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Design and Implementation of an IoT-Based System for Remote Monitoring of Vital Signs

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Abstract: This paper presents the development of telemonitoring system for real time measurement of crucial vital signs like human temperature, heartbeat, oxygen level (SPO_2), and ECG signals. The system analyzes human signal data by using a Raspberry Pi 4 as a unit control with input devices represented by medical sensors. The doctor can see the vital information on a touchscreen and at the same time can transmit it to the ThingSpeak IoT platform for telemonitoring for storing and analyzing. To keep continuous system working, a supercharger was used instead of a normal charger and an uninterrupted power supply (UPS) to keep the medical data during electrical cutoffs. In this study, it was enhanced the system's stability, particularly in the field and home-based monitoring. The system generated alerts upon finding abnormal values, enabling instant medical intervention. The system operated using medical sensors, which are prone to minor fluctuations due to high sensitivity. The validation was carried out through (i) comparative checks against certified reference devices for temperature, heart rate, and SpO_2 and (ii) field testing on 20 individuals with diverse ages and health conditions, streamed across four ThingSpeak channels with color-coded notifications. Recorded ranges during testing were 97.5–104.4°F for temperature, 69–130 bpm for heart rate, 88–99% for SpO_2, and 0.5–1.7 mV for ECG, demonstrating practical applicability for home and field monitoring with rapid anomaly detection. It recommend applying the Advanced Encryption Standard (AES) for future enhancements to secure sending data. AES progress was strong, symmetric encryption that helps protect the confidentiality and privacy of patient data sent over the internet. This system demonstrated a practical low-cost solution for contact-based remote healthcare monitoring with strong potential for scalability and improved security.

Keywords: Medical sensor, Raspberry Pi4, ThinkSpeak, Advanced Encryption Standard

Introduction

The strength of management and control has grown in many fields, such as energy and communication, by using the Internet of Things system with these fields (Al-Dulaime et al., 2024; Hamza & Duhis, 2024). In the healthcare field, IoT has significantly advanced the possibility of easily supervising patient vital readings. This reading is sent to the device of the doctors responsible for their care, enabling them to access it from a remote location. An important step forward in health is the introduction of EHRs, which consist of the digital archiving and administration of patients' health records (Abdulmalek et al., 2022; Ramalakshmi et al., 2024). Medical facilities managers may now remotely monitor their patients' cases in real time thanks to IoT devices, which improved patient health outcomes by allowing for fast delivery of medical instructions (Okolo et al., 2024). Because easy access to health records can practically save patient lives, such monitoring is of the utmost importance in the treatment of critical cases, chronic diseases, elderly care, and emergency status (Abdulmalek et al., 2022; Chauhan et al., 2024). When creating new methods for remotely tracking and supervising health status, the use of IoT

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technology is essential. This modern method is represented by the use of multiple sensors, such as those for electrocardiography (ECG), temperature, blood pressure, skin, oximeters, and heart rate monitors (Khan et al., 2024), which allow healthcare personnel to keep monitoring a patient's health (Hassan et al., 2021). The sensors read a person's status score and then send the information to a central database for evaluation. A responsible doctor will read patients' vitals and administer the situation as it's needed to make decisions, all from a remote distance with this technology (Akkaş et al., 2020). For example, some researches displayed vital signs devices like BPM and SPO2 by using a MAX30100 device to send warnings through Telegram (on phone) when get abnormal readings as in (Nwibor et al., 2023) This introduces remote displayed of vital signs through an IoT platform with high accuracy of storing, analysing and ease of operation and control. In another study where it showed an online tracking method for pacemaker sufferers using IoT to send ECG signal, temperature, and heart beats information via Wi-Fi to the platform (Thinger.IO) (Luthfiyah et al., 2022). That helped doctors to control patients' cases remotely in a time. Moreover, some research discusses the issue from another angle, reviewing the importance of having a system for transmitting vital signs to the patient in their lives like (Abdul-jabbar & Abed, 2020; Nookala Venu et al., 2022).

IOT-based system uses a medical device to measure basic vital signs improve healing process. Some studies contributed to presents an IoT-based intelligence healthcare monitoring system to get trac, store and analyze patient data continuously artificial intelligence techniques as in (Weenk et al., 2020). The device displayed parameters like pulse rate, electrocardiogram (ECG) and environmental sound levels, thereby facilitating early revealing and fast medical intervention. Another study refering to developing a wearable, and wireless EEG inspection system with low cost that can read signals and sent them to a controller like Raspberry Pi unit to process and display the reading using library of EEG sensor that showes in (Ahmad). As an example for a system that using Arduino and Raspberry Pi as a unit control to get a intelligence monitoring model submitted by this research (Al-Awadhi & Harris, 2024). A medical system can effectively worked at home to tracking the elderly, that enhancing the treatment accuracy and effectiveness (Jebane et al., 2021). To provide a healthy system that utilizes an Arduino as the control unit with input sensors that can measure pulse rate, temperature and blood pressure by using ESP8266 module for linking to a IoT platform for instant storage and analysis of health informations. Some papers has depended on the IoT platform to create a remote healthcare tracking system using it during the COVID-19 pandemic to reduce direct touch. System consists of a Raspberry Pi as the central unit connected to a many sensors for measuring temperature, oxygen saturation, and ECG then data sent via MQTT to the Node-RED platform as in (Kamarozaman & Awang, 2021).

