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Original Article

Improving Healthcare Accessibility in Arequipa, Peru: Designing a Low-Cost IoT Vital Signs Monitoring System

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***Abstract** - This paper presents the implementation of a real-time remote biosignal monitoring system based on Internet of Things technology. The number of people requiring medical attention is increasing, and with the passage of the pandemic, it became known the deficiencies of the state medical sector, especially in non-urban areas of the department of Arequipa. Forcing people with limited resources to travel to hospitals with greater capacity which is a high risk for critical patients. One of the causes of this situation is the low budget that is managed in rural hospital centers, which is why we have developed 3 low-cost sensors that can detect heart rate signals, body temperature and blood pressure, all in real-time through a dashboard both a web and mobile application. The IoT interface was developed on the BLINK platform. The results of these low cost sensors were validated against other commercial sensors generally used in hospitals, verifying their reproducibility and accuracy by having a coefficient of variation of less than 5%. The tests were performed in the emergency area of the Honorio Delgado Espinoza Regional Hospital in Arequipa.*

***Keywords** - IoT, Body temperature, Blood pressure, Bpm, Monitoring.*

1. Introduction

In Arequipa, Peru, health services face serious challenges due to a lack of financial and human resources, which hinder access to adequate medical care, especially in terms of constant monitoring of patients' vital signs. The lack of trained medical personnel and adequate monitoring equipment exacerbates this situation, resulting in insufficient care and a lack of early detection of potential health complications. This problem is even more critical in rural and remote areas of Arequipa, where medical infrastructure is limited and economic resources are scarce. In these areas, the population faces additional difficulties in receiving timely and adequate medical care, which can have serious consequences for their health and well-being.

This study aims to address these limitations by designing and developing a low-cost vital signs monitoring system based on IoT technology intended for implementation in the Arequipa health system. The goal is to create an accessible and innovative system that allows for the continuous and remote monitoring of crucial health indicators such as heart rate, blood pressure, and blood oxygen saturation. This system will be comprised of portable data capture devices, vital sign sensors and an IoT communication platform that will facilitate data transmission over inexpensive wireless networks. The system hardware will be designed to be compact, low power consumption and easily portable, enabling its use in a variety of medical settings, including hospitals, clinics and primary care centers. In addition, special attention will be paid to the durability and robustness of the devices to ensure optimal operation in adverse conditions and areas with limited infrastructure.

The system's software will be responsible for collecting, processing and analyzing patient vital sign data, using algorithms specifically designed to detect and alert on possible anomalies in real-time. These alerts will enable early medical intervention and more informed decisions by healthcare personnel, improving the quality of medical care and reducing the risk of complications for patients.

The rationale for this project lies in the urgent need to overcome the limitations of Arequipa's healthcare system through an innovative and accessible solution that improves vital signs monitoring and contributes to better medical care in the region. The lack of resources and medical personnel in health facilities makes it difficult to constantly monitor patients' vital signs, which can lead to delays in the detection of critical conditions and less effective care. Given these difficulties, the development of a low-cost vital signs monitoring system based on IoT technology offers an effective and sustainable solution. Implementing this system in Arequipa will improve the quality of medical care by providing real-time data on the health status of patients, facilitating early medical interventions, reducing the risk of complications and improving population health outcomes.

2. Related Works

Health monitoring through emerging technologies such as the Internet of Things (IoT) has been a topic of growing interest in the medical field. Several studies have proposed innovative solutions to address the challenges associated with conventional diagnosis and medical care [1]. For example, one study has developed an IoT-based healthcare application that enables continuous, wireless monitoring of vital signs, such as heart rate and body temperature, via an online mobile application [2]. This system, which uses a microcontroller to transmit data to the cloud, has proven effective in emergencies, enabling timely intervention by healthcare professionals [3].

In addition, other work has explored the application of specific technologies, such as Li-Fi and IoT, for health monitoring in acute care settings [4]. These smart-systems transmit heart rate and temperature data via Li-Fi, providing remote access to physicians and email notifications in abnormal cases [5]. In a different approach, a low-cost initial verification platform based on FPGA systems has been proposed, which uses wearable technologies and robot sensors to communicate patient status via SMS and web applications [6].

