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Research Article

IoT-Based Vital Signs Monitor Testing with a Vital Sign Simulator

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Abstract : Vital Signs Devices function to detect vital signs from the human body, such as body temperature, blood pressure, heart rate, and blood oxygen levels. These vital signs provide us information whether our body is healthy or not. This vital sign monitoring device used Arduino Node MCU ESP32 as the data processor integrated with a Wi-Fi module, thus, supporting Internet of Things (IoT) application system. It is connected to an Android smartphone and can display measurement data in real-time. There are three sensors used, namely skin temperature sensor, Nellcor Saturation Partial Oxygen (SPO2) sensor and NIBP sensor that can display parameters such as SPO2, NIBP, heart rate, and body temperature in real-time. Vital Sign Simulator was used to test the SPO2, NIBP and heart rate parameters. Body temperature parameter was tested using warmed water medium in a water bath. The results of normal SPO2, NIBP, heart rate, and body temperature measurement showed fairly small differences.

Keywords: ESP 32, IoT, NIBP, SPO2, Vital Sign, Vital sign simulator

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1. Introduction

The health condition of the human body can be determined from the vital signs on the body. The vital signs are: body temperature, pulse, respiration and blood pressure. The temperature of the human body is regulated by physiological and behavioral mechanisms of the human itself. Thus, on the surface of the body the normal body temperature fluctuates between 36°C to 37.5°C [1]. A body temperature above normal is called hyperthermia while a body temperature below normal is called hypothermia.

In addition to body temperature, the next vital sign of the body is the pulse. This pulse is assessed by: frequency, rhythm, strength and uniformity. The normal pulse frequency in adults ranges from 60-100 beats per minute (BPM). If the frequency is above normal it is called tachycardia, and if below normal it is called bradycardia [2]. The next measured parameter is Partial Oxygen Saturation (SPO2), which is the oxygen content in the blood [3]. The percentage of oxygen contained in the blood depends on the amount of hemoglobin in the blood cells. The normal value of SPO2 in the blood for adults is 95%-100%, if the value drops below 95% it is called hypoxemia [4].

The respiratory vital sign in normal adults are 10-20 breaths per minute [5]. The last vital sign is blood pressure. The blood pressure when the heart pumps blood into the arteries is called systole, while the blood pressure when the heart expands is called diastole. Normal blood pressure in adults is 120 mmHg for systole and 80 mmHg for diastole or usually written as 120/80 mmHg. Meanwhile, in elderly people it is higher at 140/90 mmHg [6]. High blood pressure is called hypertension, while low blood pressure is called hypotension.

To measure the vital signs above, IoT-based vital signs devices were used [7], so that the measurement results can be directly observed from the display of the vital sign device and also from Android smartphones. The goal is to eliminate the need for medical personnel to look closely at the vital sign information on the vital sign monitors and simply do so from their Android smartphone. The application of IoT in health services facilitates fast-access monitoring of patient conditions and medical records [8].

The method used by previous researchers in calibrating vital signs with similar tools was direct measurement of human objects. This raises doubts in setting standard values for the study. In this study, the researchers used a vital sign simulator to calibrate the vital signs so that the vital sign values were produced in accordance with the standard. The contributions of this study include:

1. The calibration data generated from the simulator data can be used as a measurement standard for vital sign monitor.
2. Vital sign information can be displayed on smartphones through Internet of Things (IoT)

2. Methods

This vital sign monitor used a number of sensors, namely skin temperature sensor to measure temperature and oxygen saturation sensor (SPO_2) from Nellcor to measure the percentage of oxygen carried by hemoglobin in blood cells. If the oxygen carried is maximum, the value can reach 100% [9]. This sensor can also calculate the average pulse. The last sensor is a blood pressure sensor from Omron to measure blood pressure as shown in Figure 1.

a b. c.

Figure 1. a. Skin temperature sensor, b. Nellcor SPO_2 sensor, c. Omron blood pressure sensor.

The working system of the vital sign monitor can be seen in the block diagram in Figure 2. All sensors would feed measurement data to the ESP32 MCU Node microcontroller for processing. Then, the results would be displayed on the Nextion 7” LCD. This screen was a touchscreen display. The display on this LCD was created using the Nextion editor. The measurement results would also be sent to the cloud which could be accessed via Wi-Fi on Android smartphones. The cloud platform used was Firebase [10].