A medical health system is presented in this paper that can read body parameters such as heart rate, temperature, ECG, and oxygen levels in blood through academic medical sensors. It collects vital signs reading for the examined people and sends them to IoT platform for analysis and storage. The model used a Raspberry Pi as processor unit to read data from the sensors, processing it, storge it with an internal memory unit, then transmit data to Thing Speak platform, enabling supervisor to track the data and triggers an alert for abnormal reading crosses the range so that specialists can give the correct medical decision at the right time. Additionally, the proposed system is provided with internal storage 8 GB memory unit with internal storage. This ensures no loss of data and increasing the reliability of the model, on the other hand the computer can store the transmitted reading from the Thing Speak platform after downloading it from its channels. The proposed system stands out from other similar models by integrating data visualization via three methods: a local display represented by touchscreen, the ThingSpeak IoT platform for remote display, and the ability to store data to a personal computer. It also offers reliability by using an uninterruptible power supply (UPS) and supercharger, making it able for uses with unstable electricity. The work included a field-tested for a different group of people, and its results were compared with certified medical devices to improve the accuracy and reliability of the reading. Then practical tests process made for many people of different ages to transmit their reading on the IoT platform with graphical analysis including with visual alerts. The system depends on high-performance represented by a Raspberry Pi and precision medical sensors, with future scalability through using encryption algorithms to get high data protection.

ThingSpeak Platform

ThingSpeak is one of cloud Internet of Things (IOT) platform, enabling users to disply, analyze and store data from IOT systems. Created by MathWorks company, It is widely used by researcher for projects because of its easy to integration with MATLAB, It can process advanced programs to provide a clear vision to provide solutions or display. Its enables immediate data aggregation and analysis, this enables it to deal with applications, including medical applications like patient monitoring, heath environmental monitoring, which creates a healthy, smart environment and this is known as smart cities (Singhal et al., 2023). ThingSpeak progress available gateway without restrictions to displaying data and ensures easy communication between the devices and servers

(Sindhwani et al., 2022; Sofia & Sambathkumar, 2024). The IOT enabled devices transmit instant data to ThingSpeak platform, to get safe stored then can accessed by authorized like healthcare professionals, doctors, caregivers and other relevant person can tracking patient's condition from remote location to progress providing a proactive approach to patient case. The professionals can make timely decisions and enhanceing patient care by using this technology (Anusha et al., 2024). As its know, the IOT makes lives easier(Nnamdi et al., 2024), and by utilizing it, the project will provide individuals with information about their health, allowing them to check their historical health data (Ait Mouha, 2021). Everyone can use our project, which simplifies health management compared to existing systems. Additionally, the IOT-based healthcare system is a more affordable healthcare device for both patients and doctors. We chose the "THINGSPEAK" cloud service to store all the data in the cloud, which is very useful for doctors during treatment (Sivabalaselvamani et al., 2024). This project is primarily based on the Raspberry Pi 4 and various sensors. The results are shown on ThinkSpeak (Figure 1), which shows the four channels of the sensors used in this project, as will be detailed later in this research paper. We implemented the monitoring system as a simulation using Raspberry Pi software and then developed a device model for the health monitoring system. This paper discusses the results of the device model. The patient healthcare system is an innovative concept that helps citizens monitor their health by tracking parameters such as ECG, body temperature, heart rate, and oxygen saturation levels.

