International Journal of Electrical and Computer Engineering (IJECE)
Vol. 15, No. 3, June 2025, pp. 2888~2899
ISSN: 2088-8708, DOI: 10.11591/ijece.v15i3.pp2888-2899

Remote medical care monitoring system

Amer Alsaraira[1], Samer Alabed[1], Omar Saraereh[2]
[1]Biomedical Engineering Department, School of Applied Medical Sciences, German Jordanian University, Amman, Jordan
[2]Department of Electrical Engineering, Faculty of Engineering, The Hashemite University, Zarqa, Jordan

Article Info

Article history:

Received Feb 7, 2024
Revised Jan 19, 2025
Accepted Mar 5, 2025

Keywords:

Digital transformation
Intelligent health care system
Medical device
Sustainability
Sustainable medical system
internet of things
User-friendly design

ABSTRACT

Neglecting one's health is a major contributor to the decline in overall well-being, often resulting in the onset of various diseases and health issues. The avoidance of such complications becomes feasible with the introduction of a device capable of monitoring heart pulses at regular intervals, ideally every 60 seconds. The main goal of this article is to design a healthcare system that ensures continuous monitoring of heart activity and temperature, functioning as a proactive tool to keep individuals informed about their physiological parameters. This involves the incorporation of a heart rate sensor and temperature sensor in a wearable device, essentially serving as a first aid tool. The heart rate is measured by detecting pulses and calculating beats per minute, utilizing an appropriate heart monitoring sensor tailored to the specific needs of the individual. The main concept revolves around designing a wearable device that harnesses the capabilities of the digital age, making use of features such as wireless sensors and rapid data transfer through the internet of things, accessible on various smart devices. The device focuses on detecting and monitoring heart rate and temperature, with the sent data being relayed to the healthcare provider. The doctor can then monitor the patient's status through the displayed data on thing-speak.

Corresponding Author:

Amer Alsaraira
Biomedical Engineering Department, School of Applied Medical Sciences, German Jordanian University
Amman 11180, Jordan
Email: amer.alsaraira@gju.edu.jo

1. INTRODUCTION

Recently, humans have many factors that can expose them to perilous situations requiring immediate assistance, spanning psychological, physical, and environmental influences. The multitude of potential life-threatening scenarios necessitates a continuous commitment to ensuring human safety around the clock. Conversely, a prevalent and critical issue lies in the lack of convenient and accessible healthcare systems, presenting a persistent threat to individuals daily. Challenges like congested ways hindering medical assistance and the time and financial burdens associated with crowded hospitals and costly health check-ups contribute to this problem. Addressing these concerns, an innovative smart wearable healthcare system has been developed which is specifically designed to regularly monitor two vital body parameters: heart rate and body temperature. In cases of abnormal temperature readings, a light emitting diode (LED) will signal a specific color, while abnormal heart rate readings trigger an automatic message sent to the doctor, along with the patient's location for immediate assistance. The measured parameters are conveniently posted on the thing-speak website and a mobile application. Notably, the compact smart system is designed to operate both with and without internet connectivity, ensuring continuous wearer safety.

2. LITERATURE REVIEW

Throughout history, medicine has been instrumental in driving human progress, with innovations in the medical field making significant contributions to both disease prevention and treatment. Initially, medicine began with homemade herbal remedies as a primary mode of treatment. Currently, the clear collaboration between medicine and technology is evident, with many pivotal technological breakthroughs shaping the medical field. The forefront of medicine prominently features many technological advancements that have become indispensable. Sensor technology forms the foundation of most contemporary medical devices, providing doctors with enhanced capabilities for diagnosis and treatment. The continuous evolution of technology in medicine introduces innovative and beneficial systems, often referred to as 'modern medicine' by many. In healthcare systems worldwide, it's essential to consistently perform ongoing observation of patients' essential indicators, which include breathing rate, pulse, cardiac rhythm, blood pressure, and oxygen levels. Healthcare professionals vigilantly observe these parameters to guarantee precise and timely evaluations of patients' health conditions. Monitoring technologies employ non-intrusive sensors to gather and present physiological information [1], [2]. The connection between intensive care and patient resuscitation lies in its role in identifying health issues and preventing complications. The earliest documented reference to patient intensive care dates back to 1550 BC in the Ebers papyrus, where ancient Egyptian physicians recognized the correlation between peripheral pulse and heartbeat [3]. The integration of electronic components into healthcare dates back to Waller's exhibition in 1887, which highlighted the electrical phenomena linked to the human heart's contractions. In the 1950s, there was widespread adoption of the electrocardiogram (ECG) for monitoring cardiac activity during and post-surgery. Subsequently, alarms were integrated into these monitoring devices to notify medical personnel of deviations in vital signs like heart rate, respiratory rate, and blood pressure. Initially, there were issues with false alarms, but adjustments were made by narrowing down the frequency range [4]–[6].

