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The Future of Healthcare: Portable IoT-based Patient Monitoring Systems

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Abstract:

The healthcare industry is currently the one with the fastest technological and service advancements. The most cutting-edge advancement in this field is the capacity to remotely or portably monitor patients, which is very beneficial given the rapidly expanding global population, rising healthcare costs, and limited access to medical institutions in less developed nations. A patient monitoring system is used to get the patient's vital signs. The patient's vital signs, including blood pressure, temperature, heart rate, ECG, and SpO2, are measured by this instrument. For the improvement of healthcare in the future, we have created and constructed an IoT-based patient monitoring system in this study. The device used in this study can record four parameters: body temperature, heart rate, SpO2, and ECG. The values can be viewed on an LCD, and the device's IoT base allows it to send data to a web application that can be easily accessed from any location. Given the issues, the gadget is designed to be affordable, dependable, and portable, making it simple for patients to roam around the hospital while being monitored for temperature, heart rate, and SpO2. Its accuracy is 98.11%, 98.11%, and 99.73%, respectively. Additionally, because medical gadgets are either unavailable or in restricted supply at hospitals, patients can utilize them at home.

Keywords: *Electrocardiogram (ECG), Vital Signs, Heart Rate, Oxygen Saturation, Body Temperature, Patient monitoring system, Reliable.*

I. INTRODUCTION

A. Healthcare Challenges and the Role of Patient Monitoring Systems:

Healthcare professionals are increasingly using Patient Monitoring Systems and multiparameter monitors to address various challenges in healthcare, such as equipment shortages, hospital capacity issues, and the strain on paramedics [1]. The primary goal of PMS is to collect vital signs, including ECG, SpO2, heart rate, and body temperature, to inform healthcare decisions [2]. The integration of PMS with the Internet of Things (IoT) and mobile health (e-health) technologies enables real-time data transfer, making it easier for healthcare workers to monitor patients' vital signs remotely [3]. This innovation has a significant impact on the global healthcare industry, improving patient care and outcomes. In addition to being commonly employed in OT and intensive care units (ICUs), the approach is also advised for certain patients with coronary heart disease to incorporate into their everyday routines [4]. The normal oxygen saturation in blood is defined as being between 95% and 100%, while other articles claim that anything below 100% is considered lethal. In other instances, however, >92% is also considered appropriate [5].

B. Technological Integration and Advancements in Healthcare:

One LED and one phototransistor make up the optical sensors used to measure the oxygen saturation of blood; light absorption is the mechanism that powers the sensors [6]. The quantity of beats per minute is called the heart rate. Heart rate has a significant role in characterizing atherosclerosis, cardiovascular risk, heart disease, and heart health

[7]. Heart rate can be measured in a variety of ways. The first technique involves taking a patient's pulse physically at the wrist and counting it for a minute in order to determine their heart rate. In the second method, a pulse sensor is used to count the number of beats and measure the amount of light absorbed by the blood moving through the finger, utilizing the Beer-Lambert law phenomenon. The third method uses an ECG to count heartbeats per minute [8]. The human body has a resting heart rate between 60 and 100 beats per minute. It changes depending on the age and gender of a person. Physical activity plays an important role in the condition of the heart, which is linked to BMI [9]. ECGs, or electrocardiograms, have long been used in the diagnosis, prognosis, and treatment of cardiovascular diseases such as myocardial infarction, stroke, and heart failure. They are an essential tool for assessing a patient's cardiac health [10] [11]. The discipline of cardiology has advanced due to the ECG. The electrocardiogram (ECG) visualizes the electrical activity of the heart as a wave that represents each heartbeat. ECG helps in the identification of ischemia and arrhythmia, among other cardiac disorders [12]. Given that a greater body temperature is seen to indicate a more severe disease, taking one's temperature at predetermined intervals is thought to be one of the vital signs that should be monitored to assess the severity of a condition [13]. The human body has an average temperature of 37 °C, or 98.6 °F. The patient monitoring system, or PMS, is always changing to keep up with the most recent developments in the medical field. It handles the continuous monitoring of physiological parameters through the use of a device resembling a palmtop and notifies healthcare professionals when critical conditions arise [14].