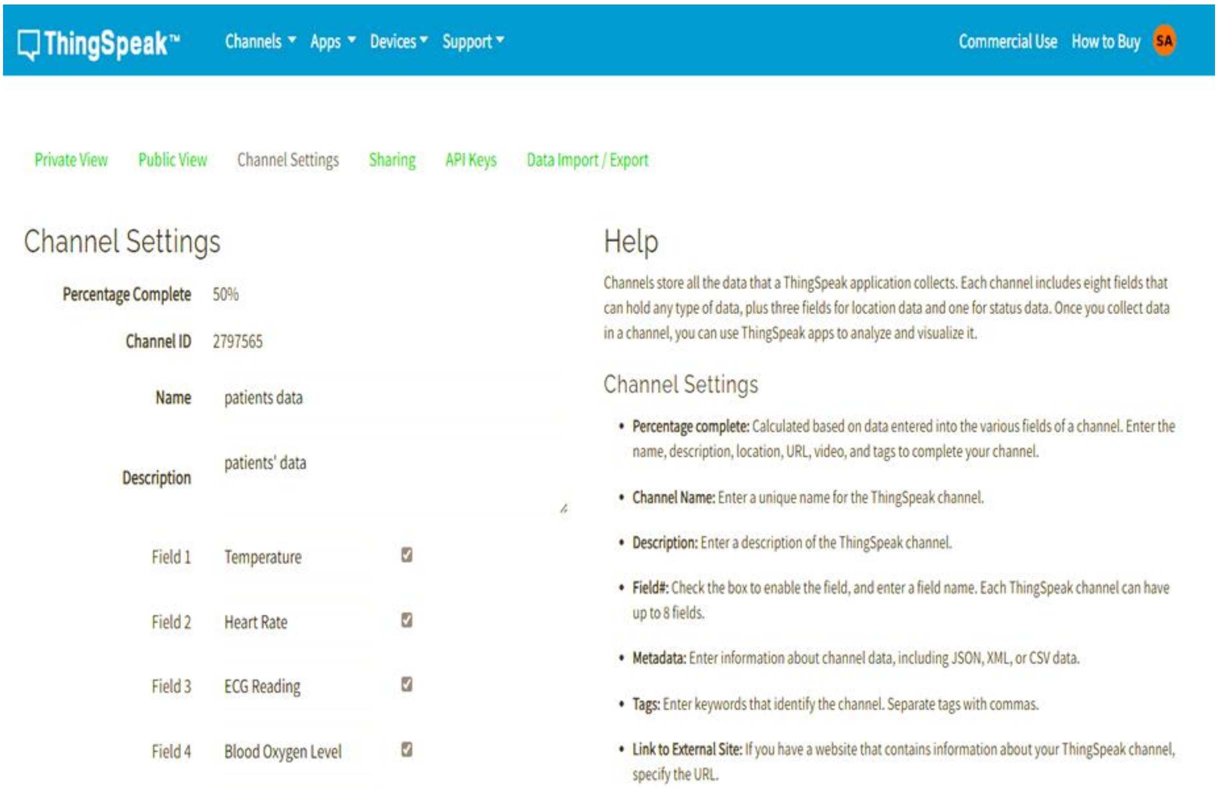

Figure 1. Think speak platform

Methodology

The methodology to build an integrated, low-cost, electrical energy-saving health system that can be used to process health monitoring of patients remotely and analyze that data in a smooth and integrated manner, in that many types of input and output, the input devices can be used for reading a vital sign like sensors connected to controller then the results sent to cloud platforms to process, show, and archive health information like heart rate, temperature, oxygen level, and ECG. The used sensors chosen are the MLX90614BCC for human temperature, HW-827 read heart rate degree, MAX30102 measured oxygen saturation, and ECG sensor to get the positive value of the heart electrical activity. The input sensors collect body electrical rate for each kind of reading, sent them to a processor, which can process the electrical digital signal converts it into usable reading, like temperature, heartbeat, oxygen level, and ECG. This data is displayed on a local screen panel in instant time like LCD or OLED, by using Wi-Fi can send the readings to a cloud platform for remote display, storage and analysis. That allows healthcare officials to remotely track vital signs and make decisions. The model allows continuous data analytics, monitoring and discovering the abnormal readings generating warnings. The model also progresses the possibility of using cipher methods that are used to ensure data safety while allowing an easy user interface that enables easy tracking for patients' cases.

System Design

The model design for vital sign reading and tracking integrates various components that conacted together to measure and display health prameters. Key components include the MLX90614BCC temperature sensor, heart pulse rate sensor, MAX30102 oximeter sensor, ECG monitor sensor, a microcontroller, and a display screen using the cloud to display data on a remote computer. These sensors are responsible for detecting body temperature, heart rate, oxygen saturation, and electrocardiogram (ECG) signals, which are illustrated in Figure 2. The MLX90614BCC infrared thermometer sensor measures body temperature by detecting infrared radiation emitted from the skin, providing a non-contact temperature reading. The measuring range of the sensor temperature itself is -40 to 125°C (i.e., -40 to 257°F). It communicates with the Raspberry Pi using the I2C protocol, connecting the SCL and SDA pins on both the sensor and the Raspberry Pi

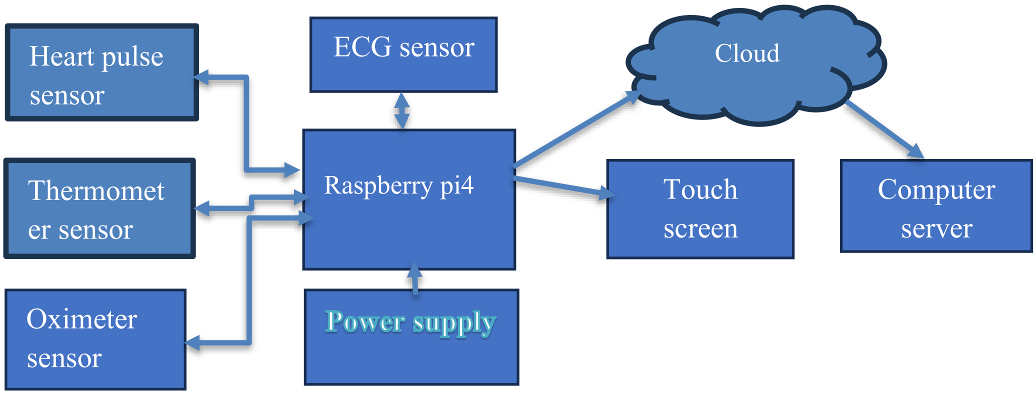

Figure 2. Real time healthcare monitoring block diagram

To convert the reading to Fahrenheit to be clearer in terms of monitoring, we use the equation (Mark, 2013):

$$F^0 = (C^0 \times 59) + 32 \quad (1)$$

Where Fo is the temperature in Fahrenheit. C^0 is the temperature in Celsius.

