireless, for short, biological sensor Network-based. Here, G^{L+1} could mean a quality metric G^{l} like data accuracy or signal strength, d *and* σ are parameters associated with the L and h^{l} could mean an outside $0,1,2,3, \ldots..$ influence or disruption.

$$max_{R(t)}\left(\sum_{v=1}^{V}\left[Q_v(r-1) + \Delta.\left(t_{gzhq}(v) - N\right)\right]\right) + kl - 1$$
(11)

Equation 11 The client's physiological signal strength at the node V, the time step $(r-1)$ for Q_v monitoring Δ, and the current time $v = 1$ of physiological data transmission $t_{gzhq}(v)$maybe used to establish a correlation $-N$ with the $kl - 1$. By giving priority to signals that need immediate action $max_{R(t)}$.

$$v_w + t_{yyw} - t + v_y + vv_y = 0,\quad 0 > y > M, 0 > V \geq v$$
(12)

The equation 12 may be connected to the v_w WBSN-PHMS technique, which could explain changes in physiological signals $t_{yyw} - t$ and interact inside v_y the human body. The sensor nodes vv_y monitor and communicate patient health data , $0 > y > M$, the terms in the calculation may explain the effect of physiological factors $V \geq v$ on the overall system state.

Using a centralized controller and a number of sensors, the above figure depicts a full-scale patient health monitoring system that records and transmits critical health data. In its most basic form, the system uses specialized sensors to monitor the patient's electrocardiogram and heart rate. A controller takes this data and adds in other environmental factors including humidity, temperature, exhaust levels, and the state of the air conditioning system. To ensure that medical workers get real-time data, the system employs a Global System for Mobile Communications module to enable wireless connection. Also used for remote control and monitoring is Blynk, an IoT application platform. The ECG data is highlighted because it gives doctors extensive information about the heart's function. With this set up, the patient's vitals can be tracked in real-time, around the clock, so any drastic changes may be addressed right away. Together, these technologies provide a strong and effective system that improves patient care and safety.

$$\frac{1}{2\delta}\int_{0}^{2\theta}\frac{\tau\sigma}{\partial + \alpha\cos\theta} = \frac{1}{\sqrt{fh^2 - lm^2}} \times \lim_{fr\times}\left(1 + \frac{1}{ax}\right)^{lm}$$
(13)

The equation 13 can be connected with the $\frac{1}{2\delta}$ integral may represent $\partial + \alpha\cos\theta$ the collection $\tau\sigma$ of physiological data, which is affected by time-dependent variables $\frac{1}{\sqrt{fh^2 - lm^2}}$ involve temperature and heart rate $\lim_{fr\times}$, and the integral may represent $\left(1 + \frac{1}{ax}\right)^{lm}$ the reliability and effectiveness of data transmission.

$$\text{frv}\,\beta\text{C} + \text{shm}\,\varepsilon\nabla = 4\tan\frac{1}{6}(\nabla + \gamma) \times \text{fjk}\frac{1}{4}(h \mp \tau - \Delta\omega)$$
(14)

Equation 14 is associated with the $\text{frv}\,\beta\text{C}$ WBSN-PHMS as it probably stands for a sophisticated $\text{shm}\,\varepsilon\nabla$ interaction model for wireless sensor network signal $4\tan\frac{1}{6}(\nabla + \gamma) \times$ processing and communication. This calculation $h \mp \tau - \Delta\omega$ captures the system's ability to monitor fjk and notify in real time by integrating $\nabla + \gamma$ various physiological and environmental data.

$$\text{C}_m V_j^{L+\frac{1}{2}} + \text{C}_m \text{C}_y W_j^{L+\frac{1}{2}} - W_j^{L+\frac{1}{2}} + \nabla_y W_j^{L+\frac{1}{2}} + \emptyset\left(V^{L+\frac{1}{2}}, V^{L+\frac{1}{2}}\right) = S_j^{L+\frac{1}{2}}$$
(15)

This Equation 15 seems to be related to the theoretical architecture of the portable $\text{C}_m V_j^{L+\frac{1}{2}}$ population health monitoring system. The use of abbreviations C_y such as $V^{L+\frac{1}{2}}$, $W_j^{L+\frac{1}{2}}$, and $S_j^{L+\frac{1}{2}}$ implies variables or functions $\emptyset$ linked to the data collected by the sensors and the reactions of the system.

To collect data for the hospital's remote patient monitoring system, wireless sensors and wireless communication are used. Data capture makes use of sensors, including those that are wearable, implantable, and non-contact. Using either an internal or external controller, the collected data may be analyzed and converted to a suitable format before being wirelessly communicated to the hospital. To get the data to the consumer, a variety of short- and long-range communication methods are used.

