Heart Rate Monitoring Device for Arrhythmia Using Pulse Oximeter Sensor Based on Android

by Lanny Agustine

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Abstract—**A monitoring and alert system for a patient with arrhythmia potential, especially during rest time at night, can reduce the fatality effect of the heart problem. General pulse oximeter connected with the Internet of things (IoT) technology enable a family member to remotely monitor the patient. The more important is the system ability to give real-time alarm to alert them when the patient in critical condition.**

The system uses a pulse oximeter sensor, a WLAN router to connect the device to the Blynk server, and the data could be displayed on an Android application. The hardware worn by the patient is battery powered. The battery capacity also monitored. The lowest accuracy of heart rate reading compared with the measured output of a fingertip pulse oximeter is 96.9% (normal, bradycardia, and tachycardia). The speed of data communication for remote monitoring depends on internet connection quality.

Keywords— *arrhythmia, heart rate, pulse oximeter, IoT, Android*

I. Introduction

The heart is a vital human organ; its health needs to be maintained. Based on SRS (Sample Registration System) survey in 2014, coronary heart disease became the highest cause of death in Indonesia with 12.9% of the Indonesian population [1]. Coronary heart disease can cause heartbeat rhythm problems or commonly called arrhythmias. Cardiac arrhythmia could be divided into two types based on its speed; tachycardia and bradycardia. Tachycardia is a condition of heart abnormalities with a heart rate above normal in resting conditions, while bradycardia is below standard. The heart rate of healthy adults is 60 to 100 times per minute at rest [2].

The rate of the human heartbeat can be measured by pressing the wrist and calculate the frequency of pulsation for 1 minute or 15 seconds and then the number of beats multiplied by 4. However, this method is not effective in determining the accurate heart rate. To accurately find a heartbeat in a patient can simply be done using a pulse oximeter [5,6]. The use of pulse oximeter can easily be done at home while the patient is at rest. The internet of things (IoT) technology makes it possible to monitor the pulse oximeter measurement through Android smartphone applications [7]. It can help to monitor the patient with arrhythmia potential, especially tachycardia and bradycardia, by the family member remotely [8,9].

Therefore it is necessary to upgrade the conventional pulse oximeter to be able to communicate its measurement output to another remote monitoring device. Alarms to indicate any arrhythmia is occurring also important to alert any people at home and those who monitor the patient remotely to increase the chances to help the patient immediately [8,10,11,12,13].

II. Materials and Methods

A. Pulse Oximeter Sensor

A pulse oximeter is a non-invasive medical device. It is used to measure oxygen saturation in blood. This medical device has an LED as its transmitter and a photodiode as its receiver. The LED will emit a specific wavelength of light that will be absorbed by the blood, then the light will be reflected, transmitted, absorbed, and spread by the skin, tissue, and blood before the light reaches the photodiode. The pulse oximeter has two sensor types based on the position of the LED and the photodiode; they are transmittance sensor and reflectance sensor [9,14].

a. Transmittance Sensor

The LED and photodiode are facing each other in the transmittance sensors, as in Fig. 1a. The LED will emit a particular wavelength of light through the fingertips tissue, and then the light that penetrating the tissue will be received by the photodiode (PD). The photodiode must be placed straight opposite to the LED so that the maximum number of transmitted lights can be detected.

b. Reflectance Sensor

The LED and photodiode (PD) are placed side by side on the skin surface in the reflectance sensors, as in Fig. 1b. The LED will emit light with a specific wavelength through the tissue and blood. Light is absorbed by blood, and then some part of the light reflected and accepted by the photodiode.

B. *Pulse Oximeter Output Waveform*

Blood pressure changes can be felt during each heartbeat when sensing heart pulses through the artery in the wrist [3,4]. The perceived pulse is actually a wave of blood pressure that travels from the heart to all the arteries [8]. A wave that formed by blood pressure compared with the ECG waveform can be seen in Fig. 2. The blood pressure waveform is divided into four parts; they are systolic pressure, the dicrotic notch, diastolic pressure, and pulse pressure. The differences between each wave part are as follows:

- Systolic pressure is the maximum blood pressure of artery walls caused by cardiac ventricular contractions.
- Dicrotic notch illustrates the disturbance of a smooth flow caused by low reverse blood flow approaching the aortic semilunar valve when the ventricle returns to its resting state.
- Diastolic pressure is the lowest blood pressure in the arteries caused by cardiac ventricular relaxation.
- Pulse pressure is the difference between systolic pressure and diastolic pressure. Pulse pressure is the pulse felt by pressing the artery location on the wrist.

The R-R interval period of the ECG waveform indicates one heartbeat interval. Fig. 3 also shows that a series of arterial pressure changes happen during the R-R interval. Both waves have a time correlation because they give different views from the results of the same physical examination, such as the heart rate [3,4]. The pulses detected by the pulse oximeter will get closer together if the heart rate increase, as the ECG signals do [2].

III. Hardware Design Method

This device is aimed to be used by two different users, the patient, and the patient's family member in the remote area. The blog diagram of the system can be seen in Fig. 3. The hardware is designed to be used by the patient during the rest time. It will communicate its measured output with Android smartphone to be monitor remotely using IoT (Internet of Things) technology by the family member [3].