In the 19th century, healthcare practitioners and biomedical researchers worked together to develop instruments focused on exploring and advancing the comprehension of the human body. Innovations such as microscopes and thermometers were developed to gain insights into the internal workings of the human body. A significant contribution came in 1816 from Rene Laennec, who invented the stethoscope, revolutionizing patient diagnoses by letting physicians to auscultate the chest. Before the invention of the stethoscope, physicians used to listen to patients' breathing and heartbeat by placing their ears directly onto the chest [7], [8]. Historical thermometers relied on fluids expanding and contracting within a glass tube to gauge body temperature, reflecting temperature shifts. Galileo Galilee introduced the thermoscope in 1592, which lacked a numerical scale and merely indicated temperature variations. The first thermometer featuring a scale was developed by the Italian physician Santorio, albeit early iterations were notably imprecise due to a rudimentary grasp of liquid expansion and contraction, as well as challenges in crafting thin glass tubes. In 1714, Gabriel Fahrenheit significantly improved accuracy by inventing the initial mercury thermometer. Subsequently, Anders Celsius further perfected temperature measurement with the introduction of the Celsius scale in 1742, which is still widely utilized today [9], [10]. The widespread utilization of thermometers in healthcare settings did not become common until the 1800s. In 1868, Carl Wunderlich, a German physician, conducted a comprehensive investigation at Leipzig University Hospital, where he meticulously recorded temperature measurements from over 25,000 patients. Through extensive analysis of this data, Wunderlich established the standard range for human body temperature as 36.3 °C to 37.5 °C. Furthermore, he observed that specific diseases manifest unique fever patterns. Wunderlich's findings LED hospitals to adopt regular temperature monitoring of patients and the representation of temperature patterns on charts. This practice proved beneficial for physicians in evaluating patient progress and monitoring temperature trends [9], [11]. Initially, essential indicators like heart rates, respiratory rates, and blood pressure measurements were obtained separately. Nevertheless, this method has evolved over time, with hospitals currently utilizing integrated data collected from bedside instruments that track vital health parameters [12]–[15]. Traditionally, monitoring of patients' vital signs was primarily reserved for individuals who were unwell or hospitalized. However, continuous advancements in technology and the emergence of the internet of things (IoT) have broadened the availability of various monitors and sensors to a wider population. In previous years, hospitals predominantly relied on stationary monitors and sensors for monitoring patient health. Presently, a diverse array of portable monitors is accessible to both hospitalized and non-hospitalized individuals for monitoring their health status [1], [16]–[18].

The increasing adoption of telemedicine and the IoT has stimulated the development of bio-wearable technologies aimed at remotely capturing and transmitting medical information to healthcare providers. The prompt accessibility of medical data enables physicians to swiftly commence essential treatments, while the user-friendly nature of such systems simplifies remote data collection and transmission, eliminating the need for human intervention [19], [20]. One illustration of this technology is the VMOTE-II, a wearable biomedical device equipped with sensors capable of detecting various biomedical metrics, including expired and inspired carbon dioxide levels, respiration rate, skin temperature, heart rate, galvanic skin resistance, and blood oxygenation [21]. Numerous research findings suggest that health monitoring can be smoothly incorporated into technologies such as mobile phones, wristbands, and watches. This progress is particularly beneficial for individuals leading hectic lives, making it challenging for them to arrange frequent appointments at healthcare facilities for check-ups. For instance, a Bluetooth-enabled device can monitor blood pressure levels with low energy consumption. Integrated into a home-based blood pressure monitoring device, this tool synchronizes with a smartphone, enabling the monitoring system to send blood pressure readings directly to smartphones. This capability empowers individuals to make well-informed decisions about their health [22]. The landscape of technology is dynamic, continually evolving and playing an essential role in our daily routines. This is particularly noticeable in healthcare, where specific devices are consistently used and relied upon. Equipment like ECG machines and pulse oximeters is employed for monitoring vital signs, contributing to the process of diagnosis and treatment. Moreover, a range of devices available to the general public not only track vital signs but also provide accurate health-related data. Some of these devices are detailed below:

a. The smart watch is designed to provide the wearer with particular body metrics like ECG, heart rate, blood pressure, and calorie details. It has the capability to retain gathered data for subsequent examination. The device is crafted to resemble the dimensions of a standard watch, and it might even be lighter, guaranteeing comfort for everyday wear. Its Bluetooth connectivity makes it compatible with various other devices in the market. Nevertheless, a potential limitation arises in situations where the wearer experiences a health issue, as the device lacks the capability to transmit data to emergency services for immediate medical care [23].
b. The VMOTE-II health monitoring system offers the ability to deliver real-time medical information at a frequency of around three times per second. It operates by integrating medical sensors into a single wearable and portable device. The system includes a base station that links to a standard PC or laptop, facilitating communication with medical experts via an Internet connection. Its primary advantages are the prompt accessibility of wearer health data and its non-invasive nature. However, a significant limitation is its lack of ECG monitoring [21].
c. The My-Chart App establishes an electronic connection between the user and the physician and is compatible with both Apple and Android devices, downloadable from their respective stores. Its advantages include the user's capacity to communicate with doctors via email, review prescriptions, renew medications, and retrieve previous test outcomes. Additionally, the application facilitates easy appointment booking and secure bill payment. However, drawbacks include the absence of a note-taking feature, which may be crucial for individuals who prefer documenting their consultations. The application necessitates internet accessibility and is currently utilized only by specific clinics in the United States [24].
d. The blood pressure monitoring system, which operates on Bluetooth technology, works by combining a standard blood pressure device with a Bluetooth low energy (BLE) monitoring system. This configuration enables the system to send the recorded blood pressure measurements to a smartphone via BLE, where heart rate, systolic, and diastolic blood pressure readings are stored. Utilizing BLE enables smooth connectivity with other devices through its specific profile, facilitating rapid data transfer within a short timeframe. However, the system's limited portability in comparison to smaller and lighter devices poses a challenge for users seeking the convenience of measuring their blood pressure anytime, anywhere [22], [25].