Evaluation of simulation analysis

A centralized controller and a network of sensors work together to deliver continuous and comprehensive health tracking in the patient health monitoring system. The system incorporates environmental conditions like humidity, temperature, exhaust levels, and air conditioning status into its monitoring of important metrics like electrocardiogram and heart rate. This monitoring is made possible via the use of specialized sensors. A GSM module allows for wireless data transmission to an IoT server, allowing for real-time monitoring. Remote control and monitoring are made easier using Blynk, an Internet of Things platform. By improving patient safety and enabling quick medical response, this connection guarantees that healthcare practitioners obtain precise health information and alarms at the right moment.

Figure 5, shows an example of an advanced patient health monitoring system that relies on the IoT. This system integrates many sensor nodes with a central server to provide full health tracking and alarms. The system collects vital physiological data from patients using a piezoelectric accelerometer, temperature sensor nodes, and heart rate sensor nodes. A centralized communication system receives data from these sensor nodes and sends it wirelessly to an IoT server. To receive, analyze, and store data for real-time monitoring, the IoT server is crucial. To ensure that medical assistance is promptly provided in the event of any identified irregularities, an alarm system has been included into the server. Healthcare practitioners may access patient data via the IoT server through the user interface, allowing for efficient and smooth health management. By improving patient safety and allowing for fast medical reactions, this technology guarantees continuous and precise health monitoring. This health monitoring framework greatly enhances the efficacy and efficiency of patient treatment by using IoT technologies.

$$C_m V_j^{L+\frac{1}{2}} + C_m C_y W_j^{L+\frac{1}{2}} - W_j^{L+\frac{1}{2}} + \nabla_y W_j^{L+\frac{1}{2}} + \emptyset\left(V^{L+\frac{1}{2}}, V^{L+\frac{1}{2}}\right) = 0 \quad (16)$$

The equation 16 $C_m V_j^{L+\frac{1}{2}}$ *denotes* the volume of variable $C_m C_y$ raised to the power of L plus the square of the number of variables plus C_m in mathematics $W_j^{L+\frac{1}{2}}$. The work done by $W_j^{L+\frac{1}{2}}$ where W raised to the power of j raised to the power of L plus the square of one $+\emptyset\left(V^{L+\frac{1}{2}}, V^{L+\frac{1}{2}}\right)$ determines the analysis of patient's temperature.

$$||v^{l+1}|| + ||w^{l+1}|| + 2\sigma|v^{l+1}|_1^2 = ||w^l||^2 + ||w^l||^2 \quad (17)$$

Equation 17 offers a way to assess the communication robustness and energy efficiency of the data transfer $||v^{l+1}||$ from the sensor network. Reliable identification $||w^{l+1}||$ of physiological problems while reducing energy consumption $2\sigma|v^{l+1}|_1^2$ may be achieved by adjusting the parameters $||w^l||^2$ and $+||w^l||^2$ denotes the analysis of patient heart rate.

$$g(gr) = Xfd_4 + \sum_{a=1}^{\infty r}\left(gd_m \tan\frac{GVH}{HV} + gv_f \cos\frac{\delta\epsilon\forall}{DH}\right) \quad (18)$$

The equation 18 probably stands $\delta\epsilon\forall$ for a mathematical model $a = 1$ that incorporates several vital signs Xfd_4, including heart rate $g(gr)$, temperature gd_m, and maybe additional variables important $\tan\frac{GVH}{HV}$ for $gv_f \cos\frac{\delta\epsilon\forall}{DH}$ denotes the analysis of the patient's health monitoring.

$$(t_1 v + y_1)(r_2 i + v_2) = h_1 i d_2 b^2 + (gj_1 fh_2 + fd_2 hv_1) rt + l_1 i^2 \quad (19)$$

The given equation 19 may be written as a mathematical structure $(t_1 v + y_1)$ or formula that aims to capture components $r_2 i + v_2$ of the planned $h_1 i d_2 b^2$ medical monitoring system $(gj_1 fh_2)$ is probably represented $fd_2 hv_1$ by text $rt + l_1 i^2$ and analysis of cost-effectiveness.

$$(tr + ji)^{rs} = \sum_{v=0}^{va}\binom{ry}{nf} jt^{1-k} rd^{pt-bk} + (sr + yf)^{m-1} \quad (20)$$

Equation 20 may be written as but rather it seems to be a $(tr + ji)$ symbolic or hypothetical depiction. Through the use of Bluetooth-equipped $\binom{ry}{nf}$, the system can track vital signs temperature jt^{1-k} and heart rate in real time, with the goal rd^{pt-bk} of notifying medical professionals $sr + yf$ of any irregularities. By improving data transmission $m - 1$ efficiency and analysis of reducing energy consumption.