In response to the need for continuous and cost-effective health monitoring, devices such as a Raspberry Pi-based health monitoring system and cloud IoT platform have been developed [7]. This inexpensive and easy-to-use device has proven its reliability compared to existing models [8]. Moreover, in pandemic situations, non-contact health monitoring has become crucial, especially among vulnerable populations such as the elderly [9]. One study has presented a non-contact health monitoring system that uses Doppler radar and infrared thermal imaging to monitor vital signs in real-time, with 90% accuracy in most cases [10].

On the other hand, in terms of specific applications, systems have been proposed to monitor patients in hospitals, nursing homes, and home care settings [11]. These systems use a variety of technologies, such as wireless body sensors, wearable devices, and wireless sensor networks, to provide continuous and accurate health monitoring [12]. In addition, several studies have emphasized the importance of accessibility and ease of use in the design of health monitoring systems, highlighting the need for cost-effective and user-centered solutions [13]. Related work in the field of IoT-based healthcare monitoring spans a wide range of technologies and applications, from smart systems in acute care settings to wearable devices for remote patient monitoring [14]. These innovative solutions have the potential to significantly improve access to and quality of medical care, especially in emergencies and for vulnerable populations [15].

Finally, advances in electronics have led to more affordable and portable health monitoring tools [16]. This article details a remote human body temperature monitoring system using an Arduino controller and temperature sensors [17]. Data are transmitted in real-time via Wi-Fi for online viewing [18]. These innovative solutions have the potential to significantly improve access and quality of medical care, especially in emergencies and for vulnerable populations [19].

3. Methodology

This article presents the development of a real-time vital signs monitoring system, all controlled by means of IoT technology. The design of different sensors that detect vital signs, body temperature, blood pressure and heart rate are designed manually to give it the relevance of low cost, then the results are compared against other commercial sensors. The system was tested in the emergency area of the Honorio Delgado Espinoza Regional Hospital.

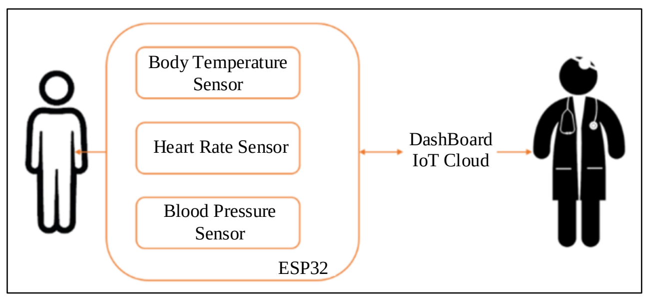

Fig. 1 General diagram of the vital signs monitoring system

4. Developed System

The electronic part is composed of the Arduino Mega2560 microcontroller that reads the signals from the sensors. The temperature sensor will be built on the basis of polyethylene terephthalate coated with indium tin oxide, which will give us an analog signal that will be encoded by the ADC1115 and this, in turn, connected to the Arduino Mega2560. The heart rate sensor is built using an infrared diode and a photosensor, and the captured signal will be amplified by an LM358N. At the same time, the blood pressure sensor uses an MPX5050GP manometer, an LM324 amplifier and a sphygmomanometer with its air pump.

A NodeMCU ESP32 WiFi module is incorporated to monitor the sensors and to display the readings on a web dashboard and smartphones. The stable communication between the NodeMCU and the Arduino is described in Figure 2. A very short message is sent from the first device to the second device to ensure that the NodeMCU serial communication is connected correctly to the Arduino

Mega2560. Then, the Arduino verifies the incoming messages and creates the JSON document to send to the NodeMCU. A structured text-based format called JSON is used for data exchange. Its structured design helps ensure that the received data is in the correct format without loss or overlap. In this article, the ECG sensor is directly connected to the NodeMCU and the Json document is used to send cardiac BPM, blood pressure, and body temperature values to the NodeMCU.

After receiving data through this device, there is a function that ensures that all data has been received and then verifies that the data has been formatted correctly. As a result, the data that is received is sent to the Blynk cloud.

