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Design of Heart Rate, Oxygen Saturation, and Temperature Monitoring System for Covid-19 Patient Based on Internet of Things (IoT)

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ABSTRACT

Instruments for measuring pulse rate, oxygen saturation, and body temperature for Covid-19 patients have been designed using the MAX30100 sensor and the Internet of Things (IoT)-based MLX90614 sensor. The MAX30100 sensor is used to measure pulse rate and oxygen saturation. A non-contact MLX90614 sensor is used to monitor body temperature, with an ultrasonic sensor used to set the maximum distance between the sensor and the object. The measurement results were transferred to the database via the ESP8266 MCU node's Wi-Fi communication line. The stored data can be accessed via a web browser. Compared to the oximeter, the MAX30100 sensor has an average error rate of 1.027% for pulse measurement and 0% for oxygen saturation. The MLX90614 sensor has a 0.42% average error rate when it was compared to the thermo-gun.Thus, the measuring device can function properly and is feasible to use. Furthermore, because there is no direct contact between the human body and the sensor, the instrument can prevent Covid-19 transmission.

1. INTRODUCTION

The World Health Organization has recorded 160 million cases of Covid-19 sufferers with 31 million deaths. The rapid transmission of this virus has increased the hospitalization of patients. Patients with Covid-19 have symptoms that indicate they have contracted Covid-19. One of the symptoms of Covid-19 sufferers is Happy Hypoxia, a condition where the oxygen saturation in the body decreases so that it can cause shortness of breath for Covid-19 sufferers (Tobin et al., 2020). Blood oxygen saturation is the concentration of oxygen in the blood, an essential physiological parameter of the respiratory and circulatory systems (Rotariu & Manta, 2012). Symptoms of COVID-19 are accompanied by an increase in the patient's body temperature to > 38°C (Perhimpunan Dokter Paru Indonesia, 2020). Thus, it is necessary to have a measuring device for the patient's oxygen saturation, heart rate, and body temperature to detect early and prevent further lung damage in patients with Covid-19. The measuring instrument designed can use IoT principles. IoT has a high potential to solve problems and develop in various fields, one of which is the health sector (Muta'affif et al., 2017).

Several studies have used the MAX30100 sensor as a heart rate and oxygen saturation sensor. The MAX30100 sensor works in the principle of reflectance where the light source and detector are placed on the same side, thus enabling measurements in various parts of the body (Wan et al., 2017). Ulfah et al. (2021) measured oxygen saturation and heart rate for 20 respondents. Measurements were made on the respondent's five fingers, displaying the data on the LCD. The results obtained show that the five fingers measurement results are not much different. Hyperastuty & Mukhammad (2021) also measured five respondents' oxygen saturation and heart rate. The results obtained are that repeated data collection produces different outputs when displayed on the blynk app. The different outputs are because the heart rate's dynamic nature changes over time. Recently, Rahmawarni & Harmadi (2021) measured oxygen saturation and heart rate for ten respondents with different ages. They found that the sensor characterization has an error percentage of 0.96% on oxygen saturation and 1.63% on heart rate. Measurement results are displayed on the telegram. Research conducted by Ulfah et al. (2021) and Hyperastuty & Mukhammad (2021) did not characterize the sensor, so sensor readings are not necessarily accurate. It is also necessary to add temperature sensors so that the tool can be used to detect early symptoms of Covid-19 sufferers. The data display platform used by some previous studies, such as telegram, blynk, or directly on the LCD, cannot store and recap the measurement data. These can be overcome by storing data online and creating a website database.