4. Result and discussion:

To identify diseases or infections early on, it is essential to continuously monitor patients' physiological characteristics, which is made possible by the WBSN-PHMS. The technology wirelessly transmits data from sensor nodes that measure temperature and heart rate to a central system so that it may be analyzed in real-time. This method guarantees that unusual health trends are detected quickly, enabling doctors to intervene quickly. By using Internet of Things technology, the WBSN-PHMS prioritizes proactive patient care, lessens the burden on healthcare professionals, and improves patient safety.

Dataset Descriptin: Previously, built a cheap system that tracked the whereabouts of hospital staff using a network of sensors. This system is used to track the mobility of healthcare professionals in a dialysis unit at the University of Iowa Hospitals and Clinics for this research. Unable to ascertain the precise beginning and ending timings of dialysis treatments are not authorized to access any patient records pertaining to their privacy. Nevertheless, the durations of patients' dialysis sessions were estimated by drawing on experts' knowledge of the procedure, namely the fact that healthcare providers must spend a considerable amount of time in the dialysis chair before and after each treatment. This information was previously used in an agent-based simulation that ran to model MSA bacteria.

4.1 Analysis of the patient's temperature:

Continuous study of the patient's temperature is provided by the WBSN-PHMS, which is essential for spotting early indicators of disease or infection. The patient's body is equipped with sensor nodes that carefully track their temperature swings in real-time. This allows for the prompt identification of any aberrant results is explained in equation 16. A centralized monitoring system can analyze the patient's temperature patterns based on the data sent wirelessly by these sensors. The algorithm is able to distinguish between typical fluctuations and worrying patterns that may indicate health decline by examining these trends. The device notifies healthcare personnel instantly in the event of a fever or hypothermia, enabling them to provide medical assistance promptly. Healthcare providers, already overburdened by a high patient-to-physician ratio, will find this constant monitoring a welcome relief, and it will also improve patient safety. Accurate recording and analysis of temperature data is made possible with the incorporation of IoT technology, which allows for a proactive approach to patient care and improves overall health results. Figure

Table 1. Overview of advanced technologies and methods used in health monitoring and data analysis, highlighting their advantages and limitations.

S.No	Methods	Advantages	Limitations
1	Machine Learning Algorithms (MLA)	- Effective in analyzing, forecasting, and categorizing health data - Enhances telemonitoring and telediagnosis quality	- Requires large datasets for training - Can be computationally intensive
2	Data Mining (DM)	- Innovative use of wearable sensors and social media for data collection - Improves healthcare monitoring	- Massive amounts of data can be challenging to organize - Data privacy concerns
3	Cloud Computing (CC)	- Efficient in processing and storing large data sets - Reduces the burden on local devices by offloading to the cloud	- Potential issues with data security and privacy - Dependent on network connectivity
4	Nano Sensors (NS)	- High sensitivity and specificity in disease diagnosis - Adaptable to varied conditions	- Energy consumption concerns - High cost and complexity of integration
5	Big Data Technology (BDT)	- Enables extraction of valuable insights from large datasets - Drives innovation and market value	- Handling and processing big data can be resource-intensive - Requires robust infrastructure and expertise

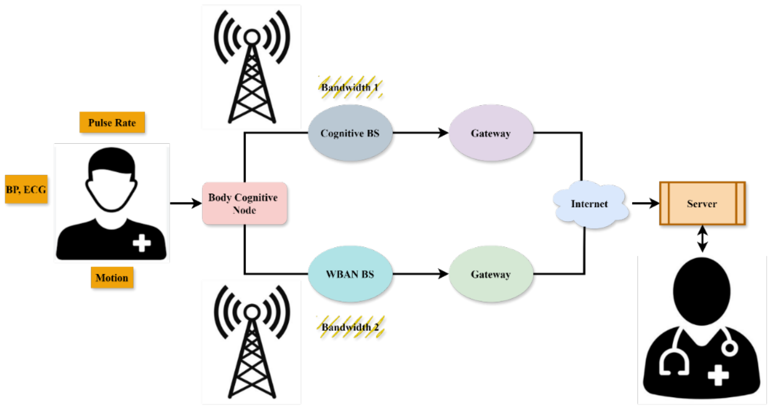

Figure 1. Wireless Body Area Network Architecture.