The heart pulse rate sensor uses infrared light to detect changes in blood flow by emitting light through the skin and analyzing the reflected signal. The heart rate sensor reading is sent to the Raspberry Pi4 via input pins general-purpose input/output (GPIO). After an ADC (analog-to-digital converter) is used between the sensor and controller to convert the analog signal into a digital signal. MAX30102 sensor functions as a pulse oximeter, it uses both red and infrared light to get measure rate of oxygen saturation (SpO2). This sensor can conacted to the Raspberry Pi by using I2C protocol, SCL and SDA pins. ECG sensor read heart's electricity by using electrodes placed touch with the skin. The analog signals of the ECG sensor convert to digital form by using ADC then are sent to the Raspberry Pi4 to process and display. To convert the value from digital format to millivolts so that it is clear to the supervisor, we use the following equation(Payyappilly & Dour, 2022):

$$V\ (mv) = \left(\frac{digital\ reading}{1023}\right) * 3300 \quad (2)$$

Where V(mv): is the value in millivolts.
Digital reading: is the value read from the analog-to-digital converter (ADC).
1023 : is the maximum value for a 10-bit ADC.
3300 : is the voltage range in millivolts (i.e., 3.3V × 1000 to convert it to millivolts).

A hybrid of a laptop and a conventional microcontroller, the Raspberry Pi serves as an integrated computing platform. The integrated general-purpose input/output (GPIO) ports allow for the operation of various electronic devices and circuits, while the powerful processing abilities enable the use of full operating systems like Linux and demanding software. The Raspberry Pi, designed in the United Kingdom by the Raspberry Pi Foundation, is about the size of a credit card (Burkitt Creedon, 2023). A flexible, low-cost environment for learning computer science and programming was its intended use. The Raspberry Pi 4 has been around since 2012, and the most recent version, Model B, came out in June 2019. With the option for 2GB, 4GB, or 8GB of RAM, this model provides much better performance, particularly for intensive jobs. Gigabit Ethernet and Wi-Fi 802.11ac are two examples of the high-speed internet connections that the Raspberry Pi 4 Model B offers. This capacity makes it a great choice for internet-based projects, applications related to the internet of things (IOT), tiny servers, and home automation systems. The specifications of Raspberry Pi 4 Model B:

• Processor: Broadcom BCM2711, Quad-core Cortex-A72 (ARM v8) 1.5 GHz
• RAM: Options for 8GB LPDDR4-3200 SDRAM
• Ports: 2 x USB 3.0, 2 x USB 2.0
• Networking: Gigabit Ethernet port and Wi-Fi 802.11ac support
• Video Outputs: 2 x micro-HDMI ports supporting up to dual 4K displays
• GPIO: 40-pin header for external devices
• Camera & Display.

All of the sensors receive power from the Raspberry Pi's 3.3V or 5V pins, with the ground pin (GND) linked to the Raspberry Pi's ground. The Raspberry Pi processes the information and presents it on a 7-inch LCD touch panel, offering real-time monitoring of temperature, heart rate, SpO2, and ECG signals. Figure 3 illustrates the frameworks employed in the actual model, accompanied by the wires that connect them. The Raspberry Pi 4 Model B (8GB) functions as the primary machine, collecting and analyzing data through sensors via GPIO and I2C interfaces. The touchscreen displays the processed data, enabling continuous monitoring of the user's vital signs for efficient health (Halfacree, 2023). Figure 3 describes the circuit diagram of the monitoring system, where the vital signs sensors of the human body are connected to a controller, which in turn displays the data on an LCD screen. It also sends the information via Wi-Fi to the cloud to store it and then displays and analyzes it via a platform on the computer screen of the person supervising the patients so that he can monitor the patients from anywhere, even if he is far away. The software for the system is designed to gather and process data from various sensors that measure vital signs such as temperature, heart rate, oxygen saturation, and ECG signals. The system communicates with the sensors using I2C and GPIO protocols, converting raw sensor data into readable values. The software processes these readings by applying necessary formulas for accurate conversions, such as temperature in Fahrenheit and ECG in millivolts. The processed data is displayed in real time on a touchscreen, allowing users to continuously monitor their health. The software ensures smooth integration of all components, providing efficient health monitoring. Figure (4) shows the system's algorithm, where the human's vital signs are read and successfully transferred to the display screen via the microcontroller. The data is also stored and sent to the personal computer of the person supervising the operation, where it is displayed at time and anywhere.