The Internet of Things (IoT) has been applied to heart rate, oxygen saturation, and temperature monitoring system. Gupta et al. (2020) use a blood pressure sensor as a heart rate sensor, a MAX30100 as an oxygen saturation sensor, a DS18B20 as a temperature sensor, and the Thinkspeak platform as a medium for displaying measurement results. Basu et al. (2020) use a MAX30100 as a heart rate and oxygen saturation sensor, an LM35 sensor as a temperature sensor, and a web browser as a medium for displaying measurement results. Imanda et al. (2020) use a grove heart rate sensor as a heart rate sensor, a MAX30100 as an oxygen saturation sensor, an MPU6050 sensor as a temperature sensor, and the Thinkspeak platform as a medium for displaying measurement results. The use of the Thinkspeak platform has a weakness in the form of limited features if the user does not subscribe because this platform is open source. In addition, in handling Covid-19 patients, a temperature sensor is needed to avoid direct contact with the patient.

Based on the above problems, an IoT-based measuring instrument for heart rate, oxygen saturation, and body temperature was developed. The MAX30100 sensor was selected to measure heart rate and oxygen saturation. The MLX90614 sensor was chosen as a non-contact body temperature sensor to avoid the Covid-19 transmission. Measurement data is stored in an online database and displayed on a web browser, allowing the patient to view the history of measuring pulse, oxygen saturation, and body temperature.

2. METHOD

2.1 Tools and Materials

The instrument consists of the MAX30100 sensor as a heart rate and oxygen saturation sensor, the MLX90614 sensor as a non-contact body temperature sensor, and the HC-SR04 ultrasonic sensor as a sensor for the distance from the object the temperature sensor. The ESP8266 MCU node is used as a microcontroller that reads sensor input and can send data to an online database. The data were displayed on the Personal Computer (PC). A multimeter was used to measure the sensor output voltage, a digital thermo-gun as a comparison tool for the MLX90614 sensor output, and an oximeter as a comparison tool for the MAX30100 sensor output.

2.2 The Hardware Design of Heart Rate, Oxygen Saturation, and Temperature Monitoring System

The hardware design scheme for measuring heart rate, oxygen saturation, and body temperature can be seen in Figure 1. The touch of a finger to the MAX30100 sensor will allow the sensor to sense blood flow in the finger and read changes in the output voltage processed at the ESP8266 MCU node. The output voltage that has been processed at the ESP8266 MCU node will be converted into heart rate (BPM) and oxygen saturation (%). The MLX 90614 sensor will sense infrared radiation on the forehead if the distance detected by the HC-SR04 sensor is right at a distance of 2 cm. Thus, there is no direct contact for body temperature measurement. The output voltage that has been processed at the ESP8266 MCU node on each sensor will be displayed in degrees Celsius.

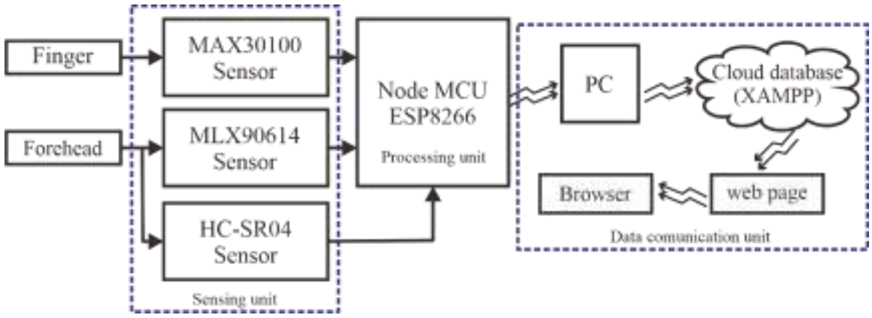

Figure 1. Block diagram of heart rate, oxygen saturation, and body temperature.

All data that has been processed at the ESP8266 MCU node is sent to the PC online. The ESP8266 MCU node consists of a server and a client. The ESP8266 MCU node as the client takes the MLX90614 sensor data and sends it to the MCU server node. The MCU node as server functions to retrieve ultrasonic sensor data, the MAX30100 sensor, and receives data from the client MCU Node, then sent to the database via the Application Programming Interface (API). The data will be stored in MySQL and displayed on a Personal Computer (PC) using the Laravel framework. Thus, the data were stored in the database and displayed in the web browser.