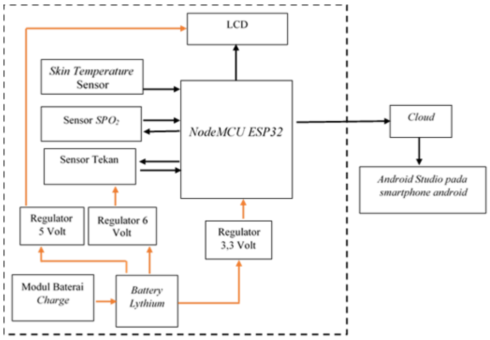


Figure 2. block diagram.

Description:

1. Nextion 7" LCD
2. Socket charger
3. Power button
4. SPO_2 socket
5. Socket jack for skin temperature sensor
6. NIBP cuff socket
7. Cuff
8. Nellcor SPO_2 sensor
9. Skin temperature sensor

Figure 3. Vital Sign Design.

On Android, the display used an application, namely Android Studio. Android Studio is based on IntelliJ IDEA, an IDE for the Java programming language. The main programming language used was Java, while to create a display or layout, the XML language was used [11]. The display on the LCD screen and Android is shown in figure 4.

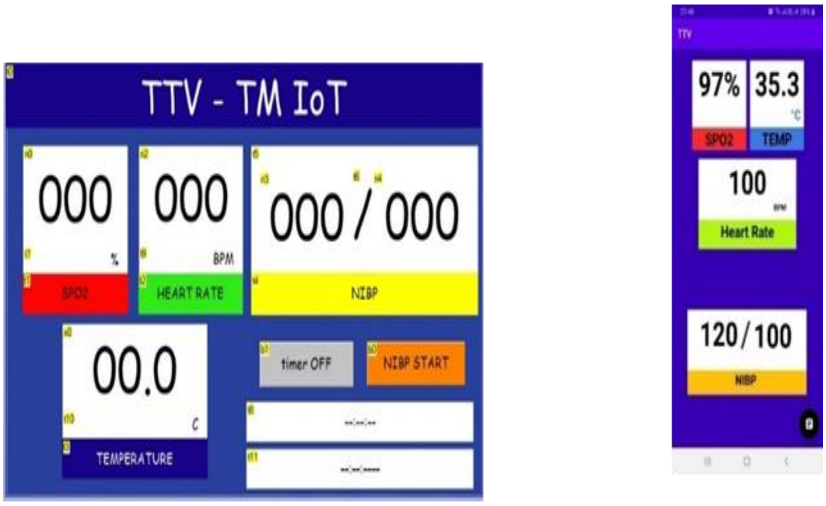


Figure 4. a. The display on the vital sign LCD. b. The display of an Android smartphone.

Nellcor SPO_2 Sensor

The design of the SPO2 sensor connected to the ESP32 can be seen in Figure 5 below:

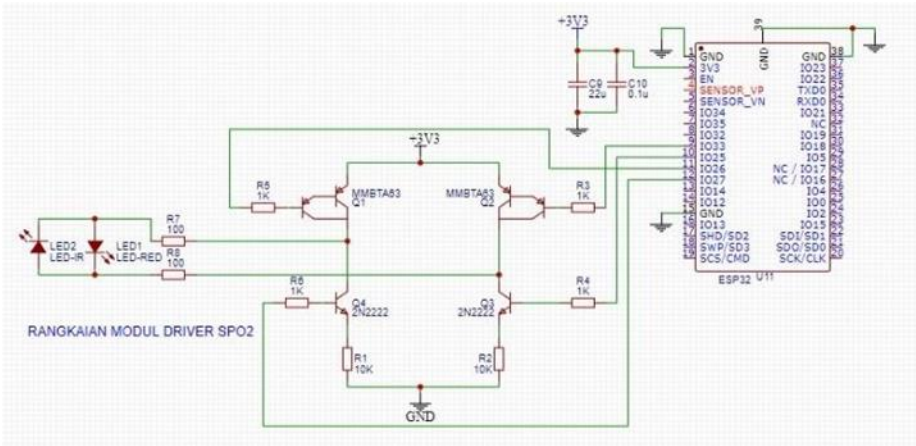
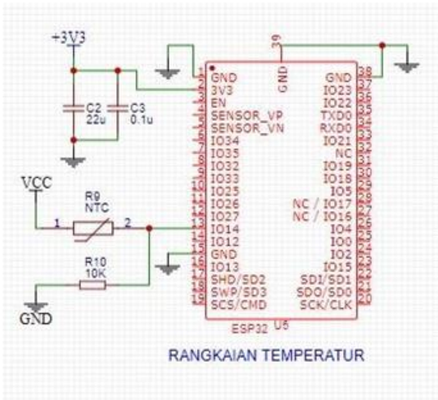


Figure 5. SPO_2 Sensor wiring diagram.