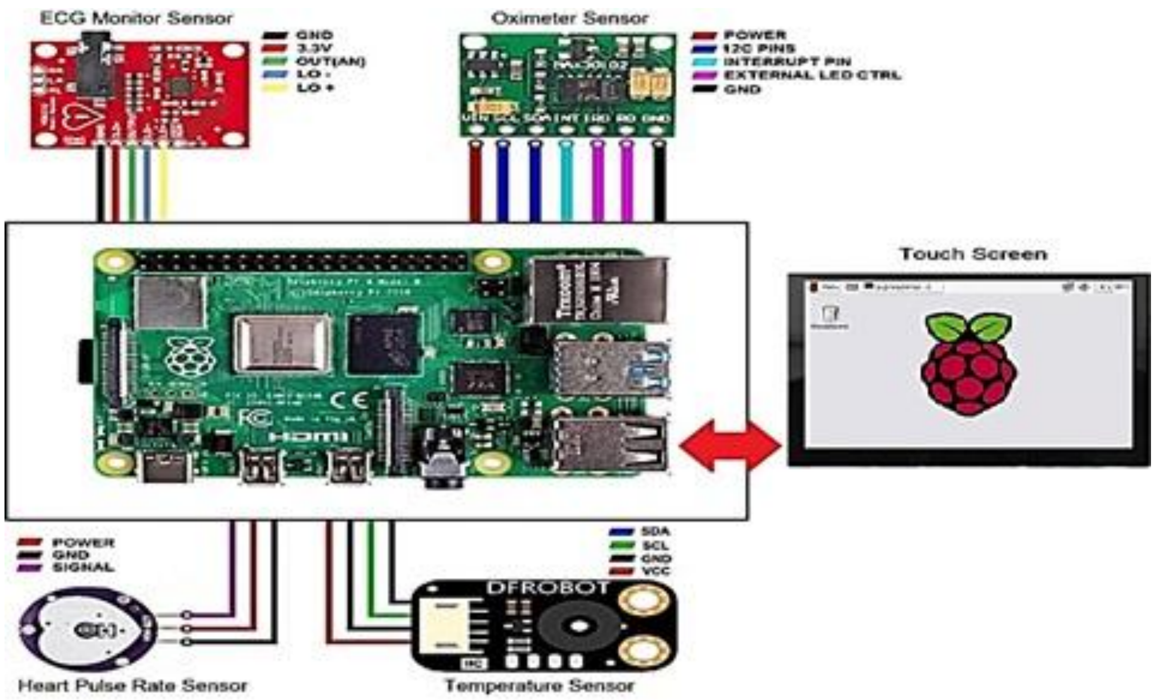

Figure 3. Circuit diagram of the monitoring system

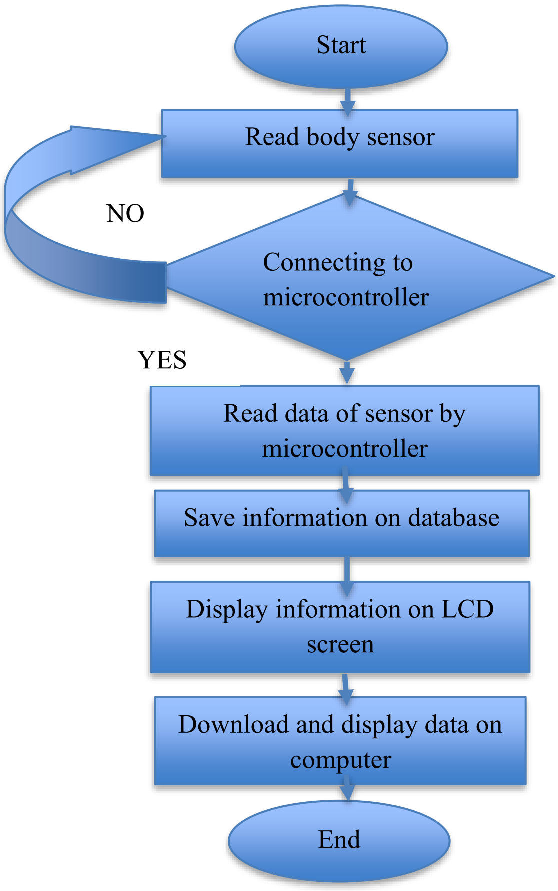

Figure 4. Software algorithm

Results and Discussion

The developed vital signs monitoring model underwent a comparative validation process to evaluate its accuracy and reliability. We utilized identical physiological parameters. So, for temperature testing, we use the Accuser electronic temperature sensor as shown in Figure 5. When the examination shows that the reference device is used and the temperature is measured by the system sensor for the same person, we notice that the values are close, noting that the slight change in the sensor readings is due to the person's movement.