2.3 Characterization of MAX30100 Sensor and MLX90614 Sensor

Sensor characterization is used to determine the sensitivity of a sensor by putting it through a series of tests. A multimeter and lux meter were used to characterize the MAX30100 sensor. The LED on the sensor will emit light into the bloodstream in the finger and will be sensed by a photodetector located parallel to the LED. This characterization is done so that in the process of measuring heart rate and oxygen saturation, there can be space between the finger and the sensor. The MAX30100 sensor characterization data is then compared with an oximeter to see the percentage error of the tool designed. The space between the finger and the sensor allows for more comfortable use without hitting the sensor with a rough surface.

The MLX90614 sensor is characterized by altering the distance between sensor and object (1-10 cm). This characterization aims to determine the optimal distance between the MLX90614 sensor and the object. The MLX90614 sensor characterization data is then compared with a a thermo-gun to see the percentage error of the tool designed. Based on the characterization result, a gap can be made between the sensor and the object to avoid direct contact with the tool. This effort was made to reduce the risk of direct contact with Covid-19 sufferers.

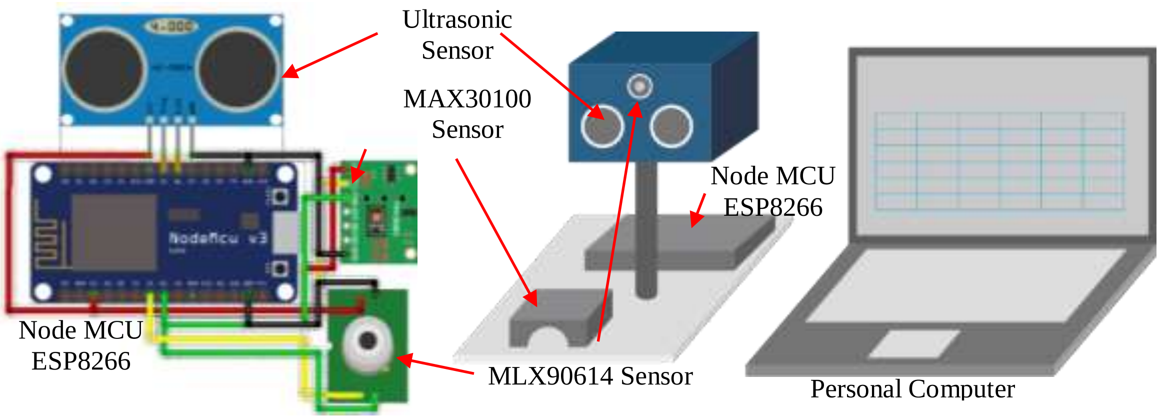

Figure 2. The circuit schematic and physical form of heart rate, oxygen saturation, and temperature monitoring system.

2.4 The Overall Design of Heart Rate, Oxygen Saturation, and Temperature Monitoring System

Designing measuring instruments as a whole are assembling the components needed by measuring instruments. The assembled components are then inserted into the tool casing that has been designed and printed using a 3D printer. The measuring instrument's circuit schematic and physical form can be seen in Figure 2. The measuring instrument that has been assembled is then flashed on the ESP8266 MCU node so that the program can be embedded using the Arduino IDE application. The embedded program connects the ESP8266 MCU node and the Wi-Fi server by entering the IP address and SSID used. First, the data sent to the PC will be stored in a database created using the XAMPP application. The database is then connected to the Laravel application to receive the ESP8266 MCU node data. The measurement data that has been stored in the database can then be viewed using a web browser by typing “localhost:8000” into the browser search tab. Data will be sent if the object distance to the small ultrasonic sensor is 2 cm. The data stored in the database consists of heart rate, oxygen saturation, and body temperature. The flow chart of the program for measuring heart rate, oxygen saturation, and body temperature is shown in Figure 3.