C. *Impact of IoT in Healthcare Monitoring:*

These articles cover the most current developments in IoT-based patient monitoring systems in healthcare from 2012 to 2016. The survey studies provide a solid understanding of most cutting-edge gadgets, their drawbacks, and potential improvements to these already available devices [15] and [16]. Some significant advancements in the realm of healthcare, like the cuff-less blood pressure meter, have been examined through Systematic literature review and normal literature review; a review of some fall detection bands may be found in [17]. It is very beneficial to the design and development process to talk about the significance of E-health and some of its applications related to consumer demand and cost-effectiveness [18]. A few of the apps include a haemoglobin meter and a heart rate monitor that works with a smartphone. A few previous uses for baby monitoring have also been examined in the literature [19]. There are two classifications for HMS: advanced systems and traditional systems. Finding the flaws and imperfections in the previous systems was the outcome of comparing several health monitoring systems. For example, unlike traditional systems that are still wired together, smart systems rely on wireless and remote health monitoring systems [20]. Using their cutting-edge development tools, some sophisticated systems have discovered unique features. One such feature is a medical device prototype called electrocardiography that was combined with a smartphone to enable more expedient and thorough analysis of the data [21]. In a study, C. Kim and A. Soong discovered an Internet of Things-based solution for healthcare applications. The survey seeks to offer comprehensive data on the ways in which Internet of Things, RFID, and multi-agent technologies can enhance people's access to technology, enhance health services, and streamline the healthcare delivery process [22]. Some IoT-based solutions are more advantageous for evaluating, appropriating, and implementing data in medicine [23]. Furthermore, many systems are to be regarded as useful since they use telemedicine, various media platforms, and cutting-edge technologies to provide better clinical monitoring and consulting [24]. D. S. R. Krishnan, S. C. Gupta claim that the health department may use the Internet of Things to remotely capture and transmit patient data, as well as to keep an eye on all patient behaviors [25]. Ensuring safe data transmission is crucial to preserving this link. IoT must be correctly developed with strong and numerous communication protocols to be used in healthcare. A resource-based method for recovering data is presented to handle health applications that require a lot of information. This technology is used in conjunction with a smart box, which functions as a medical system, to monitor patient behavior. V. D. Soni talked on how four protocol layers are maintained in order to enable the Internet of Things [26]. Systems are coupled to sensors and transmitters at the physical layer. Through a network layer, the signals are sent from the sensors to the clouds. Data can be made available and stored in the cloud by the middleware layer. Diagnostic and analysis procedures are executed at the application layer. The high employment rate demonstrates the significance of the medical technology sector to the European economy. By contrast, the pharmaceutical sector in Europe employs about 740,000 people [27]. In 2018, Pakistan purchased 143346 patient monitors for approximately 20 billion Pakistani rupees [28]. The approximate cost of our item is 6000 PKR, or about 28 USD.

Recent studies have significantly advanced the integration of the Internet of Things (IoT) in healthcare, particularly in patient monitoring systems (PMS). The paper by B. M. Mahmmod et al. provides a comprehensive review of IoT-based patient monitoring systems, discussing various challenges such as data security, sensor limitations, and the need for real-time data processing in remote monitoring [29] It emphasizes the critical role of IoT in improving medical services by enabling continuous and remote monitoring of patients, with applications ranging from disease management to medical diagnosis. The study further highlights the potential of edge computing in enhancing the efficiency of data processing in IoT-based healthcare systems. Similarly, the paper Scientific Reports (2023) delves into the importance of sensor integration and real-time systems for effective disease monitoring, with a focus on wearable devices and microcontrollers for patient health tracking [30]. This aligns with findings in IEEE Transactions on Parallel and Distributed Systems (2023), where researchers discuss advancements in biomedical monitoring, particularly the role of IoT in enabling smarter, more reliable healthcare systems, ensuring timely diagnosis, and supporting patient-centric care in remote settings [31-36]. These works collectively underscore the growing significance of IoT technologies in transforming healthcare delivery by enabling real-time, accurate monitoring and diagnostics.