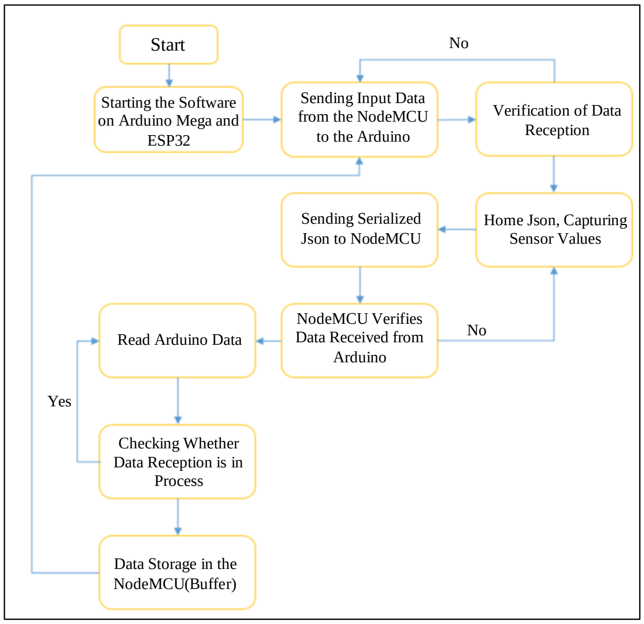

Fig. 2 Flowchart of data transmission through NodeMCU

4.1. Temperature Sensor

Polyethylene terephthalate, which is coated with indium tin oxide, is used; with a thickness of 190 microns has a surface resistance of 80 ohms/sq. ITO's readily available sputter-coated PET film is ready to meet the appropriate size requirements. A tightly stretched 10" x 10" polyester mesh is used to make the screen printing frame. For printing conductive silver ink, a mesh of 77 Threads per Inch (TPI) is recommended. A 26 µm thick chromatin film emulsion is used to set a mask over the polymer mesh. AutoCad tool is used to design the electrode layout.

A high-resolution mask is printed on a transparent film, and both the transparent film and the screen are directly exposed to 380 nm wavelength ultraviolet radiation for 45 seconds. After applying water to the screen, the electrode pattern can be observed, which is then printed on the ITO film. The squeegee and the screen have a contact angle of 45°, and the printed Ag ink is dried for 8 minutes at 140 °C.

A digital multimeter is used to examine the electrical resistances of the developed sensors and measured in the range of 260 ±4 ohms. The fabricated sensors, along with dimensions, are presented in Figure 3.

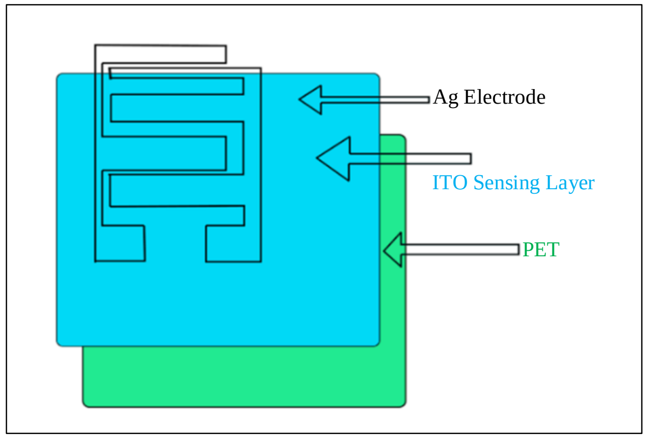

Fig. 3 Diagram of the temperature sensor composition

The connection to the ADC1115, Arduino Mega and ESP32 is shown in the figure below.

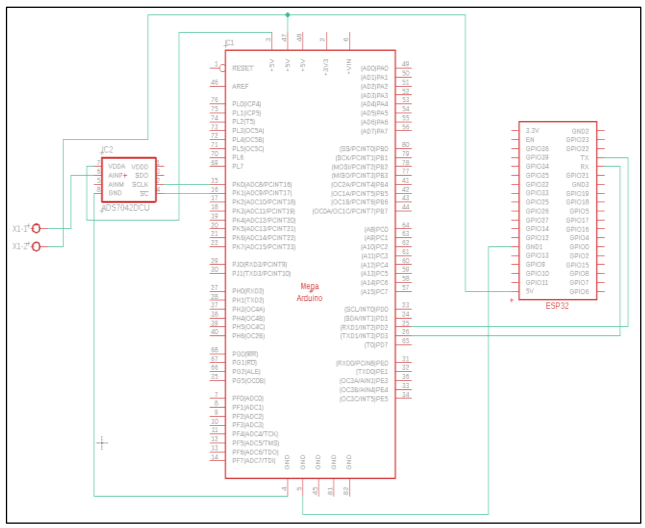

Fig. 4 Connection between the Arduino Mega, ESP32 and the ADC1115

4.2. Heart Rate Sensor

The photosensor initially receives the high-intensity light emitted by an LED. This is the state in which the resistors are used to calibrate the heartbeat to zero. A patient limits the light when he places his finger between the photosensor and the Infrared (IR) diode. If blood is pumped into the finger, the intensity of light penetration decreases. The light intensity is high if no blood is pumped. High and low light intensity helps to measure the heart rate. The duration of the disturbed light is measured, which gives the duration of each heartbeat, and the inverse of this duration gives the heart rate per minute. Dual LM358N operational amplifiers amplify this signal in two stages.