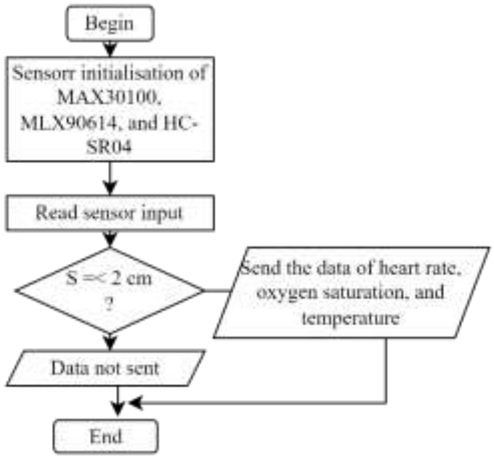

Figure 3. The flowchart of heart rate, oxygen saturation, and temperature monitoring system

3. RESULTS AND DISCUSSION

3.1 Effect of an LED to Finger Distance on the Output Voltage and Light Intensity on the MAX30100 Sensor

Figure 4 shows linear relationship between LED distance to voltage and light intensity. Characterization is done by varying the distance between the LED and the finger, 1-10 mm. The farther the distance from the LED to the lux meter, the smaller the measured light intensity. Changes in the output voltage also occur when the distance between the LEDs and the finger gets farther away. The LED light can be transmitted and reflected maximally if the distance between the sensor and the finger is getting closer. The proximity of the sensor to the finger makes the light emitted can be focused, while if the distance is far, it will make the LED light spread out. Based on the picture, the distance between LED and finger can be given as far as 1-2 mm so that finger does not hit other components on the MAX30100 sensor to provide comfort in its use. This distance can be used as a gap between the sensor and the body to avoid direct contact to transmit Covid-19.

3.2 Characterization of the MAX30100 sensor as a heart rate and oxygen saturation sensor

The characterization of the MAX30100 sensor begins with observing changes in pulse width with time. The change in pulse width occurs in the Infrared (IR) and red LED that is part of the MAX30100 sensor. The MAX30100 sensor is equipped with a 50 Hz filter to minimize noise (Strogonov, 2017). The graph of the change in pulse width with time is shown in Figure 5.

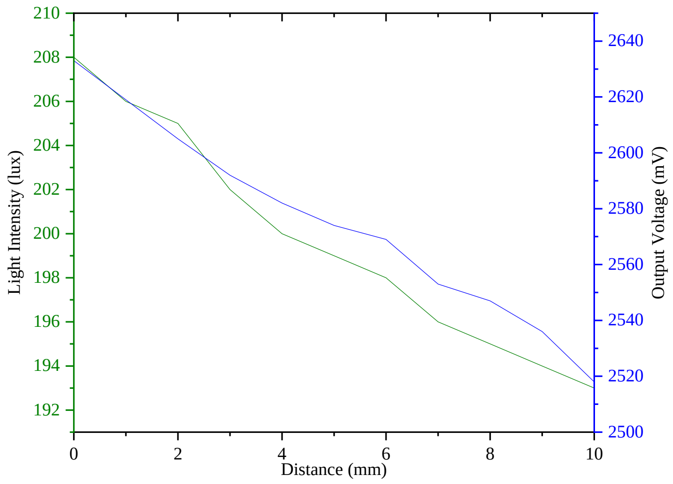

Figure 4. Graph of the effect of the LED distance to the finger on the output voltage and light intensity

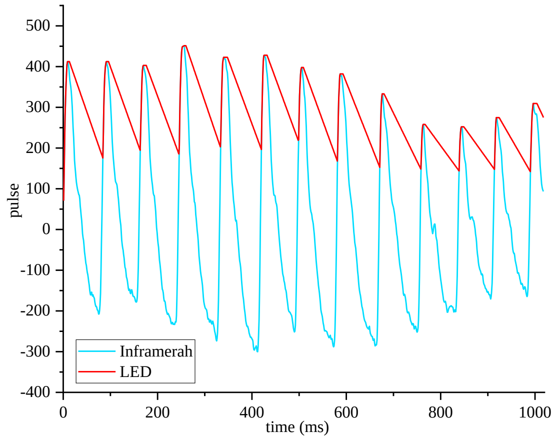

Figure 5. Pulse width against time of LED and Infrared

The maximum amplitude of the LED and IR pulses meet at the same point every second. The sensor will indicate "Beat!" when the maximum amplitude between the LED and IR meets. If the timestamp between the two peaks of the pulse width is known, the heart rate expressed in BPM units can be calculated using Eq. 1 (Chan & Underwood, 2012).