3. METHOD

During the initial phase, the work embarked on the implementation of the first proposed hardware system to assess the functionality of its individual components. The resulting configuration, as shown in Figure 1, served as a crucial step in validating the feasibility of the initial design. After this initial implementation, systematic modifications were introduced to improve and refine the initially proposed system. This iterative process involved refining the integration of various components, aiming to achieve a more seamless and cohesive system. The outcome of these modifications was a consolidated and refined hardware configuration, vividly presented in Figure 2. This intermediate phase marked a notable progression in the development process, highlighting the design's flexibility to incorporate essential enhancements.

The evolution did not stop there. As the work progressed towards its final stages, the integrated system was transformed into a more user-friendly and practical form. The result was the development of the final prototype, creatively depicted in the form of a blazer in Figure 3. This ultimate version represented the culmination of endeavors to attain not only technical prowess but also to devise a design seamlessly integrated into users' everyday routines. The progression from the initial proposed system to the final prototype encapsulated a dynamic process of refinement, innovation, and adaptation. Each stage contributed to the work's evolution, ultimately leading to the creation of a sophisticated and aesthetically appealing hardware prototype that aligned with the envisioned goals of the monitoring system.

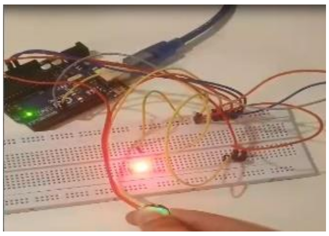

Figure 1. First proposed hardware system

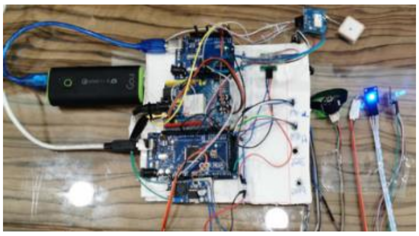

Figure 2. Final proposed hardware system

Figure 3. Final proposed system as a blazer

The components used: the heart rate monitor sensor is developed to monitor a patient's heart rate. This sensor, utilizing the Pittsburgh plate glass (PPG) technique. It functions in both analog and digital modes and identifies variations in blood volume within small blood vessels, guaranteeing accurate and reliable measurements. Consisting of two primary elements, it incorporates miniature circuits to reduce interference utilizing light dependent resistor (LDR) and pairs an LED with a light sensor. To measure the patient’s heart rate, the LED light must be positioned over the vein, as depicted in Figure 4. As the blood frequency in the vein fluctuates with heartbeats, the LDR begins to assess the intensity of the LED. Consequently, during heartbeats, the LED's light absorption causes a decrease in intensity and an increase in the LDR's resistance. Subsequently, the amplifier connected to the LDR converts this resistance into signal voltage, yielding the heart rate measurement. Moreover, its inherent analog-to-digital converter and autonomous error correction capability influenced its selection, eliminating the need for additional conversion steps.

The temperature sensor (LM35) serves to measure the patient's temperature by converting the output voltage into centigrade through a predefined formula. One notable benefit of this component is its capacity to directly measure temperature in Celsius. Its output voltage shows a linear relationship with the temperature in centigrade. Additionally, the LM35 operates at less than 0.08 A and demonstrates minimal self-heating, thereby improving wearer safety compared to alternative sensors on the market, as illustrated in Figure 5.

Wi-Fi module (nRF): The function of this module is to send the wearer's recorded data to the Thing-Speak website, facilitating its visualization on both a laptop and a mobile phone. The nRF module, acting as a Wi-Fi microchip, establishes a connection between the microcontroller and the internet via a system on chip (SOC) that integrates TCP/IP functionalities. Moreover, this module has the capability to autonomously manage Wi-Fi functions or assist an application. Additionally, the nRF's onboard storage and processing capabilities enable seamless integration with other sensors and applications. The decision to utilize this Wi-Fi module was influenced by its 1MB Flash memory capacity, sufficient for storage, and its low power consumption of less than 10 µA as shown in Figure 6.

The GSM module, which stands for global system for mobile communication, is utilized within the healthcare system to dispatch an emergency message to doctors when abnormal readings occur in areas lacking coverage. Primarily, it functions for transmitting and receiving SMS messages and mobile calls. The decision to use GSM stems from its global applicability, capable of functioning across various countries due to its adaptability to different frequencies, as well as its high-speed capability as shown in Figure 7.

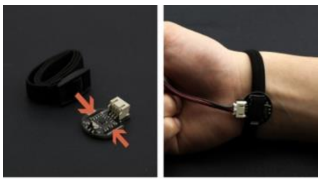

Figure 4. Sensor for monitoring heart rate

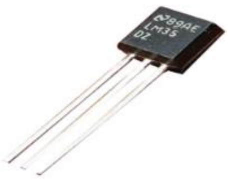

Figure 5. Temperature sensor LM35

Figure 6. WIFI Module nRF

Figure 7. GSM module

The function of the RF transmitter and receiver within the wearable healthcare system is to send and receive the recorded data. These modules operate on a 433MHz radio frequency, facilitating data transfer at a specific rate through an antenna. Additionally, the RF transmitter and receiver function as one-way communication devices. Ultimately, these modules were selected for their availability and compatibility with digital pins as shown in Figure 8.

Arduino Mega: The primary microcontroller utilized in the wearable healthcare system is the Arduino Mega, based on the ATmega2560. It comprises 54 digital input and output pins, 16 analog pins, and 4 serial ports, all of which were advantageous for the prototype. Notably, its flash memory size of 256Kb enhances its capabilities, rendering it a potent microcontroller as shown in Figure 9.