The square wave pulse achieved is adjusted by resistance, and a capacitor is used as a feedback capacitor. After amplification, the output of the LM358N operational amplifier is connected to PIN 7 of the Arduino Mega microcontroller.

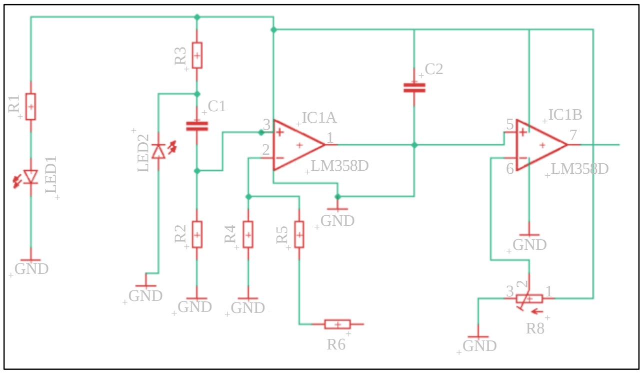

Fig. 5 Schematic diagram of the heart rate sensor

4.3. Blood Pressure Sensor

The MPX5050GP pressure sensor is a piezoresistive transducer made of monolithic silicon that is designed for a variety of applications, particularly those involving A/D inputs for microcontrollers or microprocessors. It has an integrated 0 to 50 kPa (0 to 7.25 psi) pressure sensor, which can reach a pressure of 0 mmHg to 375 mmHg. It also has an internal operational amplifier for signal conditions and six pins. This MPX5050GP pressure sensor uses a unique technique to measure air pressure. In addition, it uses piezoresistive technology to convert air pressure into an electrical signal. This sensor has a sensitivity of 90 mV/kPa and can measure pressure from 0 to 50 kPa from 4.75 V to 5.25 V. 1 Pa is equivalent to 0.0075 mmHg, which allows measurement with a sensitivity of approximately 12 mV/mmHg between 0 and 375 mmHg. An operational amplifier will be used instead of an inverter. The output gain of the amplifier is positive for the value when applied directly to the non-inverting (+) input terminal. This means that the input signal and output signal are in phase. Figure 6 shows the non-inverting amplifier circuit.

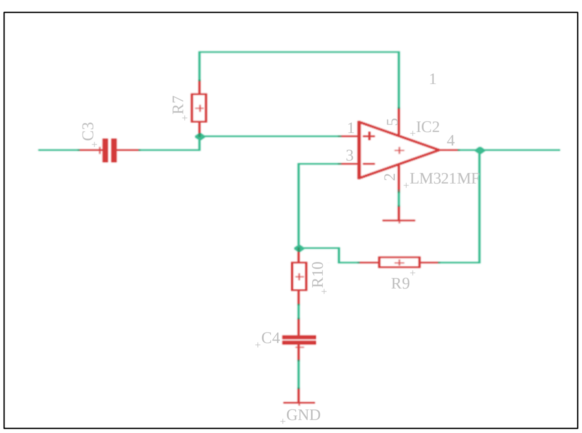

Fig. 6 Schematic of the non-inverting amplifier of the blood pressure sensor

4.4. Blynk

Blynk is an IoT platform used to display patient data. Blynk's cloud service enables live and professional monitoring of the patient's condition. In addition, it can run on a local server, such as in or near a hospital, while the cloud service ensures live streaming of data on the patient's condition outside the hospital. Three gauges are inserted at the top of the page for a live display of heart rate, body temperature and blood pressure, as shown in Figure 7.