$$BPM = \frac{60000}{current\ beat\ timestamp - previous\ beat\ timestamp} \quad (1)$$

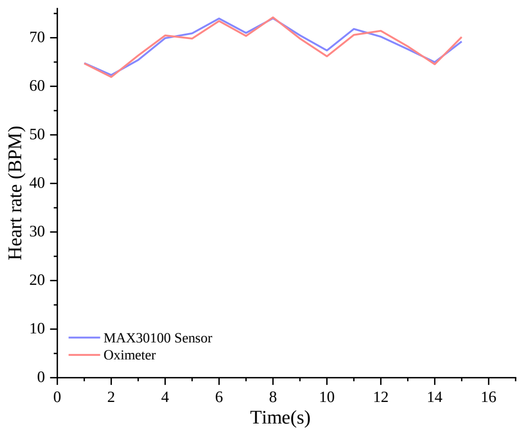

Figure 6. Comparison between heart rate measurement using the MAX30100 sensor and oximeter.

In the MAX30100 sensor, only IR plays a role in sensing the heart rate on the finger (Strogonov, 2017). Figure 6 is a graph of heart rate measured against time using the MAX30100 sensor. Figure 6 shows that the measured pulse is by the standard range given by Gibson (2013), between 60-100 BPM. An unstable BPM value is caused by the heart continuously pumping blood in the body. The rapid movement of blood in the body causes the IR waves to become unstable. Pulse measurement using the MAX30100 sensor with an oximeter produces an error percentage of 1.027 %. These results indicate that the sensor used to measure the pulse is feasible.

Measurement of oxygen saturation requires both IR and LED to sense the blood vessels in the arteries. Figure 7 shows oxygen saturation towards time using the MAX30100 sensor. The measured pulse is at the tolerance value given by Gibson (2013), between 95-100%. Oxygen saturation measurements on the MAX30100 sensor and oximeter show 96% oxygen saturation on both devices.

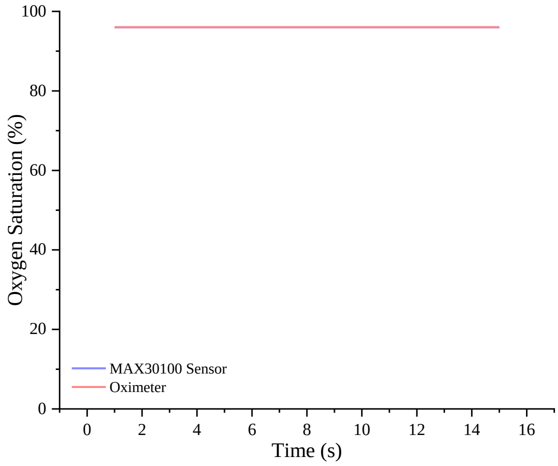

Figure 7. Comparison between oxygen saturation measurement using the MAX30100 sensor and oximeter.

3.3 Characterization of MLX90614 Sensor as Temperature Sensor

The purpose of the MLX90614 sensor characterization was to observe how the sensor distance affected the observed temperature. Sensor testing is done by varying the distance of 1-5 cm to the measured temperature. The object being measured is water with a temperature of 30°C and 40˚C. Table 1 shows the results of testing the distance of the sensor to the object against the measured temperature.