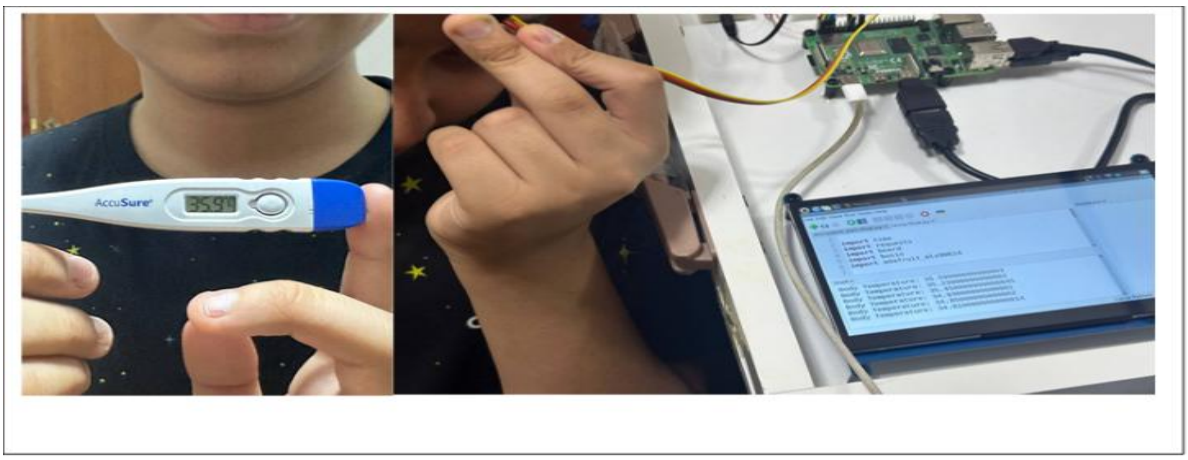

Figure 5. Temperature test

For heart rate measuring, we use a clinically approved Microlite monitor as the reference. Figure 6 explains the small difference between the medical device and the system sensor.

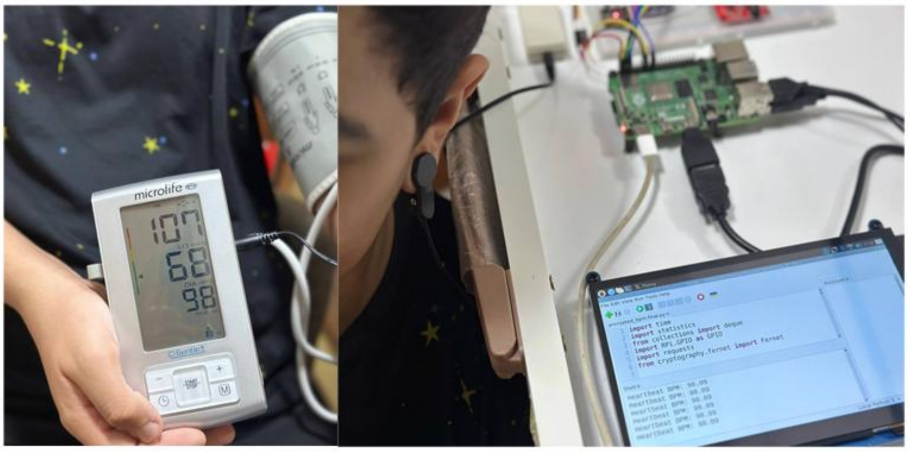

Figure 6. Heart rate test

For measuring oxygen saturation, we use a medical reference device (Pulse Oximeter LK87 medical oxygen sensor) to evaluate the sensor reading from the system, as shown in Figure 7, demonstrating how closely the two readings align.

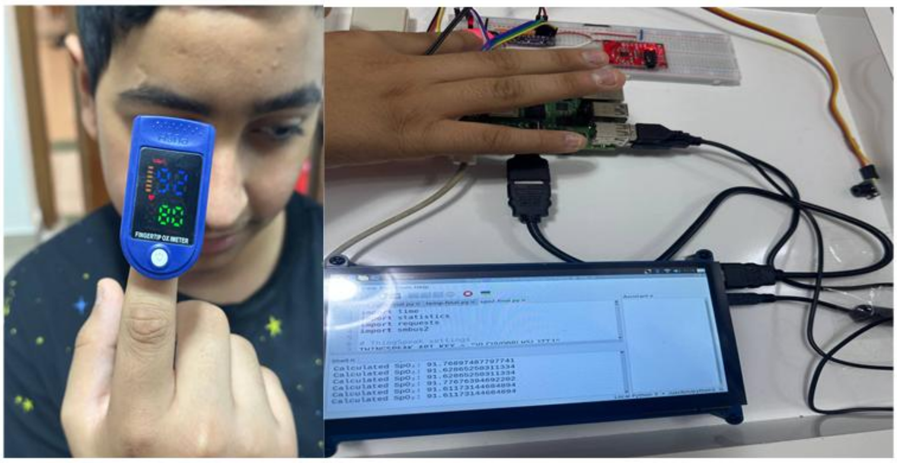

Figure 7. Oxygen rating test

They were measured using standard clinical medical devices, and the sensors integrated in the proposed model integrated sensors and standard clinical medical devices for measurement. The use of dual measurement of people through the approved medical device and the sensor of the proposed model provides us with a comparison to determine the accuracy of the readings taken from the model.