Arduino Uno: The Arduino UNO, a type of microcontroller board, includes both digital and analog input/output pins, alongside features like a power jack, USB connection for computer connectivity, and a reset button. We selected this microcontroller for its ease of use and cost-effectiveness. Specifically, it was utilized as the microcontroller for the receiver circuit in the system, as depicted in Figure 10.

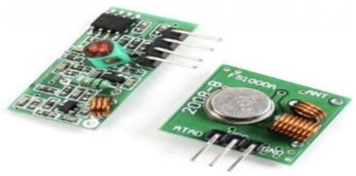

Figure 8. RF transmitter and receiver modules

Figure 9. Arduino Mega

Figure 10. Arduino UNO

Neo-6M GPS module: The GPS module within the healthcare system serves the purpose of pinpointing the patient's location during emergency scenarios. GPS, short for global positioning system, functions by providing essential geographical coordinates-longitude and latitude. These coordinates are subsequently input into the Google Earth website to obtain the precise location. Moreover, the GPS module provides accurate and high-quality outcomes, rendering it an appropriate element for incorporation into the healthcare system as shown in Figure 11.

RGB LED: The RGB LED, representing red, green, and blue lights, serves to indicate the measured data's status within the healthcare system. It displays green for normal readings, red for abnormal ones, and blue for values below the norm. The RGB LED functions through a combination of binary inputs to generate various colors based on the entered numerical combinations. The LED usually contains four pins, with three designated for colors and the remaining one for either positive or negative, depending on whether it's a common cathode or anode variant. The rationale for its use lies in its capability to operate in both digital and analog modes, along with its cost-effectiveness as shown in Figure 12.

LCD screen: An LCD, short for liquid crystal display, is a commonly used screen technology. In the design, we've implemented a 16×2 LCD, capable of exhibiting sixteen characters across two lines. This particular display was chosen due to its cost-effectiveness and easy-to-use programming capabilities. Its primary function is to showcase the data received from the RF receiver as shown in Figure 13.

Figure 11. NE0-6M GPS module

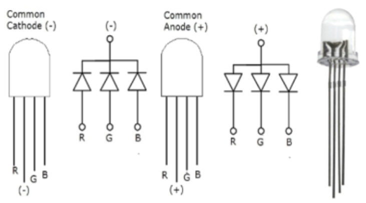

Figure 12. RGB LED

Figure 13. LCD screen

All of these components were connected to gather. Within the block diagram of the transmitter circuit as shown in Figure 14, the components are as follows:

a. Heart rate sensor: detects ECG and heart rate.
b. LM35: temperature sensor for temperature measurement.
c. Power supply: for device functionality.
d. GPS: global positioning system for patient location tracking.
e. GSM: global system for mobile communications, utilized for emergency messaging.
f. RGB: provides notifications to the patient regarding heart rate and temperature sensor readings.
g. RF transmitter: utilizes radio frequency to transmit data via the internet.

This configuration consists of a solitary microcontroller with three input components. The heart rate sensor is a sophisticated apparatus responsible for recording and assessing heart rate, thereby allowing the device to anticipate potential medical issues. The LM35 serves as a temperature sensor, while a power supply is essential for powering both the device and the circuit. Concerning the outputs, the system will utilize RF for transmitting signals to the receiver circuit. GSM is utilized to send out emergency messages to doctors when needed. The RGB module will display three colors: green (to denote a normal range), blue (for readings below normal), and red (indicating an abnormal range). Lastly, the GPS functionality will provide the patient's location in critical situations.

Within the block diagram of the receiver circuit as shown in Figure 15, the components are as follows:

a. RF receiver: captures signals transmitted by the transmitter circuit.
b. Power supply: necessary for the functioning of the device.
c. LCD: short for liquid crystal display, utilized for signal visualization.

The inputs of the receiver circuit encompass the power supply essential for circuit operation and the RF input for receiving signals from the transmitter circuit. Subsequently, the output message will be showcased on an LCD display.

Figure 16 illustrates the system's flowchart, wherein the initial step involves checking the temperature to ensure it remains within normal limits. Once normal temperature readings are confirmed, the system then proceeds to assess the heart rate to ensure it meets acceptable criteria. This cyclical assessment occurs every 5 minutes. In case an abnormal temperature is detected, the device will promptly identify the patient's location and transmit a signal to the hospital. Similarly, if the heart rate deviates from acceptable ranges, the process will repeat.