II. MATERIALS AND METHODS

To create a functional prototype, the following sensors and parts had to be included: an LCD to display the data, a Node ESP32, a custom-made heart rate sensor, an LCD to record temperature, a custom-made SpO2 sensor to detect blood oxygen saturation, and a microcontroller, which serves as the prototype's core.

A. Functionality of the Device:

Custom-made sensors are used to record the bio signals from the human body. Flowcharts illustrate the basic workflow of the machine, which begins with the sensing of the patient's body bio-signals and concludes with their display on the screen and in a web application. The machine filters the signals in between these steps and converts them into signals that a microcontroller can read. The device's functioning is explained in Figure 1, in addition to how data is transmitted through a web application, bio-signals from the body are investigated, and the outcomes are displayed on the screen using a block diagram.

B. Oxygen Saturation Reading:

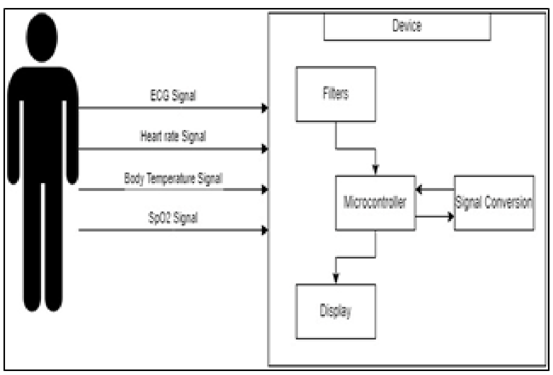

Figure 1. Block diagram illustrating the flow of vital signals (ECG, heart rate, body temperature, SpO2) from the patient to the monitoring device. The signals are processed by the microcontroller, which filters, converts, and displays the data for monitoring purposes.

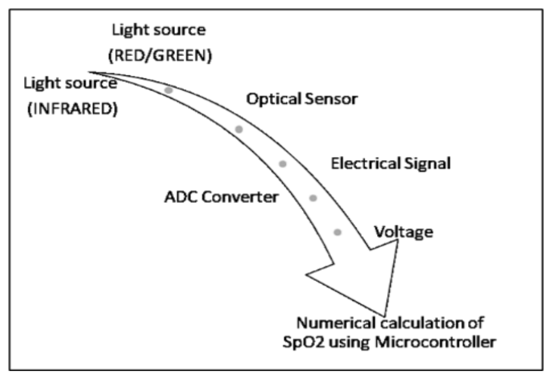

Figure 2. A diagram showing an arrow indicating the flow of data or process typically used to represent the direction of information or signals within the system.

Figure 1 illustrates how the microcontroller and SpO2 sensor work together to produce the intended output. The finger-based SpO2 measurement method is depicted in Figure 2.

C. Temperature Recording:

In Figure 3, a flow chart illustrates how the microcontroller and body temperature sensor work together to produce the intended output. Figure 3 illustrates the temperature sensor's operation from the moment it records the voltage change brought on by a change in the surrounding heat to the temperature that is reached.

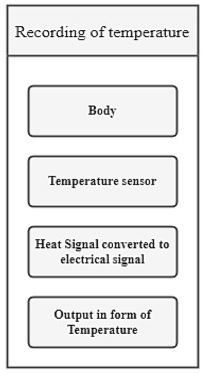

Figure 2. A flowchart illustrating the process of temperature recording

D. Electrocardiogram and Heart Rate Recording:

A flowchart shows how the processor and electrocardiography sensor work together to get the electrocardiogram and heart rate you want. The electrocardiogram and heart rate sensor's operation is shown in Figure 4, beginning with the recording of the voltage change following the cardiac cycle and the heart rate, to the final electrocardiogram and heart rate measurement.