To evaluate the effectiveness of the system in practice, a field examination was conducted on 20 individuals of different ages and health conditions, including young and elderly people, those suffering from cold symptoms or real illnesses, or healthy people. As in Figure 8, which shows the model's operation as it sends data taken from the field examination field information, such as temperature, heart rate, oxygen saturation rate, and electrical heart rate, was then displayed on. The first channel displayed the temperature measured in Fahrenheit and issued a coded warning when the reading exceeded normal limits. The second channel monitors the heart rate and also issues alerts if the heart rate exceeds physiological thresholds. The third channel displays oxygen saturation levels, with a warning indicator emitting when the level drops below the acceptable range. The last channel showed the electrical degree of the heart in millivolts and also issued a warning in the event of an unacceptable measurement degree after changing the digital inputs and indicated any unusual electrical activity of the heart. This multi-display configuration enables automatic detection critical cases can be detected more quickly through the use of a prominent light alert in real time, which allows the medical officer to respond quickly to critical situations and thus improve the efficiency of care.

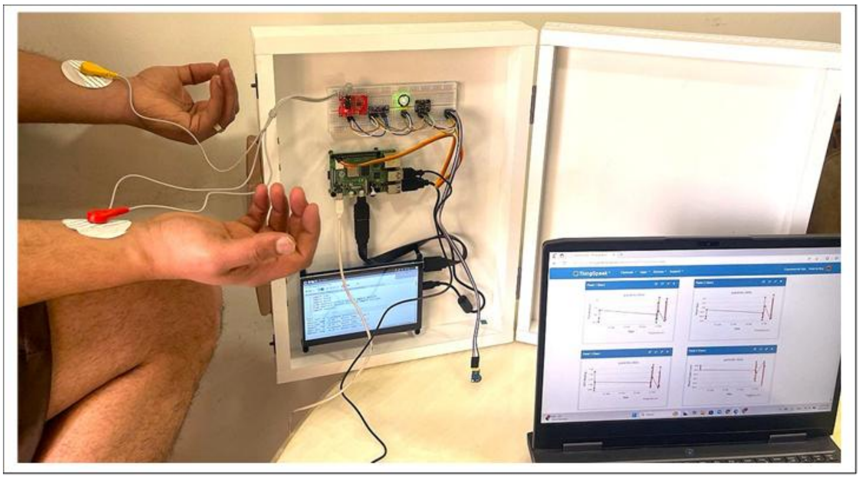

Figure 8. Practical work

Figure 9 shows the analytical graphs for the examined people, clarify the actual testing time alongside each person reading. Through this graphic, the doctor can collectively know if there are any unusual readings for the people.