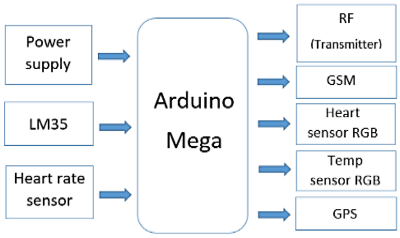

Figure 14. Block diagram illustrating the transmitter circuit

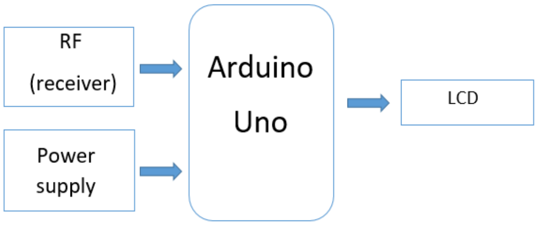

Figure 15. Block diagram illustrating the receiver circuit

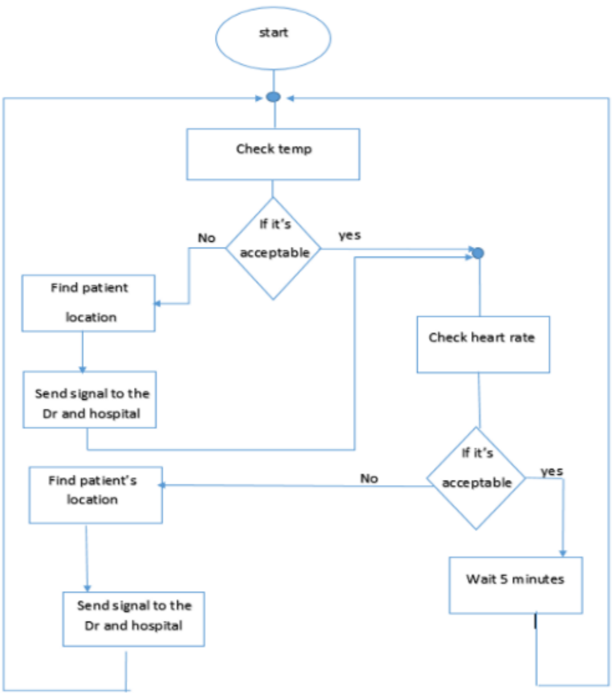

Figure 16. The flowchart of the design

In Figures 17 and 18, the transmitter and receiver circuits, along with their corresponding connections, are illustrated, providing a comprehensive overview of the hardware components and their interconnections within the system. The transmitter circuit's role involves capturing data from sensors or input sources, processing it as needed, and wirelessly transmitting it to the receiver unit. The receiver circuit is responsible for receiving wireless transmissions from the transmitter unit, decoding the data, and processing it for display.

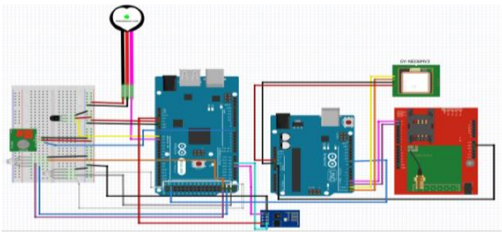

Figure 17. Connection setup for the transmitter circuit

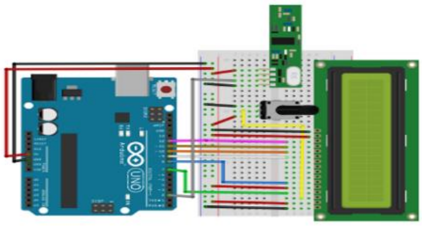

Figure 18. Connection setup for the receiver circuit

4. RESULTS AND DISCUSSION

The initial steps in deploying the wearable healthcare system comprised several tasks. Initially, the temperature sensor was interfaced with the microcontroller to measure body temperature, utilizing a predefined equation within the code to convert voltage output into Celsius temperature. Following this, the RF transmitter was connected to the Arduino Mega, while the RF receiver was paired with the Arduino Uno, facilitating data presentation on the LCD display. Next, the heart rate monitor sensor was incorporated into the transmitter and underwent testing by placing it directly on a human vein to ensure precise heart rate readings. Additionally, two RGB LEDs were included-one to signify temperature readings and the other for heart rate readings. These LEDs were programmed to illuminate green for normal readings, red for abnormal, and blue for values below normal. Once the coherence of the sensor readings was verified and the LED colors were synchronized with the readings, along with the successful display of transmitted data on the LCD screen, the subsequent phase involved integrating the Wi-Fi module. This element facilitated the transmission of collected data to the internet. Subsequently, the microcontroller was connected to the Thing-Speak website via the Wi-Fi module, allowing the measured data to be showcased on the website accessible through both a laptop and a mobile.

Subsequently, the GSM module was integrated into the system, programmed to send an emergency message to the mobile phone upon detecting abnormal sensor readings. Furthermore, a GPS module was added to accurately determine the wearer's location in emergency situations. In the last stage of implementation, the system was subjected to testing under diverse conditions, demonstrating impeccable functionality without encountering any issues. During testing, the process of gathering and displaying data in the last stage took around 20 seconds, although this duration was reduced to less than 10 seconds under optimal conditions. Consequently, the average time required for data collection was established at 15 seconds. Lastly, an adjustable strap was introduced to the heart rate monitor sensor to ensure precise positioning directly above the vein for accurate readings. The prototype underwent a test on an individual for thirty minutes in normal conditions. The objective was to verify the device's functionality, assess the accuracy of its readings, and determine the time taken for each reading. The device continuously recorded readings without interruption, and the findings are presented in Figure 19.

In the context of the monitoring system, Figure 20 serves as a pivotal visualization representing the output testing results provided on Thing Speak. This platform enables users to collect, analyze, and visualize data from various sources, making it ideal for displaying physiological metrics such as heart rate. The readings showcased in Figure 20 depict the normal values of an adult's heart rate, typically ranging between 60 and 120 beats per minute (BPM). These normal values serve as a reference range commonly observed in healthy adults, reflecting a resting or moderately active state. By interpreting these measurements visually, individuals can promptly determine if someone's heart rate aligns with the anticipated range, offering valuable indications about their heart health and general welfare. Conversely, Figure 21 showcases abnormal values detected during the testing process, highlighting deviations from the normal range established for adult individuals. These abnormal readings may indicate potential health issues or anomalies that warrant further investigation or intervention. For example, a heart rate exceeding 120 BPM or falling below 60 BPM could signal cardiac arrhythmias, cardiovascular conditions, or other underlying health concerns. Through recognizing and displaying these irregular measurements, the monitoring system enables users to take proactive steps in addressing health concerns and seeking necessary medical assistance when required. Furthermore, Figure 22 illustrates how these output testing results can be displayed on a gauge, providing a visually intuitive representation of the measured values. Gauges are effective visualization tools that allow users to quickly assess whether readings fall within normal parameters or deviate from them. By presenting the data in a clear and easily interpretable format, gauges facilitate informed decision-making and proactive health management.