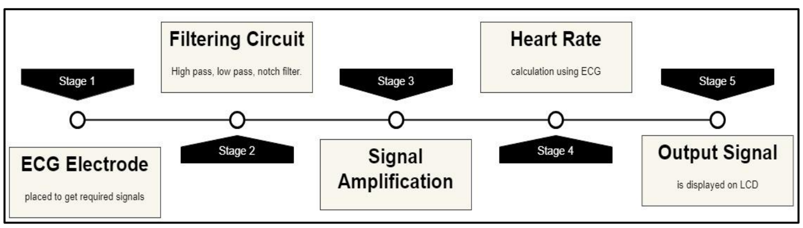

Figure 3. Flowchart illustrating the stages of the ECG-based heart rate measurement process. The process includes signal acquisition through the ECG electrode, signal amplification, filtering, heart rate calculation, and displaying the output on the LCD screen.

III. RESULTS

To verify the results, the CE-certified device's recorded data for the same person is compared to the prototype's vital readings.

A. Heart Rate Results:

After getting a continuous value from the planned prototype for approximately two minutes, the three volunteers performed three heart rate tests with the CE- CE-certified pulse oximeter. Tables 1 and 2 provide a comparison of heart rate findings. Figure 5 shows the data from our device for the heart rate, whereas Figure 6 shows the data from a CE-certified pulse oximeter for the heart rate.

Table 1: Results for HR obtained from our designed prototype

Sub No.	HR 1 (bpm)	HR 2 (bpm)	HR 3 (bpm)	Mean (bpm)
1	76	77	76	76.3
2	79	80	80	79.6
3	65	66	66	65.6

Table 2. Results for Heart Rate obtained from a CE Certified Pulse Oximeter

Sub No.	HR 1 (bpm)	HR 2 (bpm)	HR 3 (bpm)	Mean (bpm)
1	78	78	78	78
2	82	82	82	82
3	68	68	68	68

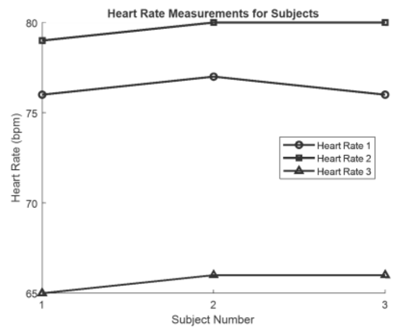

Figure 5. Results for Heart Rate obtained from the prototype

B. Oxygen Saturation Results:

After receiving a continuous value from the developed prototype for approximately two minutes, each of the three individuals had three SpO2 tests using the CE-certified pulse oximeter. Tables 3 and 4 present a comparison of the SpO2 data. Figure 7 shows the SpO2 results from our gadget, though Figure 6 shows the SpO2 results from a heartbeat oximeter with a CE confirmation.

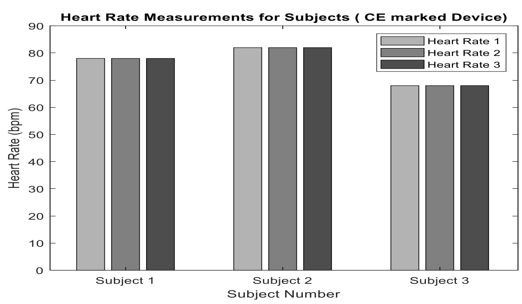

Figure 6. Results for heart rate obtained with a CE-certified pulse oximeter

Table 3. Oxygen Saturation Results

Sub no.	SpO_2 1 (%)	SpO_2 2 (%)	SpO_2 3 (%)	Mean (%)
1	98.2	98.5	97	97.9
2	97.8	97.5	98	97.7
3	98.2	98.7	98.3	98.4

Table 4. CE Certified Pulse Oximeter oxygen saturation results

Sub No.	SpO_2 1 (%)	SpO_2 2 (%)	SpO_2 3 (%)	Mean (%)
1	98	98	98	98
2	97	97	97	97
3	99	99	99	99

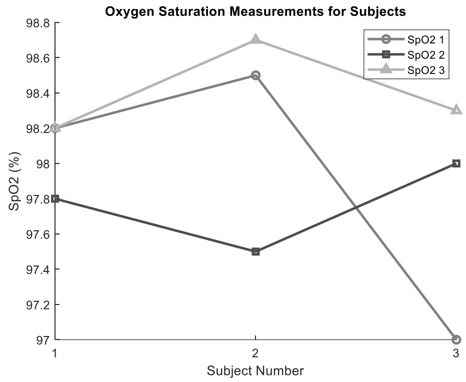

Figure 7. Results obtained for SpO2

C. Body Temperature Results:

After receiving a continuous reading from the constructed prototype for roughly two minutes, each of the three individuals had their body temperature measured three times using a mercury thermometer. **Tables 5** and **6** present a comparison of the body temperature findings. **Figure 8** depicts the results from our thermometer, while **Figure 9** depicts those from a mercury thermometer.