This SPO2 sensor circuit used two LEDs, namely an LED that produced red light with a wavelength of 660nm [12] and an infra-red LED that produced a wavelength of 960nm. the sensor was a photodetector. The sample could not be taken at the same time because there was only one photodetector for two signals, therefore, the signals must be multiplexed. The GPIO controlled analog multiplexer allowed selection of the wavelength to be sampled. The intensity of the LEDs was controlled using a PWM signal. The process of operating this vital sign monitor is that after all sensor devices are installed on the patient, the vital sign monitor is then activated. Then, all parameters such as temperature, SPO2 and heart rate will be displayed on the LCD screen and the ESP32 will be connected to Wi-Fi.

Skin Temperature Sensor

The design of the skin temperature sensor connected to the ESP32 can be seen in Figure 6.



(S Padmini, 2019)

Figure 6. Skin Temperature wiring diagram.

The skin temperature sensor was given a voltage of 3.3 volts DC. The end of the cable had the shape of a tip-sleeve (TS) type jack. This jack consisted of two conductors, namely the tip conductor and the sleeve conductor. The tip conductor was connected to pin IO14 while the sleeve was connected to ground.

NIBP Sensor Module

The design of the Omron NIBP module sensor connected to the ESP32 can be seen in Figure 7.

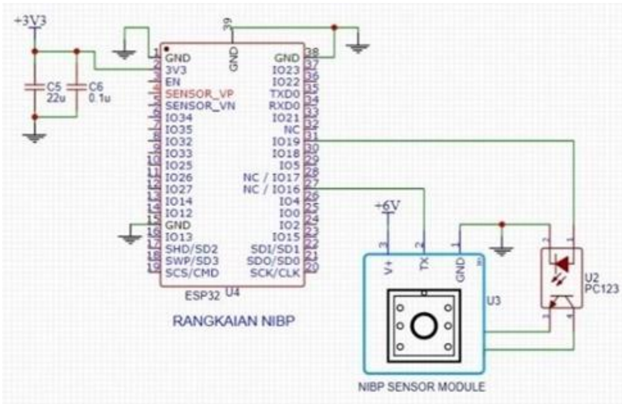


Figure 7. Omron Pressure Sensor wiring diagram.

This NIBP sensor was a sensor kit module from Omron [14]. The working principle of this sensor is that when the pump fills the air in the cuff, the sensor reads the air pressure in the cuff [15]. After that the air comes out slowly. At this time the sensor also detects the first pulse which we call systole. Then, the sensor also detects the last pulse that can still be detected by the sensor called diastole. This pulse will later be read as systole and diastole. Systolic blood pressure is the highest blood pressure achieved by the arteries during ventricular contraction while diastolic blood pressure is the lowest blood pressure achieved during ventricular relaxation [16]. After finishing pumping up to a certain pressure, that is, when no pulse is detected, if no pulse is detected, the pump will stop pumping the cuff. During the measurement of blood pressure measurement of pulse rate was also taken for heart rate parameters. Communication between the Omron module and the ESP32 used serial communication RX (Receiver) on Omron which was connected to the TX (Transmitter) pin on the ESP32, while the TX (Transmitter) on Omron was connected to the RX (Receiver) pin on the ESP32.

Testing

Next, to determine whether the results of the vital sign measurement were suitable or not, tests were carried out using test equipment. The tool to test the performance of the skin sensor was from the thermistor using a water bath as a comparison [17]. The tool to test the performance of the SPO2 sensor, blood pressure and pulse sensor was a vital sign simulator [18]. The vital sign simulator used was ProSim 8 from Fluke, which had several simulators for testing various ECG signals, a simulator for testing oximetry (SPO2) and a simulator for testing non-invasive blood pressure.

a b

Figure 8. a. Vital Sign Simulator ProSim 8. b. Waterbath.