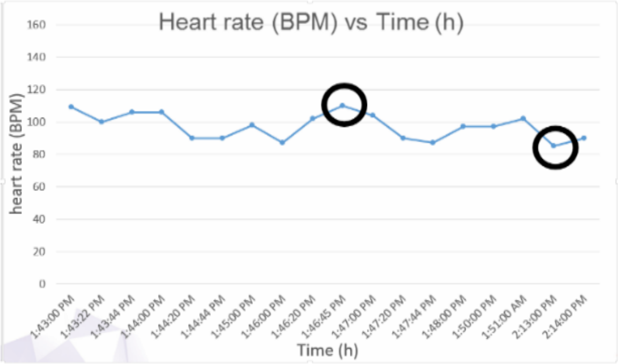

Figure 19. Statistics of the heart rate vs time

Figure 20. Heart rate data obtained from think-speak (normal)

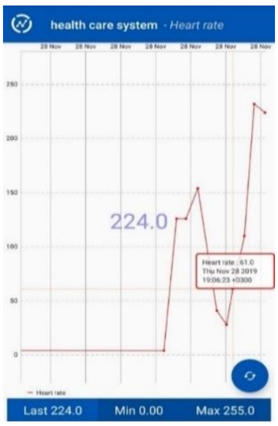

Figure 21. Heart rate data obtained from think-speak (abnormal)

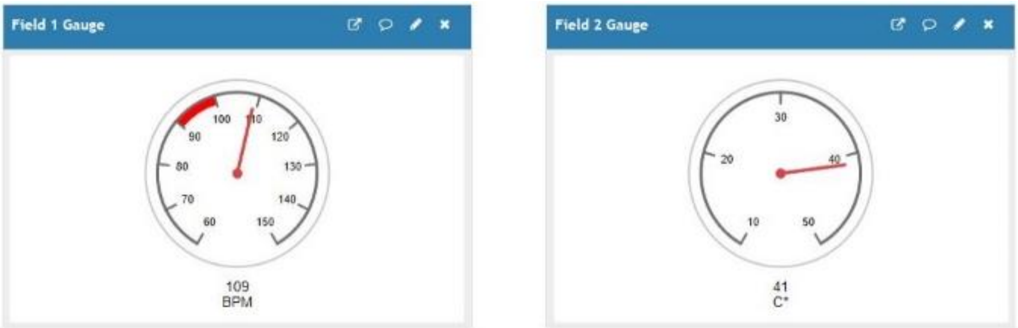

Figure 22. Normal heart rate and abnormal temperature

In Figure 23, the system's response to abnormal values is showcased, illustrating a crucial aspect of proactive healthcare monitoring and management. When the system identifies abnormal values, it's programmed to activate a notification system, sending a message to a specified contact or recipient. This feature serves as an alert system, promptly notifying relevant stakeholders such as healthcare providers, caregivers, or the individual being monitored about potential health concerns that require attention. The transmission of messages in response to abnormal values plays a pivotal role in facilitating timely interventions and appropriate follow-up actions. By swiftly alerting healthcare professionals or caregivers, the system allows them to evaluate the circumstance, take appropriate actions, and offer prompt medical aid or advice. This proactive approach to healthcare monitoring helps prevents potential complications, improve health outcomes, and enhance overall patient safety and well-being.

In the finalized design of the monitoring system, Figures 24 and 25 depict the implementation and functionality of the RGB LED, which plays a crucial role in providing visual feedback to users. The RGB LED's capacity to produce different colors enables dynamic data representation and improves user engagement with the system. Figure 24 demonstrates one possible scenario where both the heart rate and temperature readings are within normal ranges. In this instance, the RGB LED emits a soothing green light, serving as an indicator of normalcy and providing reassurance to the user. The green light signifies that all monitored parameters are within acceptable limits, offering a visual confirmation of the individual's well-being. Conversely, Figure 25 showcases a different scenario where the heart rate remains normal, but the temperature reading exceeds the expected range, indicating an abnormal condition such as fever. In this case, the RGB LED displays a combination of colors to convey the status of the monitored parameters. The green light remains indicative of the normal heart rate, ensuring consistency in visually representing this aspect. However, the abnormal temperature triggers the illumination of a red light, signaling a deviation from the expected range and prompting attention from the user or caregiver.

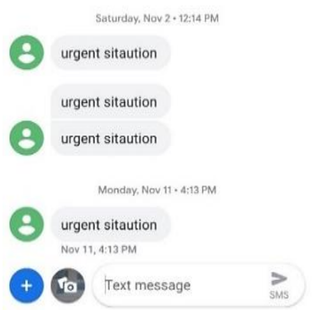

Figure 23. Received emergency message

Figure 24. Normal heartrate and temperature RGB LED results

Figure 25. Normal heartrate and abnormal temperature RGB LED

The primary goal of developing the healthcare system is to create a solution that meets the needs of users while ensuring sustainability, scalability, and reliability. To achieve this, several key design principles have been emphasized:

a. User-friendly design: the device is engineered to be intuitive and easy to use, catering to a wide range of users, including individuals with varying levels of technical expertise. Its simple operation ensures that users can easily integrate it into their daily routines without encountering significant barriers.
b. Sustainability: sustainability is prioritized throughout the design process, with a focus on creating a device that can withstand long-term use. Utilizing lightweight materials not only improves portability but also aids in minimizing the device's ecological impact. Integration of a rechargeable battery, and potential plans for solar battery integration, further enhance sustainability by minimizing reliance on disposable batteries and reducing overall energy consumption.
c. Scalability: the device is designed to accommodate potential future enhancements and expansions, ensuring scalability to meet evolving healthcare needs. Its lightweight construction allows for easy adaptation to different user requirements and preferences. This scalability guarantees that the healthcare system can expand and adjust in tandem with technological advancements and shifts in healthcare methodologies.
d. Dependability and reliability: rigorous testing procedures have been conducted to validate the device's performance across various patient scenarios. The system's consistent delivery of precise and dependable data builds trust in its functionality, assuring users of the reliability of the information it offers. Robust signal transmission and reception mechanisms further enhance reliability, minimizing the risk of data loss or communication failures. In emergency situations, the system's prompt dispatch of messages underscores its reliability in ensuring user safety and well-being.

5. CONCLUSION

The smart healthcare system that has been developed-a wearable vest-provides multifaceted health monitoring, benefiting all segments of society. Its lightweight and wearable design cater to individuals who prefer minimal accessories. Suitable for both young and elderly users, the device operates autonomously, constantly monitoring heart rate and temperature without requiring user intervention. Its LED indicators visually display parameter changes, chosen for their simplicity and universal understanding. With a focus on wearer safety, the system promptly alerts a doctor of the wearer's location in emergency situations, facilitating rapid medical assistance and reducing the risk of exacerbating symptoms. Moreover, its affordability, ease of use, and autonomous anomaly detection reduce the necessity for frequent doctor visits or expenses for regular check-ups. This contributes to decongesting hospitals, curbing contamination, and lowering disease transmission rates. Additionally, reduced hospital visits translate to lesser transportation usage, diminishing air pollution generated by vehicles and positively impacting the environment.

ACKNOWLEDGMENTS

The authors would like to express their gratitude to the German Jordanian University and Aeon Medical Supplies Company for their generous support of this work.

FUNDING INFORMATION

This work is funded by Seed Grant No. SAMS 03/2023 from the German Jordanian University under decision number 2023/15/344 and is also supported by a grant from Aeon Medical Supplies Company. The authors express their gratitude for this generous support.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Amer Alsaraira	✓	✓	✓	✓				✓	✓				✓	
Samer Alabed									✓	✓		✓	✓	✓
Omar Saraereh					✓	✓	✓		✓		✓			

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

REFERENCES

[1] K. Boikanyo, A. M. Zungeru, B. Sigweni, A. Yahya, and C. Lebekwe, "Remote patient monitoring systems: Applications, architecture, and challenges," *Scientific African*, vol. 20, p. e01638, Jul. 2023, doi: 10.1016/j.sciaf.2023.e01638.

[2] L. P. Malasinghe, N. Ramzan, and K. Dahal, "Remote patient monitoring: a comprehensive study," *Journal of Ambient Intelligence and Humanized Computing*, vol. 10, no. 1, pp. 57–76, Oct. 2019, doi: 10.1007/s12652-017-0598-x.

[3] J. S. S. Stewart, "The aim and philosophy of patient monitoring," *Postgraduate Medical Journal*, vol. 46, no. 536, pp. 339–343, Jun. 1970, doi: 10.1136/pgmj.46.536.339.

[4] M. Rivera-Ruiz, C. Cajavilca, and J. Varon, "Einthoven's string galvanometer: The first electrocardiograph," *Texas Heart Institute Journal*, vol. 35, no. 2, pp. 174–178, 2008.

[5] R. Vincent, "From a laboratory to the wearables: a review on history and evolution of electrocardiogram," *Iberoamerican Journal of Medicine*, vol. 4, no. 4, pp. 248–255, Sep. 2022, doi: 10.53986/ibjm.2022.0038.

[6] A. Baldassarre *et al.*, "The role of electrocardiography in occupational medicine, from Einthoven's invention to the digital era of wearable devices," *International Journal of Environmental Research and Public Health*, vol. 17, no. 14, pp. 1–28, Jul. 2020, doi: 10.3390/ijerph17144975.

[7] E. Grodzinsky and M. Sund Levander, "History of the Thermometer," in *Understanding Fever and Body Temperature*, Springer International Publishing, 2020, pp. 23–35. doi: 10.1007/978-3-030-21886-7_3.

[8] M. Ali, "A multidisciplinary approach to innovations in biomedical engineering for improved patient care and well-being," *Archive of Biomedical Science and Engineering*, vol. 9, no. 1, pp. 001–009, Aug. 2023, doi: 10.17352/abse.000029.

[9] J. M. S. Pearce, "A brief history of the clinical thermometer," *QJM: An International Journal of Medicine*, vol. 95, no. 4, pp. 251–252, Apr. 2002, doi: 10.1093/qjmed/95.4.251.

[10] M. Bellis, "The history of the thermometer," *ThoughtCo*, 2021. https://www.thoughtco.com/the-history-of-the-thermometer-1992525 (accessed Apr. 05, 2023).

[11] F. J. Ring, "Pioneering progress in infrared imaging in medicine," *Quantitative InfraRed Thermography Journal*, vol. 11, no. 1, pp. 57–65, Jan. 2014, doi: 10.1080/17686733.2014.892667.

[12] F. L. Becking-Verhaar, R. P. H. Verweij, M. de Vries, H. Vermeulen, H. van Goor, and G. J. Huisman-de Waal, "Continuous vital signs monitoring with a wireless device on a general ward: A survey to explore nurses' experiences in a post-implementation period," *International Journal of Environmental Research and Public Health*, vol. 20, no. 10, p. 5794, May 2023, doi: 10.3390/ijerph20105794.