Table 5. Body Temperature results obtained from our device

Sub No.	Temperature 1 (°c)	Temperature 2 (°c)	Temperature 3 (°c)	Mean (°c)
1	34	35	36	35
2	36	36	35	35.6
3	38	37	37	37.3

Table 6. Body Temperature result using a mercury thermometer

Sub No.	Temperature 1 (°c)	Temperature 2 (°c)	Temperature 3 (°c)	Mean (°c)
1	35	35	35	35
2	37	37	37	37
3	38	38	38	38

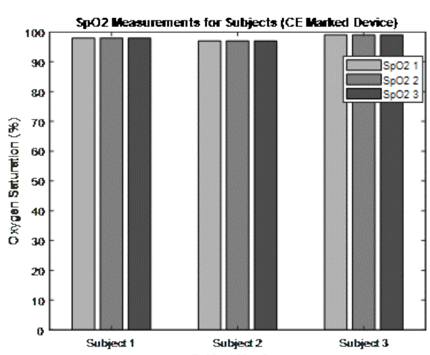

Figure 8. Body Temperature results obtained from our prototype

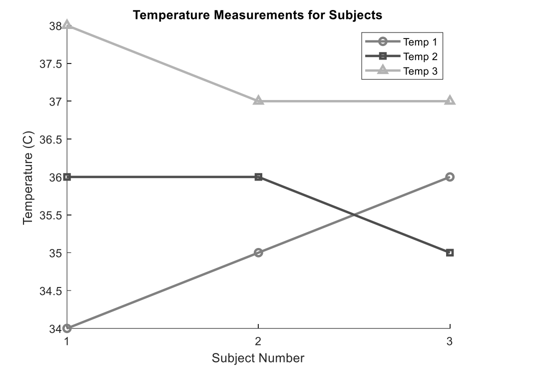

Figure 9. Body Temperature measurement for subjects

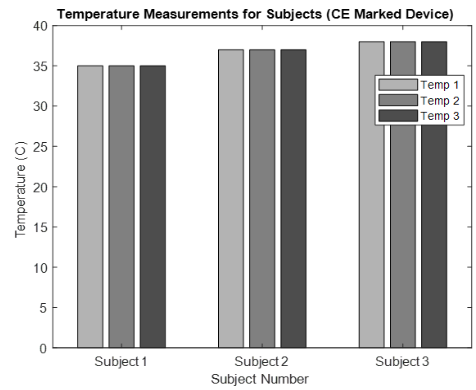

Figure 10. CE marked device

D. *Electrocardiogram Results*:

After receiving a continuous value from the intended prototype for approximately two minutes, each of the three subjects had an electrocardiogram test. The electrocardiogram waveform. Figure 11 shows the electrocardiogram waveform for subject 1, Figure 12 shows the electrocardiogram waveform for subject 2, and Figure 13 shows the electrocardiogram waveform for subject 3.