Table 1. MLX90614 sensor test results at a distance of 1-5 cm

Distance of sensor-object (cm)	Object Temperature at 30°C		Object Temperature at 40°C	
	Temperature from MLX90614 sensor (°C)	Error Percentage (%)	Temperature from MLX90614 sensor (°C)	Error Percentage (%)
1	30.38	1.26 %	40.28	0.70 %
2	29.82	0.60 %	39.67	0.83 %
3	28.74	4.20 %	38.23	4.43 %
4	28.11	6.30 %	37.08	7.30 %
5	27.62	7.93 %	35.64	10.90 %

Table 1 shows that when the distance between the sensor and the item increases, the measured temperature approaches room temperature (27°C), resulting in a higher proportion of error. The error is caused by the thermal radiation sensed by the sensor decreasing as the sensor's distance from the radiation source increases. Based on the data from Table 1, the 1-2 cm distance to the object has a smaller error percentage. This distance can be used as a gap between the sensor and the body to avoid direct contact to transmit Covid-19. Characterization is done by measuring the temperature with the MLX90614 sensor in response to the object's temperature rise. Figure 8 shows that the temperature value measured using the MLX90614 sensor and thermo-gun is almost the same as the average error percentage, 0.42%. Thus, the MLX90614 sensor is suitable for a body temperature sensor.

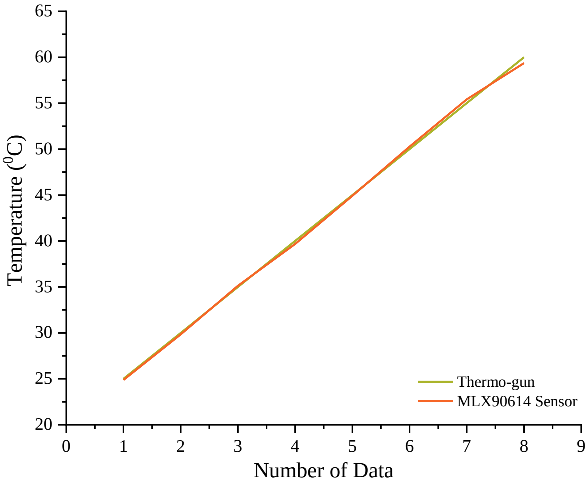

Figure 8. Comparison between body temperature measurement using MLX90614 sensor and thermo-gun.

3.4 The Overall Test of Heart Rate, Oxygen Saturation, and Temperature Monitoring System

Overall tool testing is done to test and get the data on the tool that has been appropriately arranged. The physical form of the tool is shown in Figure 9. Figure 9 shows a device arrangement consisting of the MLX90614 sensor as a temperature sensor, the HCSR-04 sensor as a distance sensor from the temperature sensor to the object, and the MAX30100 sensor as a heart rate sensor and oxygen saturation sensor. This sensor is placed in a box made of *Polylactic Acid* (PLA) material and made using a 3D printer. The ESP8266 MCU node, which acts as the centre for processing and sending data to the PC, is covered in a box to protect against external impacts.

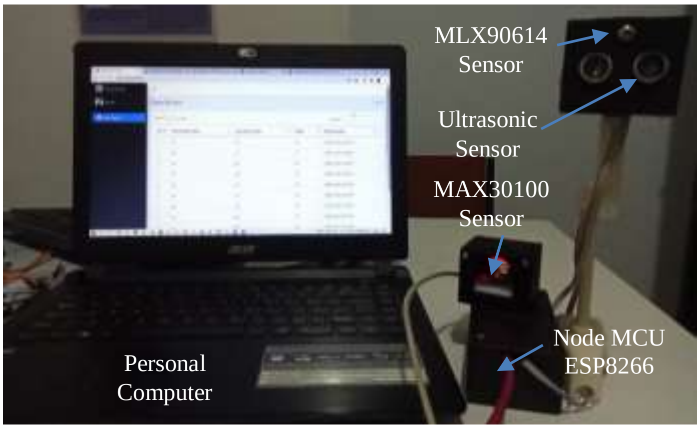

Figure 9. The overall design of heart rate, oxygen saturation, and temperature monitoring system.