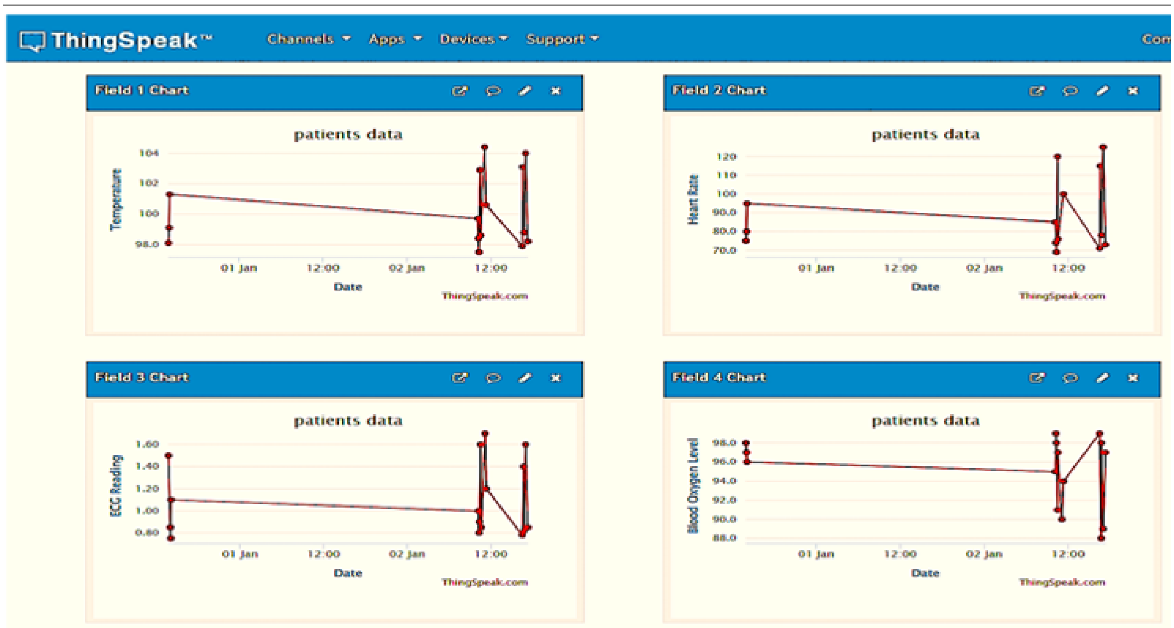

Figure 9. Graphical analysis of temperature data

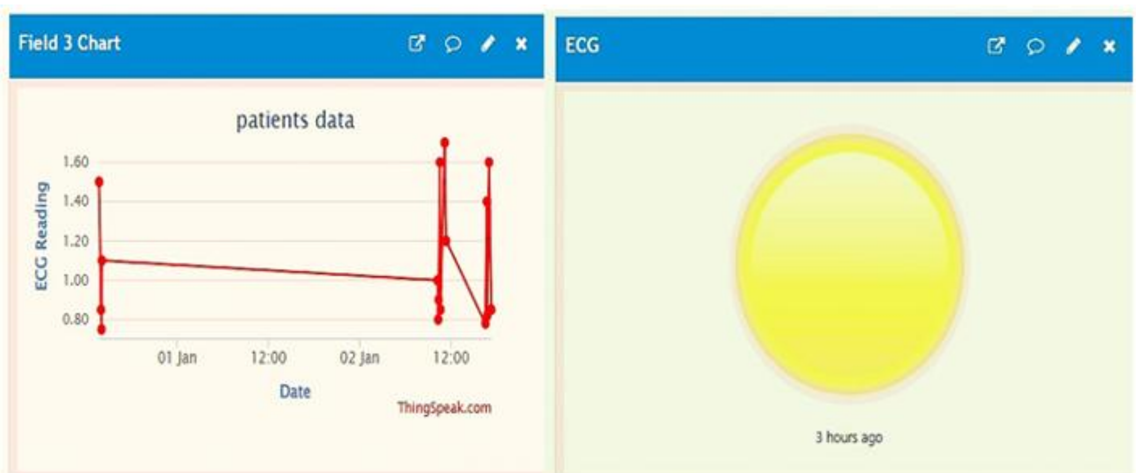

Figure 10. Graphical analysis of ECG data

Figure 10 displyed the analysis of the heart rate data. The medical sensor measures the signal in millivolts and amplifies it to digital form within the ADC. The digital reading can process by Raspberry Pi, which processes it before displaying it in millivolts on the screen.

Heart rate signal ranges from (0.5- 1.5) mV.
• Amplification it by 1000 converts it from(1 mV to 1 V).
Conversion the Digital Value in form of Millivolts:
The controller processes the digital reading from the convertar, which has a voltage of 3.3V and a resolution of 10 bits.
Each value of the digital reading is calculated as:

$$D\ Level\ = \frac{3.3}{1024} \approx\ 3.22\ mV \tag{3}$$

The digital reading value represented by D Level.

- By multiply digital value by this conversion equation to get the original reading in millivolts.
- This allows professionals person to see the actual values in millivolts then get accurate monitoring.
- Rate were recorded between 0.75 mV to 1.7 mV, noting that the acceptable rate of the heart reading is 1.5 mV , then a scale in yellow color if a reading exceeds the normal limit.

Figure 11 shows the heart rate reading for examined people, the rang was between 69 and 130 beats per minute. Noting that the normal heart rate rang for a healthy young people is between 60 to 100 beats per minute. That means the reading below 60 degree or above 100 degree will indicate abnormal conditions that get attention. In the second figure, the heart rate readings is anther analyzed to showed any r that eading exceed the normal heart range. The model allow get trigger a visual alert automatically and continuasly if the heart rate reading goes outside the expected rate. So, when the degree is either too high or too low, the warning light will appear hellping healthcare staff to take fast action to assess and address the patient's condition, that improving the chances of timely patient care.

Figure 11. Graphical analysis of heart rate data

Figure 12. Graphical analysis of oxygen rate data

Figure 12 displyed the analysis chart of blood oxygen saturation level for the patients, with readings ranging from 89% to 99%. Normaly, for the healthy person the blood oxygen levels ranging from 95% to 99%. The figüre show the reading with a notification scale, presented in blue color, adjacent to the analysis photo. This alert indicates when the oxygen levels are below the normal rang, so when its drop below 95% will be appear. A decrease in oxygen reading refer decline in the patient's case, and this case prompts healthcare personnel to make act swiftly to save patient live. By administer the requisite treatment to rectify the patient's oxygen level deficiency.

Conclusion

An implementation was completed for medical model that can read vital signs for remote monitoring and analysis. The system utilizes medical academic sensors with the ThingSpeak platform for data transport and analysis. The work included field inspection of 20 patients of different ages and sexes, collecting their vital signs, which are temperature, blood oxygen level, heart rate and ECG reading. That helps doctors to keep track of their patients and make fast decisions. The work was categorized into four channels on ThingSpeak platform, featuring color-coded notifications for abnormal readings. For temperature testing the reading was between 97.5°F (36.9°C) and 104.4°F (40.20°C), while heart rate readings recorded between 69 to 130 beats per minute, with warning for values exceeding the normal range of 60-100 bpm. For oxygen level rates record from 88% to 99%, triggering alerts if the reading dropped below 90%. ECG reading recorded the heart's electrical degree from (0.5 to 1.7) mV, the alarm appeared when degree exceeds the normal

Recommendations

1. Additional Vital Signs collecting: Like blood pressure and EEG.
2. Using AI to forecast health anlysis through machine learning.
3. Using Solar Energy: To improve energy efficiency.
4. Data encryption: To ensure the protection of patient information.

Scientific Ethics Declaration

* The authors assert that the scientific, ethical, and legal accountability for the content of this paper published in the EPSTEM journal rests only with the authors.

* The authors affirm that the study adheres to ethical norms, that the work is free from plagiarism, and that all data were gathered and presented with academic integrity.

Conflict of Interest

* The authors declare no conflict of interest for the publishing of this work.

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