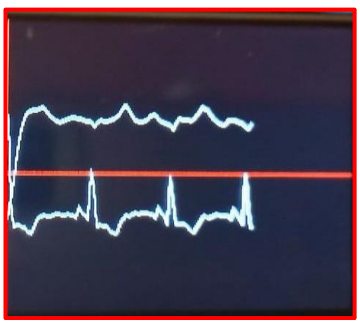

Figure 11. ECG for subject 1

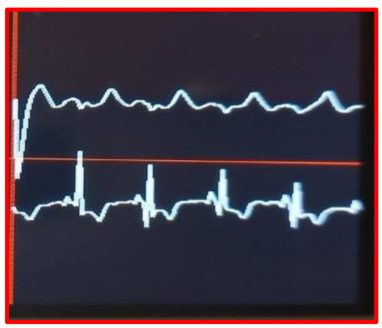

Figure 12. ECG for subject 2

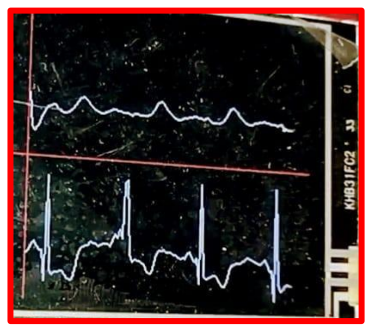

Figure 13. ECG for subject 3

E. Accuracy and Error Percentage

The accuracy for the various parameters recorded by the prototype in comparison to the CE-certified devices is displayed in Tables 7, 8, and 9. But Table 10 displays the error percentage for every parameter.

Table 7. Accuracy comparison for Body temperature between prototype and CE-certified devices

Sub No.	Mean of the prototype (°c)	The means of a mercury-based thermometer (°c)	Calculated Accuracy %	Mean accuracy % of body temperature
1	35	35	100	98.11 %
2	35.6	37	96.2	
3	37.3	38	98.15	

Table 8. Accuracy comparison for Heart rate between prototype and CE-certified devices

Sub No.	Mean of the prototype (bpm)	Mean of CE marked BPM Machine (bpm)	Calculated Accuracy %	Mean accuracy % of heart rate
1	76.3	78	97.8	97.11 %
2	79.6	82	97.07	
3	65.6	68	96.4	

Table 9. Accuracy comparison for SpO2 between prototype and CE-certified devices

Sub no.	Mean of the prototype %	Meaning of CE-marked Machine %	Calculated Accuracy %	Mean accuracy % of Oxygen Saturation
1	97.9	98	99.8	99.73 %
2	97.7	97	100	
3	98.4	99	99.3	

Table 50. Error % of the designed prototype from the standard

Heart Rate Error	2.89%
SpO_2 Error	0.27%
Body temperature Error	1.89%

IV. INTERNET OF THINGS

The combination of Arduino, MATLAB, and Bluetooth technologies, along with the integration of key sensors such as the custom-made heart rate sensor, SpO2 sensor, and temperature sensor, enables the creation of a comprehensive, web-based platform for IoT applications, as depicted in Figure 14. This platform offers centralized data administration, advanced visualization and analytics, remote monitoring and control, and collaboration capabilities by leveraging the strengths of both hardware and software platforms. Bluetooth technology plays a pivotal role in wirelessly connecting devices, such as smartphones, tablets, and sensors, enabling seamless communication between them. Moreover, the integration with Microsoft Azure enhances the system's capabilities by allowing secure cloud storage and real-time data analysis, ensuring scalable and reliable patient monitoring. This setup not only provides greater functionality but also improves the user experience by enabling intuitive access to patient data and analytics remotely, making it an ideal solution for healthcare providers and patients alike.

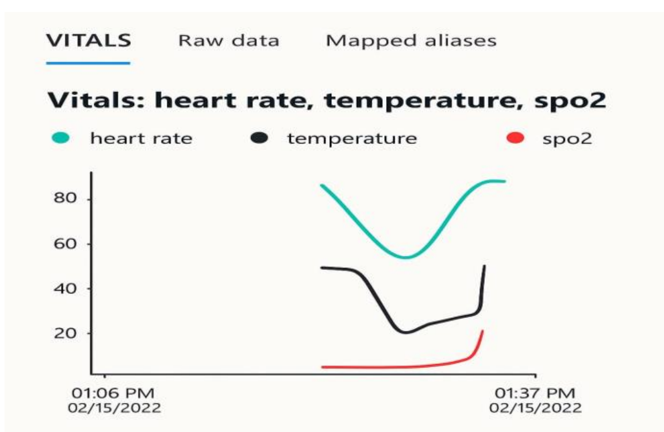

Figure 14. Web application interface displaying real-time graphs of vital signs, including heart rate, body temperature, and SpO2, for remote monitoring of patient health data. The plot tracks the changes in these parameters over time, allowing healthcare providers to monitor patient conditions effectively.