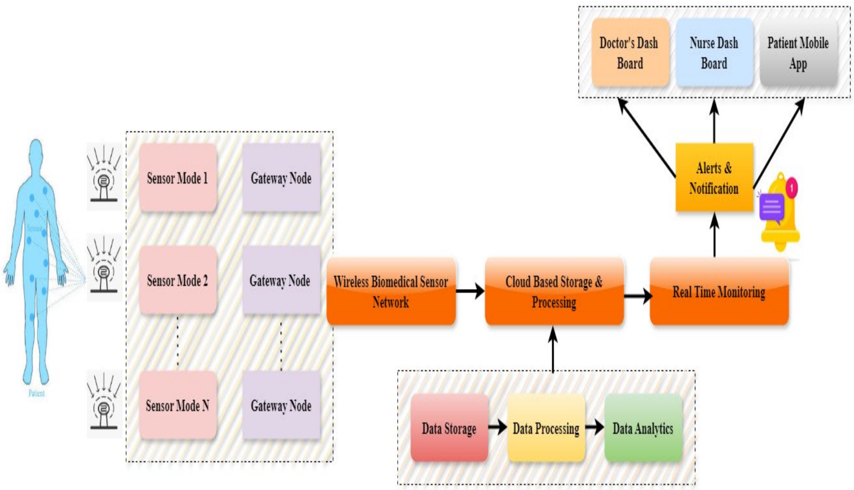

Figure 2. Block Diagram of Smart Healthcare System using WBSN.

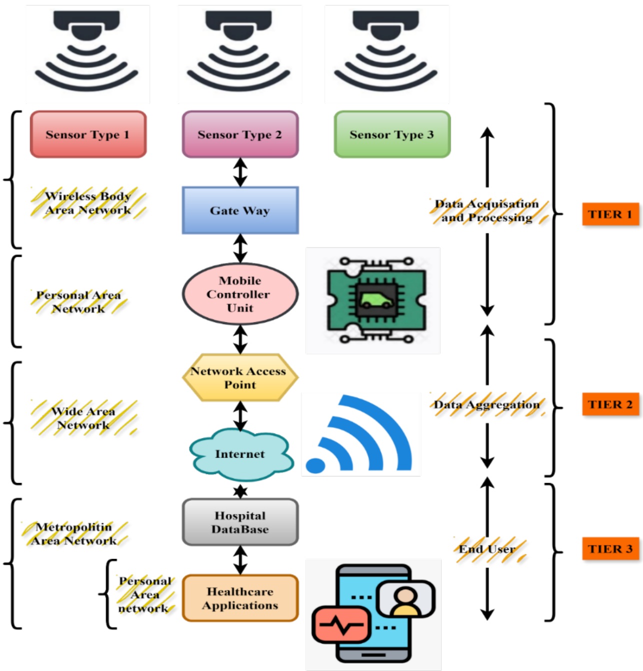

Figure 3. Method for a Remote Patient Tracking System.

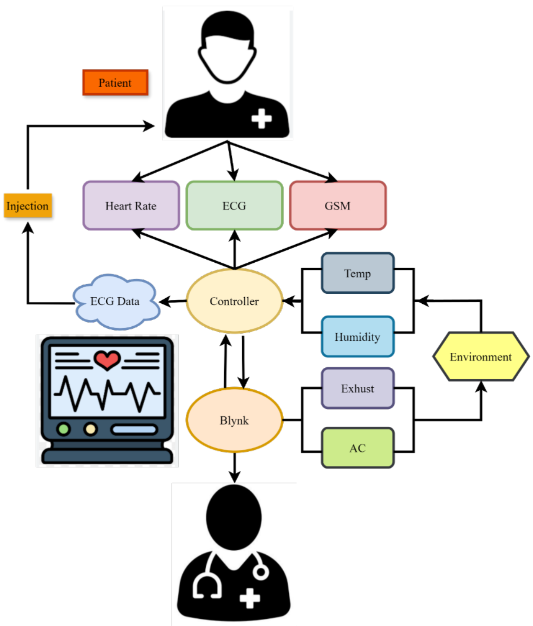

Figure 4. Flow chart of Real Time Monitoring.

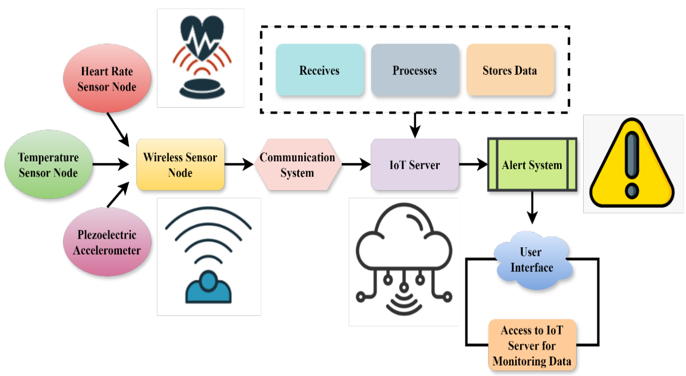

Figure 5. Block Diagram of WBSN-PHMS.