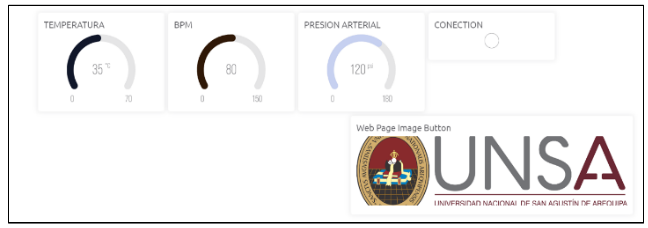

Fig. 7 Web dashboard design

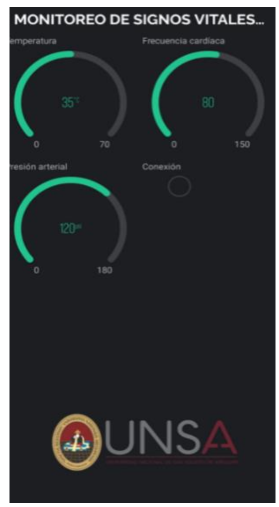

Fig. 8 Dashboard design in a smartphone

5. Tests and Results

First, the reproducibility of the results of the three sensors is verified. A population of 4 random patients from the emergency area of the Regional Hospital Honorio Delgado Espinoza of Arequipa will be taken as a population. First, the reproducibility of the heart rate sensor, Figure 9, will be tested. Three consecutive measurements will be made on each of the four random patients, and the results will be verified in Table 1.

Table 1. Reproducibility table of the proposed heart rate sensor

	BPM		
	Measure 1	**Measure 2**	**Measure 3**
Patient 1	75	75	76
Patient 2	81	82	81
Patient 3	83	83	83
Patient 4	79	78	79

It can be determined that there is a minimum standard deviation in the reproducibility of the results. The same procedure is followed with the temperature and blood pressure sensors, always considering 4 random patients as the total population and performing three repetitions.

Table 2. Reproducibility table of the proposed temperature sensor

	Temperature		
	Measure #1	**Measure #2**	**Measure #3**
Patient #1	35	35	34
Patient #2	36	36	35
Patient #3	35	35	35
Patient #4	34	34	33

Table 3. Reproducibility table of the proposed blood pressure sensor

	Blood Pressure		
	Measure #1	**Measure #2**	**Measure #3**
Patient #1	120/80	119/80	119/81
Patient #2	118/78	118/79	117/78
Patient #3	119/82	119/82	119/81
Patient #4	128/92	127/92	128/92

It is verified that the standard deviation in both results of the temperature and blood pressure sensors is minimal. Validating its good reproducibility. It also verified the accuracy of the sensors made, and it will be compared with other commercial sensors generally used in medical centers and/or hospitals of great category. First with respect to the heart rate sensor, it will be compared with a MAX30102 and an oximeter. Likewise, 4 random patients are taken as a general population. The results can be seen in Table 4.

Table 4. Accuracy table of the proposed heart rate sensor

	BPM		
	Own	**MAX30102**	**Oxymeter**
Patient #1	75	77	77
Patient #2	81	83	82
Patient #3	83	85	86
Patient #4	79	78	77

It is verified that the results of the other sensors compared with our heart rate sensor have very little variation, less than 5%. The same is replicated with the temperature sensor, and this is compared with a digital thermometer, the results shown in Table 5, have differences of less than 3%.

Table 5. Reproducibility table of the proposed blood pressure sensor

	Temperature	
	Own	**Digital Thermometer**
Patient #1	35	35.8
Patient #2	36	37
Patient #3	35	34.5
Patient #4	34	35.4

Finally, the arterial pressure sensor is compared with a tensiometer commonly used in hospital centers. Both systolic and diastolic pressures have deviations of less than 3% in comparison with the tensiometer results. See Table 6.

Table 6. Accuracy table of the proposed blood pressure sensor

	Blood Pressure	
	Own	**Tensiometer**
Patient #1	120/80	121/81
Patient #2	118/78	119/80
Patient #3	119/82	121/83
Patient #4	128/92	127/90

6. Conclusion

It is concluded that the reproducibility and accuracy of the three sensors described in this article (heart rate, body temperature and blood pressure) have deviations of less than 5%, thus validating their correct operation as well as the monitoring of the values in the web and mobile dashboards. Therefore, it can be replaced by expensive commercial sensors and equipment, which means that health centers that have a limited budget and are located far from the main cities benefit the population of scarce resources and prevent them from going to other distant hospitals for quick attention and monitoring. This article was financed thanks to the help of colleagues and friends who provided sensors and electronic components, and to the director of the pathology laboratory of the Honorio Delgado Regional Hospital for allowing the sensors to be read in the emergency area. As future research, an electrocardiogram, respiratory frequency and oxygen saturation could be included.

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