3. Results and Discussion

In the ProSim 8 simulator from Fluke, there is a NIBP simulator that has a measurement range of 10 mmHg to 400 mmHg, with an accuracy rate of ± 0.5% of reading + 0.5 mmHg. In this NIBP simulator menu, you can set measurement points for systolic and diastolic. The oximetry simulator has a measurement range of 30% to 100% with an accuracy rate of 1%. The heart rate measurement range is 30 bpm to 300 bpm with an accuracy of 1 bpm [13][19].

Each parameter was tested 10 times. The measurement results of the temperature sensor, SPO2 sensor, heart rate and NIBP sensor are presented in tables 1, 2, 3 and 4. From the data in the table, the average and standard deviation were calculated. The calculation of this standard deviation was the standard used to measure the amount of variation or distribution of a number of data values [14][20].

Mean formula: $\bar{x} = \frac{\sum x}{n}$ ………………..(1)

x = data

n = number of data

Standard deviation formula: SD = $\sqrt{\frac{\sum_{i=1}^{n}(xi-\bar{x})^2}{n-1}}$ ……………..(2)

From table 1 the temperature sensor test in the hypothermia category, the average is 35.34C. In the normal category the average temperature measured is 37.62C. In the hyperthermia category the average temperature measured is 41.47C. The calculation result of the standard deviation between the data on the vital sign display and the smartphone for the hypothermia category was 0.24, the normal category was 0.19 and the hyperthermia category was 0.08. Thus, it can be said that the deviation of the data distribution is very small.

Table 1. Temperature sensor testing.

No	Hypothermia		Normal		Hyperthermia	
	Temperature in Water Bath: 35°C		Temperature in Water Bath: 37°C		Temperature in Water Bath: 41°C	
	Display	Android	Display	Android	Display	Android
1.	35.4	35.4	37.5	37.5	41.4	41.4
2.	35.4	35.4	37.6	37.6	41.4	41.4
3.	35	35	38.1	38.1	41.4	41.4
4.	35	35	37.5	37.5	41.4	41.4
5.	35	35	37.5	37.5	41.4	41.4
6.	35.6	35.6	37.7	37.7	41.5	41.5
7.	35.4	35.4	37.7	37.7	41.5	41.5
8.	35.4	35.4	37.7	37.7	41.5	41.5
9.	35.6	35.6	37.5	37.5	41.6	41.6
10.	35.6	35.6	37.4	37.4	41.6	41.6
Average	35.34	35.34	37.62	37.62	41.47	41.47

In table 2 the measurement of the SPO2 sensor at the setting point is 94%, an average of 94% is obtained both on the display device and on the smartphone. There is a fairly small difference between the measurement setting point and the average measured result, which is 95%-94% = 1%. If calculated in the percentage of error the result was 0.53%, although the calculation result of the standard deviation of the two data groups was 0.51. At the 100% setting point, an average of 100% was obtained both on the display and on the smartphone. Thus, there was a difference between the average value and the setting value, which was 100%-99% = 1%. If calculated in the percentage of error it is 0.71%. Furthermore, the result of calculating the standard deviation of the two groups of data was 0.65. Thus, it is concluded that there is no significant deviation difference for the SPO2 measurement when measuring at the 94% point. For the standard deviation at the measuring point of 99%, the result was above 1 but still within the tolerance limit.

Table 2. SPO2 sensor testing results.

No	Hypoxemia		Normal	
	Calibrator Setting Value: 94%		Calibrator Setting Value: 99%	
	Display	Android	Display	Android
1.	94	94	100	100
2.	95	95	100	100
3.	94	94	100	100
4.	94	94	100	100
5.	94	94	100	100
6.	95	95	100	100
7.	95	95	100	100
8.	95	95	100	100
9.	95	95	98	98
10.	94	94	99	99
Average	95	95	100	100

From table 3, heart rate measurements in the bradycardia category, the average is 55 bpm both displayed on the vital sign display and on the smartphone. In the normal category, the average heart rate measured was 80 bpm. And in the tachycardia category, the average heart rate measured was 105 bpm. The result of calculating the standard deviation between the data on the vital sign display and smartphone for the categories of bradycardia, normal and tachycardia was 0. In other words, there is no difference between the setting values on the simulator and those measured on vital signs.