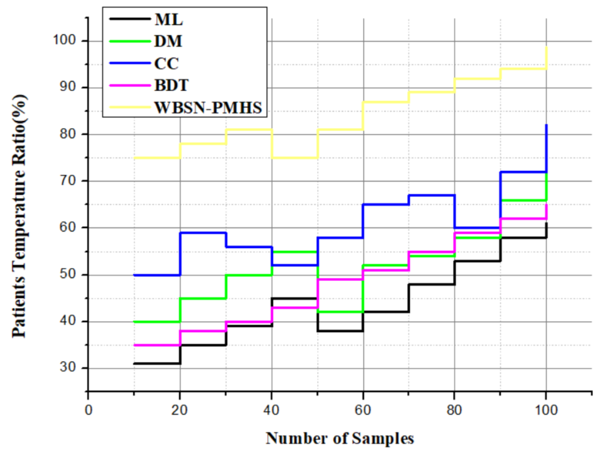

Figure 6. The Graphical Representation of Patients Temperature.

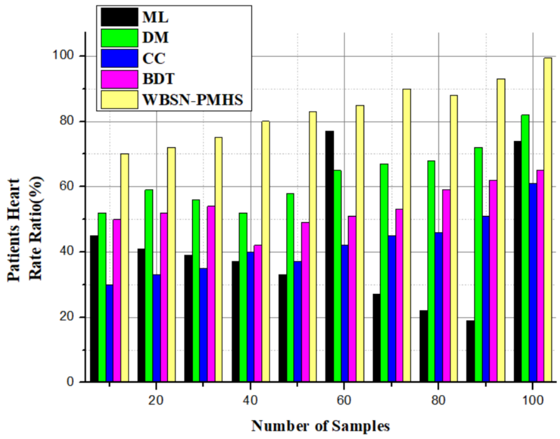

Figure 7. The Graph of Patients Heart Rate.

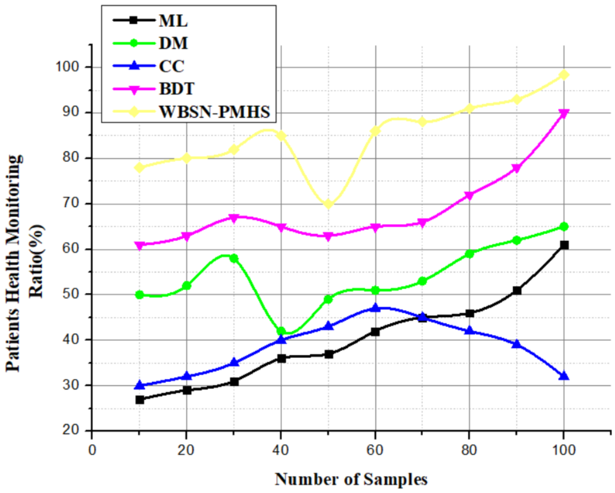

Figure 8. The Graphical Illustartion of Patients Health Monitoring.

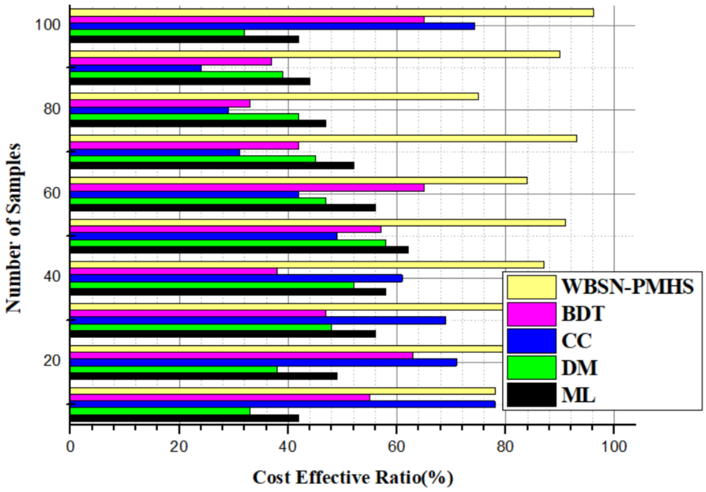

Figure 9. The Graph of Cost Effective.

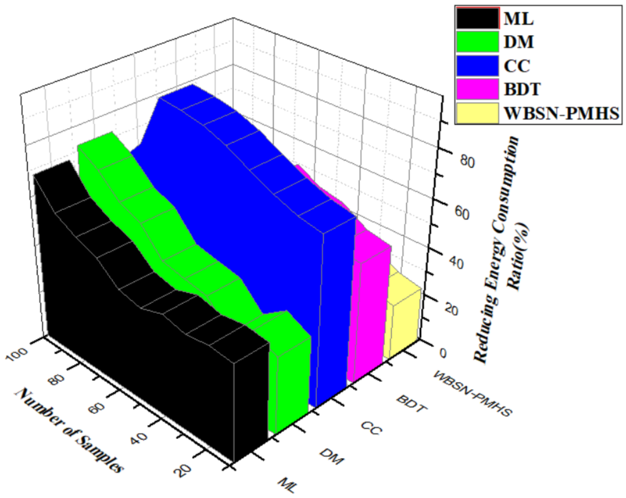

Figure 10. The Graphical Representation of Reducing Energy Consumption.