[13] J. P. L. Leenen, C. Leerentveld, J. D. van Dijk, H. L. van Westreenen, L. Schoonhoven, and G. A. Patijn, "Current evidence for continuous vital signs monitoring by wearable wireless devices in hospitalized adults: Systematic review," *Journal of Medical Internet Research*, vol. 22, no. 6, p. e18636, Jun. 2020, doi: 10.2196/18636.

[14] Y. Eddahchouri, R. V. Peelen, M. Koeneman, H. R. W. Touw, H. van Goor, and S. J. H. Bredie, "Effect of continuous wireless vital sign monitoring on unplanned ICU admissions and rapid response team calls: a before-and-after study," *British Journal of Anaesthesia*, vol. 128, no. 5, pp. 857–863, May 2022, doi: 10.1016/j.bja.2022.01.036.

[15] J. P. L. Leenen, E. M. Dijkman, A. van Hout, C. J. Kalkman, L. Schoonhoven, and G. A. Patijn, "Nurses' experiences with continuous vital sign monitoring on the general surgical ward: a qualitative study based on the Behaviour Change Wheel," *BMC Nursing*, vol. 21, no. 1, Mar. 2022, doi: 10.1186/s12912-022-00837-x.

[16] M. A. Shiwani, T. J. A. Chico, F. Ciravegna, and L. Mihaylova, "Continuous monitoring of health and mobility indicators in patients with cardiovascular disease: A review of recent technologies," *Sensors*, vol. 23, no. 12, p. 5752, Jun. 2023, doi: 10.3390/s23125752.

[17] M. Weenk *et al.*, "Continuous monitoring of vital signs using wearable devices on the general ward: Pilot study," *JMIR mHealth and uHealth*, vol. 5, no. 7, p. e91, Jul. 2017, doi: 10.2196/mhealth.7208.

[18] C. Huang, J. Wang, S. Wang, and Y. Zhang, "Internet of medical things: A systematic review," *Neurocomputing*, vol. 557, p. 126719, Nov. 2023, doi: 10.1016/j.neucom.2023.126719.

[19] M. M. Abdellatif and W. Mohamed, "Telemedicine: An IoT based remote healthcare system," *International journal of online and biomedical engineering*, vol. 16, no. 6, pp. 72–81, May 2020, doi: 10.3991/ijoe.v16i06.13651.

[20] Z. Tang, L. Jiang, X. Zhu, and M. Huang, "Aninternet of things-based home telehealth system for smart healthcare by monitoring sleep and water usage: A preliminary study," *Electronics (Switzerland)*, vol. 12, no. 17, p. 3652, Aug. 2023, doi: 10.3390/electronics12173652.

[21] E. Hughes, M. Masilela, P. Eddings, A. Rafiq, C. Boanca, and R. Merrell, "VMote: A wearable wireless health monitoring system," in *HEALTHCOM 2007: Ubiquitous Health in Aging Societies - 2007 9th International Conference on e-Health Networking, Application and Services*, Jun. 2007, pp. 330–331. doi: 10.1109/HEALTH.2007.381665.

[22] Z. M. Lin, C. H. Chang, N. K. Chou, and Y. H. Lin, "Bluetooth low energy (BLE) based blood pressure monitoring system," in *Proceedings of 2014 International Conference on Intelligent Green Building and Smart Grid, IGBSG 2014*, Apr. 2014, pp. 1–4, doi: 10.1109/IGBSG.2014.6835225.

[23] F. Sarhaddi *et al.*, "A comprehensive accuracy assessment of Samsung smartwatch heart rate and heart rate variability," *PLoS ONE*, vol. 17, Dec. 2022, doi: 10.1371/journal.pone.0268361.

[24] K. Anderson, O. Burford, and L. Emmerton, "Mobile health apps to facilitate self-care: A qualitative study of user experiences," *PLoS ONE*, vol. 11, no. 5, p. e0156164, May 2016, doi: 10.1371/journal.pone.0156164.

[25] G. Alfian, M. Syafrudin, M. F. Ijaz, M. A. Syaekhoni, N. L. Fitriyani, and J. Rhee, "A personalized healthcare monitoring system for diabetic patients by utilizing BLE-based sensors and real-time data processing," *Sensors (Switzerland)*, vol. 18, no. 7, p. 2183, Jul. 2018, doi: 10.3390/s18072183.

BIOGRAPHIES OF AUTHORS

Amer Alsaraira holds a Ph.D. in biomedical engineering from Monash University since the year 2009. He is currently an assistant professor at Biomedical Engineering Department at German Jordanian University-Jordan since 9/2022. He is teaching various courses for the undergraduate students, supervising their graduation projects, supervised undergraduate students, and a member of many committees at the department. His current research is in the fields of modeling and simulation of biomedical systems, wireless networks, and DSP. He can be contacted at email: Amer.Alsaraira@gju.edu.jo.

Samer Alabed is currently an associate professor, the director of accreditation and quality assurance center and the director of e-learning and academic performance improvement center at the German Jordanian University, Jordan. Further information is available on his homepage: http://drsameralabed.wixsite.com/samer. He can be contacted at email: samer.alabed@gju.edu.jo.

Omar Saraereh received the Ph.D. degree in electrical and electronic engineering from Loughborough University, U.K., in 2005. He is currently a full professor with the Department of Electrical Engineering, Hashemite University, Jordan. He has published many articles in various international journals and conferences. He can be contacted at email: eloas2@hu.edu.jo.