Data retrieval is done by placing the forehead in front of the ultrasonic sensor and MLX90614 sensor to measure body temperature at a distance of 2 cm from the sensor. The index finger is placed on the box containing the MAX30100 sensor to detect heart rate and oxygen saturation. The measurement data is then sent via the Node MCU ESP8266 to a database located on the PC via a Wi-Fi network.

The data stored in a database can then be accessed in the web browser by typing "localhost:8000" on the search tab. If the distance from the forehead to the ultrasonic sensor exceeds 2 cm, then the data is not sent to the database. The display of data can be seen in Figure 10. The data displayed on the web browser can be opened with a PC, smartphone or other internet-connected gadget. Data can be accessed with a note if the server and user are connected to the same network. This heart rate, oxygen saturation, and body temperature measuring device consume low power, is inexpensive to install, is easy to carry, and can work accurately based on IoT principles. This experiment result proves that this measuring instrument can function properly and can be used properly.

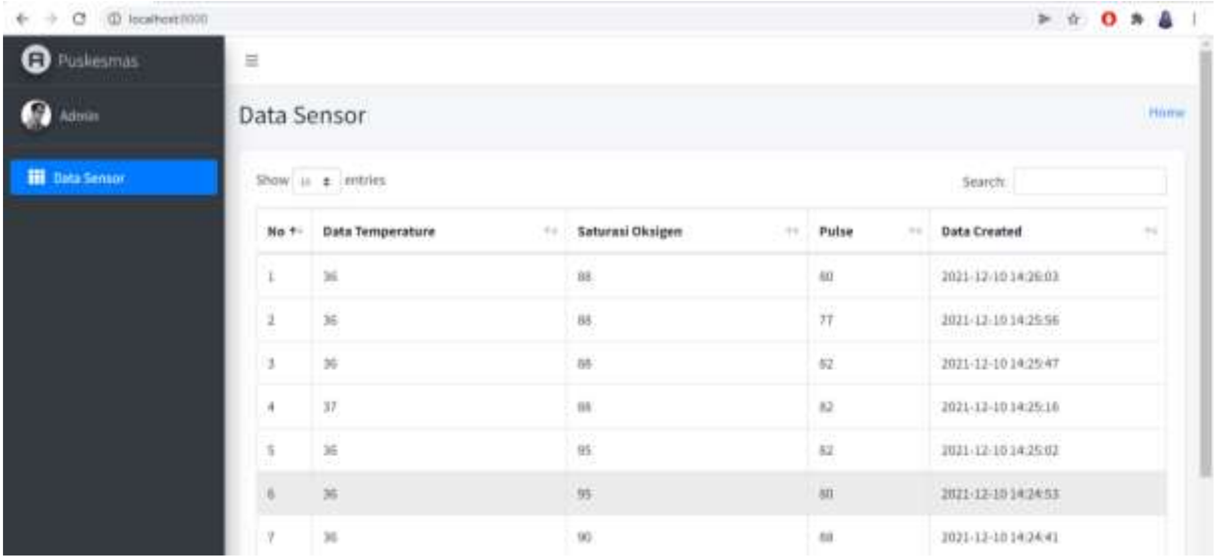

Figure 10. Display data entered into the database and accessed via a web browser.

4. CONCLUSSION

This research has successfully developed instruments for measuring pulse rate, oxygen saturation, and body temperature for Covid-19 patients using the MAX30100 sensor and the Internet of Things (IoT)-based MLX90614 sensor. The MAX30100 sensor can be utilized at a 1-2 mm distance between the finger and the sensor and has a pulse measurement error percentage of 1.027%. The MLX90614 sensor produces an average error of 0.42% when used as a body temperature sensor. The space between the MAX30100 sensor to the finger (1-2 mm) and the MLX90614 sensor to the forehead (1-2 cm) can avoid direct contact with the body, so as to prevent the spread of Covid-19. The ESP 8266 MCU Node's measurement data were transferred to a database and can be accessed using a web browser and a Wi-Fi network. Thus, the instrument is functional well and suitable for use.

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