6, shows the graphical representation of patient's temperature ratio is detected by 98.61% in the proposed method of WBSN-PHMS.

4.2 Analysis of patient's heart rate:

Vital for evaluating cardiovascular health and identifying any crises, the WBSN-PHMS provides continuous monitoring and analysis of a patient's heart rate. The patient's heart rate data is wirelessly relayed to a central monitoring system via sensor nodes that are connected to their body in real-time is explained in equation 17. Problems with the heart's rhythm, such as bradycardia, tachycardia, or arrhythmias, may be detected by this system's analysis of the data. The device monitors the patient's stress levels, cardiovascular health, and autonomic nervous system function by continually recording heart rate variability. Notifications are transmitted to healthcare practitioners immediately upon detection of aberrant heart rate patterns, allowing for fast medical treatment is shown in figure 7. Rapid fluctuations in heart rate may be life-threatening in critical care settings, therefore this proactive monitoring greatly increases patient safety. By continuously and precisely analyzing heart rates, the WBSN-PHMS guarantees prompt treatments, reduces the likelihood of problems, and promotes improved health outcomes. In the proposed method the patient's heart rate is analysed by 99.43%.

4.3 Analysis of patient's health monitoring:

A patient's overall health status may be assessed with the use of the WBSN-PHMS, which combines in-depth analysis of various physiological data. The technology guarantees an immediate evaluation of the patient's state by constantly tracking critical parameters including temperature, heart rate, and other vital indications. Data is collected by sensor nodes that are worn by the patient and sent wirelessly to a server in the cloud for processing. To identify any health problems, these data are evaluated using sophisticated algorithms that look for abnormalities and trends. Quick notifications are delivered to healthcare practitioners when anomalies are found, enabling them to intervene swiftly. Patient long-term health and treatment efficacy may be better understood with the use of the system's trend-tracking capabilities. By allowing proactive and data-driven medical choices, this continuous and automated monitoring lessens the stress on healthcare providers, improves patient safety, and increases overall healthcare efficiency is explained in equation 18. The patient health monitoring is improved by 98.42% in the proposed method of WBSN-PHMS is shown in figure 8.

4.4 Analysis of cost-effective:

Figure 9, shows an affordable option for ongoing patient monitoring is the WBSN-PHMS. The system uses wireless sensor technology to improve productivity and save labor costs by reducing the need for healthcare workers to do regular manual inspections. Reduced operating costs are a direct result of using small, low-power sensor nodes. The WBSN-PHMS is a cost-effective and flexible option since it can be adjusted to various healthcare settings, such as home care or hospitals. Potentially lowering hospital readmissions and related expenses, the real-time data transfer and automated alarms guarantee prompt medical treatments is explained in equation 19. In addition, by using IoT technology, remote monitoring becomes possible, which reduces the need for patients and healthcare professionals to physically see each other and the associated travel costs. When it comes to healthcare resource optimization and patient care, the WBSN-PHMS provides a long-term, affordable solution. The ratio of cost effective is achieved by 96.21% in the existing method.

4.5 Analysis of reducing energy consumption:

Energy efficiency is highly prioritized within the design of the WBSN-PHMS since ensuring long-term operation of sensor nodes is essential. Every single sensor node must use less energy while maintaining data accuracy without any interruptions. However, equation 20 yields low power components employed. For example; adaptive sampling rates as well as data compression techniques that reduce the amount of transmitted data in health monitoring without degrading its quality are some of the smart algorithms that control power consumption. Additionally, energy harvesting techniques such as solar power and body heat conversion can also be used to increase the lifetime of sensor nodes. These energy-saving measures ensure continuous but low-maintenance monitoring of patients' physiological signals by WBSN-PHMS. By reducing the energy used, system's sustainability and cost-effectiveness are enhanced. This is also important for early identification of diseases and improving patients' lives and Figure 10 shows a reduction in energy consumption by 23%.

Using advanced sensor nodes, WBSN-PHMS monitors real-time vital signs like temperature and heart pulse rates. Real-time data transmission helps in enhancing patient safety through early detection of problems. It is because of these components being energy efficient as well as cheaply designed that this program remains sustainable and operational costs are lower.

In today's medical practice, the WBSN-PHMS is an invaluable instrument since it allows for effective healthcare delivery by providing rapid medical reactions via automated warnings. By incorporating IoT technology, its capabilities are further enhanced, allowing for a more proactive approach to patient care and better health outcomes in general.