Table 3. Heart Rate Measurement.

No	Bradycardia		Normal		Tachycardia	
	Calibrator Setting Value: 55 bpm		Calibrator Setting Value: 80 bpm		Calibrator Setting Value: 105 bpm	
	Display	Android	Display	Android	Display	Android
1.	55	55	80	80	105	105
2.	55	55	80	80	105	105
3.	55	55	80	80	105	105
4.	55	55	80	80	105	105

5.	55	55	80	80	105	105
6.	55	55	80	80	105	105
7.	55	55	80	80	105	105
8.	55	55	80	80	105	105
9.	55	55	80	80	105	105
10.	55	55	80	80	105	105
Average	55	55	80	80	105	105

Table 4. NIBP measurement testing.

NO	Normal				Hypertension			
	Setting value on calibrator: 120/80 mmHg				Setting value on calibrator: 140/90 mmHg			
	DISPLAY		ANDROID		DISPLAY		ANDROID	
	SYS-TOLE	DIAS-TOLE	SYS-TOLE	DIAS-TOLE	SYS-TOLE	DIAS-TOLE	SYS-TOLE	DIAS-TOLE
1	122	81	122	81	142	92	142	92
2	122	81	122	81	142	92	142	92
3	122	81	122	81	142	92	142	92
4	120	79	120	79	142	92	142	92
5	120	79	120	79	142	92	142	92
6	120	79	120	79	142	92	142	92
7	120	79	120	79	142	92	142	92
8	122	81	122	81	142	92	142	92
9	122	81	122	81	143	92	143	92
10	122	81	122	81	143	92	143	92
Average	121.2	80.2	121.2	80.2	142.2	92	142.2	92

The results of the NIBP measurement test are presented in table 4. NIBP measurements in the normal category obtained an average of 121.2 mmHg for systolic and 80.2 mmHg for diastolic. In the category of hypertension, the mean measured for systolic was 142.2 mmHg and 92 mmHg for diastolic. The results of the calculation of the standard deviation of the normal category for systolic and diastolic data between what was shown on the vital sign display and smartphone were 1.0 respectively. Calculation of the standard deviation of systolic and diastolic data for the category of hypertension produced 0.41 and 0, respectively, both on vital sign displays and smartphones. Thus, it can be said that the deviation of the distribution of systolic data in the normal category is small, namely 1, and even 0 for diastolic hypertension. This difference is very small and still within tolerance.

4. Conclusions

This IoT-based vital sign monitor is tested using the ProSim8 vital sign simulator from Fluke for SPO_2, heart rate, NIBP and waterbath for skin temperature. It is generally used to calibrate vital sign monitors such as Patient Monitor, Pulse Oximeter and Digital Sphygmomanometer. Each parameter is measured 10 times. Then, the mean and standard deviation are calculated, both the results displayed on the display device and on the smartphone screen. The testing results of each parameter are as follows:

1. The means of temperature parameter on the skin temperature sensor for the 35℃, 37℃ and 40℃ setting points are 35.34℃, 37.62℃ and 41.47℃, respectively. Meaning, the temperature setting deviation with the average temperature is < 1℃. And it is reflected on the highest standard deviation of 0.24.
2. The means of SPO_2 parameter measured at the 94% and 99% setting points are 95% and 100%, respectively. There is a 1% difference for measurements at the 94% and 99% setting points. The results of the calculation of the standard deviation of both are 0.51 and 0.65. That is, the consistency of the measurement is quite good.
3. The means of heart rate parameter measured at the 55 BPM, 80 BPM and 105 BPM setting points are 55 BPM, 80 BPM and 105 BPM, respectively. There is no difference between the setting points, whether displayed on the device display or on the smartphone screen. Thus, the standard deviation is zero. Meaning, the results of the heart rate testing is accurate.
4. The NIBP parameter on the Omron NIPB sensor module at the setting point of 120/80 mmHg shows a mean of 121.2/80.2 mmHg. As for the setting point of /90 mmHg, the mean is 142.2 /92 mmHg. The difference is fairly small, which is still below 3 mmHg. Meaning, it is still within tolerance. The standard deviations of the two setting points are 1.0 and 0.

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