V. DISCUSSION

In this study, we investigate the integration of Internet of Things (IoT) technologies in healthcare, with a particular focus on the development of portable and cost-effective patient monitoring systems. As healthcare systems face increasing challenges, such as a rapidly growing patient population, escalating healthcare costs, and limited access to medical facilities, especially in less developed regions, IoT-based patient monitoring systems offer a promising solution. These systems provide the capability for continuous, real-time monitoring of vital signs, including body temperature, heart rate, SpO2, and ECG, all of which are crucial for facilitating timely medical intervention and enhancing the accuracy of diagnoses. The IoT-based prototype developed in this study is designed to be portable, reliable, and cost-effective, enabling patients to be monitored remotely via a web application accessible from any location. The accuracy of the device is significant, with measured values of 98.11% for body temperature, 97.11% for heart rate, and 99.73% for oxygen saturation, indicating its effectiveness in providing real-time, precise health data for continuous patient monitoring.

In the methodology section, we provide a comprehensive explanation of the components incorporated into the prototype, including the Node ESP32 microcontroller, custom-built sensors for heart rate and SpO2 measurement, and LCD screens for local data visualization. The seamless integration of IoT technologies and web applications facilitates efficient data transmission, allowing healthcare providers to monitor patient vitals remotely and in real-time. Our testing results validate the accuracy of the prototype when compared to CE-certified devices, reinforcing its reliability and potential for both clinical and home use. This study underscores the transformative potential of IoT technologies in healthcare, particularly in enhancing patient care, improving access to medical services, and enabling early diagnosis. The integration of real-time monitoring and remote diagnosis capabilities can significantly contribute to improving healthcare delivery while mitigating costs and alleviating the burden on healthcare infrastructure. The findings highlight the importance of further research and development in this domain to optimize IoT-based patient monitoring systems for broader healthcare applications, as shown in Prototype Figure 15.

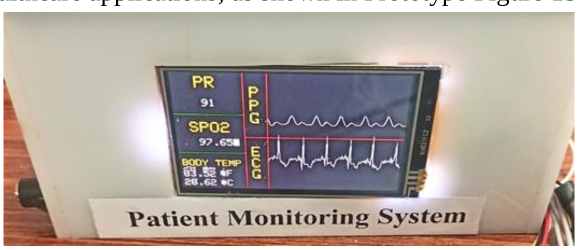

Figure 15. The Patient Monitoring System displays real-time vital signs, including Pulse Rate (PR), SpO2, Body Temperature, and Electrocardiogram (ECG) readings on an LCD screen.

VI. CONCLUSION

In this study, we developed a prototype capable of measuring four vital signs—ECG, SpO2, heart rate, and body temperature. The device successfully achieved its intended objectives, delivering real-time data that is easy to interpret and reliable. This innovation holds the potential to revolutionize healthcare by providing a cost-effective, portable, and efficient solution for remote patient monitoring, thereby enhancing patient care and reducing healthcare costs.

However, there are certain limitations in the prototype that must be addressed in future iterations. One notable limitation is the sensor capabilities, which are constrained by the cost of the components used. While the accuracy of the measurements was satisfactory, there is potential for improvement in sensor sensitivity and precision. Additionally, the wireless connectivity, although functional, could be enhanced to support a wider range of devices and to ensure more robust data transmission in environments with limited connectivity.

Moving forward, there are several avenues for improving this device. One potential improvement is the integration of additional vital parameters such as blood pressure, glucose levels, and respiratory rate, which would provide a more comprehensive overview of a patient's health. Moreover, the wireless connectivity could be enhanced by incorporating more advanced communication technologies such as 5G or low-power wide-area networks (LPWAN) to ensure better coverage and reliability, particularly in remote or underserved areas.

The future development of this IoT-based patient monitoring system could also focus on increasing the integration with cloud platforms, like Microsoft Azure, to enable real-time analytics and further improve decision-making processes for healthcare professionals. Overall, this study represents a significant step toward advancing healthcare technology, and with further research and development, this device could become a valuable tool for improving patient outcomes in both clinical and home settings.

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