5. Conclusion

A healthcare guiding and monitoring system that operates wirelessly is covered in this paper. WBSN-PHMS system has been designed, built, and tested in medical facilities and labs. On top of that, the embedded software may communicate with the server of the medical center, scan, calculate, and monitor in real-time. The integrated microprocessor analyzes the data gathered by the medical sensors to identify any irregularities in the patient's health. Consequently, medical professionals may consult with patients online using the scanned data. This system is highly capable of processing biosensor signals in real-time and sending the measured signals to the server of the medical center via the internet. It compared the functioning and readings of the built prototype to those of trustworthy, industry-standard, and calibrated medical equipment. The healthcare monitoring is a good fit for the suggested system. Its operation is quite comparable to that of standard monitoring systems seen in hospital intensive care units. Glucose, uric acid, cholesterol, and other test units may be added to the proposed system as an internet-connected home device. The widespread use of WSNs has the potential to revolutionize many consumer applications, most notably in the fields of environmental and healthcare monitoring.

Many people's health and longevity may be greatly enhanced in the not-too-distant future as WBSN-PMHS for symbiotic and bio-inspired structures continue to advance. The concept of remote patient monitoring, made possible by the development of mobility technologies, is not new. A less intrusive option for patient placement is wireless sensor networks, which provide low-cost environmental sensing capabilities because to their wireless nature. Analyzed these difficulties from the viewpoint of WSNs in healthcare. Soon, common people will be able to use context-aware, ubiquitous healthcare apps due to a convergence of many sound modalities, such as video sensing and medical sensors, smart devices, and remote monitoring capabilities. WBSN-PMHS are going to be more popular as smart spaces become more integrated with wireless sensor networks. These networks will be able to detect changes in the surrounding environment and respond accordingly, depending on whether or not people are in the area. Thus, the system may achieve ubiquity, where every person has a computational module that can effortlessly communicate with the smart space's system and avert health issues.

Author contributions

Y.M. conceptualized the study and prepared the original draft. R.R. contributed to data analysis and critical revisions. R.P. assisted with methodology and data interpretation. J.D. participated in the review and editing process. All authors reviewed and approved the final manuscript.

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Competing financial interests

The authors have no conflict of interest.

References

Abedi, A. F. A., Goh, P., & Alkhayyat, A. (2024). Nano-Sensors Communications and Networking for Healthcare Systems: Review and Outlooks. Journal of Computational Science, 102367. https://doi.org/10.1016/j.jocs.2024.102367

Adarsh, A., & Kumar, B. (2020). Wireless medical sensor networks for smart e-healthcare. In Intelligent Data Security Solutions for e-Health Applications (pp. 275-292). https://doi.org/10.1016/B978-0-12-819511-6.00015-7

Adeniyi, E. A., Ogundokun, R. O., & Awotunde, J. B. (2021). IoMT-based wearable body sensors network healthcare monitoring system. IoT in healthcare and ambient assisted living, 103-121. https://doi.org/10.1007/978-981-15-9897-5_6

Ahmad, N., Awan, M. D., Khiyal, M. S. H., Babar, M. I., Abdelmaboud, A., Ibrahim, H. A., & Hamed, N. O. (2022). Improved QoS aware routing protocol (IM-QRP) for WBAN based healthcare monitoring system. IEEE Access, 10, 121864-121885. https://doi.org/10.1109/ACCESS.2022.3223085

Ali, F., El-Sappagh, S., Islam, S. R., Ali, A., Attique, M., Imran, M., & Kwak, K. S. (2021). An intelligent healthcare monitoring framework using wearable sensors and social networking data. Future Generation Computer Systems, 114, 23-43. https://doi.org/10.1016/j.future.2020.07.047

Bedi, P., Goyal, S. B., Sharma, R., Yadav, D. K., & Sharma, M. (2021). Smart model for big data classification using deep learning in wireless body area networks. In Micro-Electronics and Telecommunication Engineering: Proceedings of 4th ICMETE 2020, pp. 215-224. https://doi.org/10.1007/978-981-33-4687-1_21

Behura, A., Sahu, S., & Kabat, M. R. (2021). Advancement of Machine Learning and cloud computing in the field of Smart Health Care. Machine Learning Approach for Cloud Data Analytics in IoT, 273-306. https://doi.org/10.1002/9781119785873.ch11

Bhandari, K. S., Seo, C., & Cho, G. H. (2020, September). Towards Sensor-Cloud Based Efficient Smart Healthcare Monitoring Framework using Machine Learning. In The 9th International Conference on Smart Media and Applications, pp. 380-383. https://doi.org/10.1145/3426020.3426138

Chakraborty, C., & Kishor, A. (2022). Real-time cloud-based patient-centric monitoring using computational health systems. IEEE transactions on computational social systems, 9(6), 1613-1623. https://doi.org/10.1109/TCSS.2022.3170375

Chakraborty, S., Mali, K., & Chatterjee, S. (2021). Edge computing based conceptual framework for smart health care applications using z-wave and homebased wireless sensor network. Mobile Edge Computing, 387-414. https://doi.org/10.1007/978-3-030-69893-5_16

Chandra, S., Chandra, A., & Gupta, R. (2021). An efficient data routing scheme for multi-patient monitoring in a biomedical sensor network through energy equalization strategy. Wireless Networks, 27(1), 635-648. https://doi.org/10.1007/s11276-020-02472-3

Dewangan, N., Vyas, P., & Mandal, S. (2022). Smart healthcare and intelligent medical systems. In Computational Intelligence and Applications for Pandemics and Healthcare, pp. 205-228. https://doi.org/ 10.4018/978-1-7998-9831-3.ch010

El Attaoui, A., Largo, S., Jilbab, A., & Bourouhou, A. (2021). Wireless medical sensor network for blood pressure monitoring based on machine learning for real-time data classification. Journal of Ambient Intelligence and Humanized Computing, 12(9), 8777-8792. https://doi.org/10.1007/s12652-020-02660-1

Ettyem, S. A., Ahmed, I., Ahmed, W. S., Hussien, N. A., Majeed, M. G., Cengiz, K., & Benameur, N. (2023). Intelligent Wireless Sensor Networks for Healthcare: Bridging Biomedical Clothing to the IoT Future. Journal of Intelligent Systems & Internet of Things, 9(2). https://doi.org/ 10.54216/JISIoT.090203

https://www.kaggle.com/datasets/hankyujang/healthcare-personnel-movement-data

Ivanov, M., Markova, V., & Ganchev, T. (2020, September). An overview of network architectures and technology for wearable sensor-based health monitoring systems. In 2020 International Conference on Biomedical Innovations and Applications (BIA), pp. 81-84. https://doi.org/10.1109/BIA50171.2020.9244286

Jain, P., Panesar, S. F., Talwar, B. F., & Sah, M. K. (2021). IoT-Based Solutions for Smart Healthcare. Emerging Technologies for Healthcare: Internet of Things and Deep Learning Models, 25-67. https://doi.org/10.1002/9781119792345.ch2

JARIAL, R., DUBEY, A., & DUBEY, A. (2024). Real-Time Health Monitoring Using IoT Sensors. Advanced Research in Electronic Devices for Biomedical and Health, 181.

Lamonaca, F., Carnì, D. L., & Scuro, C. (2021, October). Synchronization of Wireless Sensor Networks for Biomedical Measurement Systems. In 2021 15th International Conference on Advanced Technologies, Systems and Services in Telecommunications (TELSIKS), pp. 325-328. https://doi.org/10.1109/TELSIKS52058.2021.9606332

Nayak, M., & Barman, A. (2022). A real-time cloud-based healthcare monitoring system. In Computational Intelligence and Applications for Pandemics and Healthcare, pp. 229-247. https://doi.org/ 10.4018/978-1-7998-9831-3.ch011

Rajan Jeyaraj, P., & Nadar, E. R. S. (2022). Smart-monitor: Patient monitoring system for IoT-based healthcare system using deep learning. IETE Journal of Research, 68(2), 1435-1442. https://doi.org/10.1080/03772063.2019.1649215

Salunke, G. D., Singh, V. P., & Jadhav, C. R. (2022). A Review Approach to Modeling, Analysis, and Design Framework for Wireless Sensor Network Health Monitoring Systems. Journal of Pharmaceutical Negative Results, 165-177.https://doi.org/ 10.47750/pnr.2022.13. S02.24

Subasini, C. A., Karuppiah, S. P., Sheeba, A., & Padmakala, S. (2021). Developing an attack detection framework for wireless sensor network-based healthcare applications using hybrid convolutional neural network. Transactions on Emerging Telecommunications Technologies, 32(11), 4336. https://doi.org/10.1002/ett.4336

Uddin, R., & Koo, I. (2024). Real-Time Remote Patient Monitoring: A Review of Biosensors Integrated with Multi-Hop IoT Systems via Cloud Connectivity. Applied Sciences, 14(5), 1876. https://doi.org/10.3390/app14051876

Vistro, D. M., Munawar, A., Iftikhar, A., Qasim, A., & Rehman, A. U. (2020). Tertiary care hospital monitoring system using wireless sensors. Journal of Critical Reviews, 7(10), 1504-1511. http://dx.doi.org/10.31838/jcr.07.10.281

Zhao, J., & Li, G. (2020). Study on real-time wearable sport health device based on body sensor networks. Computer Communications, 154, 40-47. https://doi.org/10.1016/j.comcom.2020.02.045