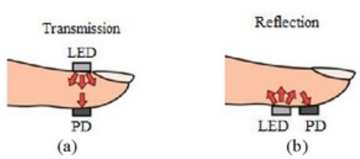


Fig. 1. Pulse oximeter sensor, a) Transmittance sensor, b) Reflectance sensor [5,14]

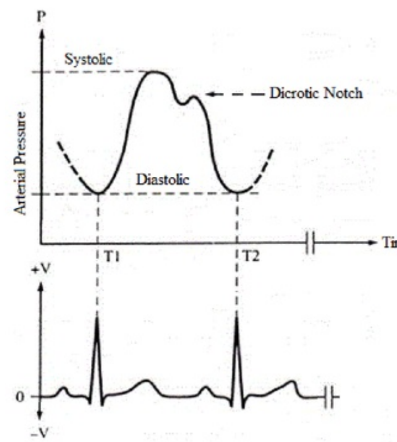


Fig. 2. ECG waveform compare with pulse oximeter output waveform [2,5]

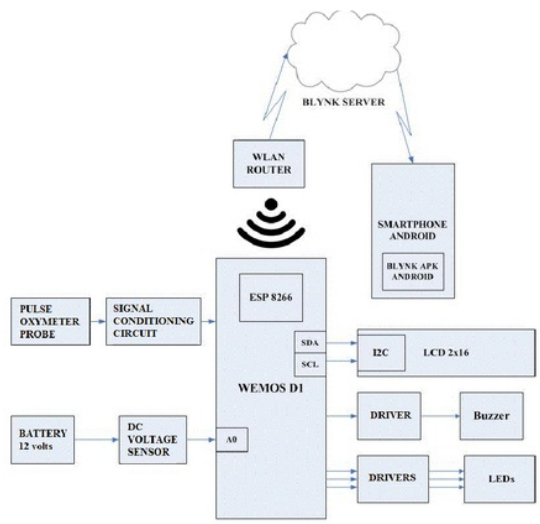


Fig. 3. The designed a system block diagram

The signals to be measured and detected are the patient's heart rate, and also the heart rate type and battery capacity to stimulate LEDs and buzzer.

The system is divided into three parts; hardware to be used by the patient, WLAN router for connecting the device to the Blynk server, and the data monitor via an Android application. The initial proses of the system are collecting the input data. The input data obtained is from the voltage sensor and a pulse oximeter sensor. Voltage sensor serves to detect the voltage of the battery into a resource at the time of use of the tool, and the pulse oximeter sensor will detect the heartbeat. Microcontroller's outputs are in the form of LED indicator, 2×16 character LCD, buzzer, and data delivery to the Android application with IoT system. The details of the design are explained in the next sub-sections.

A. I/O Human Interface Connection

In this research, Wemos D1 is using as a microcontroller module. Wemos D1 is integrated with wifi module ESP8266. The microcontroller function is to read the output pulse signal from, a signal conditioning circuit and to read output voltage from the voltage sensor. The function of Wemos D1's pins used in this research can be seen in Table I.

B. Pulse Oximeter Sensor and Signal Conditioning Circuit

In this research, a Nellcor DS100a pulse oximeter sensor is used. Physical picture and its internal schematic can be seen in Fig. 4a and 4b respectively. Only 5 out of 9 pins are used, they are pin 2, 3, 5, 7, and 9. The first part of the schematic in Fig. 5 shows the pulse oximeter sensor connection with its additional component and to the current to voltage converter (I-to-V) circuit. Pin 2 is connected in series with a 330-ohm resistor, and powered by 5Vdc, while pins 3, 5, and 7 are grounded. Pin 9 is connected to an I-to-V circuit to convert the current produced by sensor's photodiode to voltage. The produced current is in order of nanoAmpere since a 100kΩ feedback resistor is used in the I-to-V circuit, then the output voltage will be at the order of millivolt [5].

The second part of the schematic is two cascaded 2nd order bandpass filter to form a 4th order bandpass filter. Each bandpass filter is composed of a 1st order passive high pass filter, and an integrator that functions as a 1st order active low pass filter with non-inverting voltage amplification [5]. This 4th order bandpass filter is designed to passes signals with the frequency range of 0.5 Hz to 2.34 Hz and inhibits the signals outside of that frequency range. Each bandpass filter also gives different voltage level amplification. The voltage gain of a bandpass filter with operational amplifier U1A is 15.4 times, while bandpass filter with operational amplifier U1B is 175 times. The total gain of both circuits is 2695 times. The goal of this high gain is to conditioning the weakest heartbeat pulses to reach minimum peak level as high as 1,9V before reaching the comparator circuit.

The last part is a comparator circuit with hysteresis. The circuit function is to convert analog input signals into pulses based on the analog signals peak level.

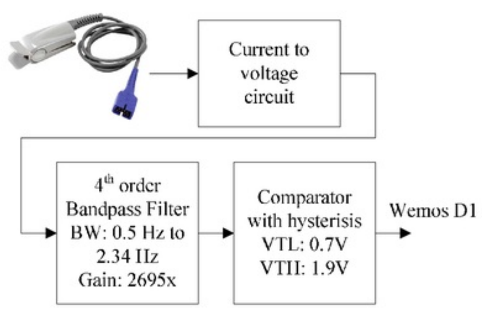
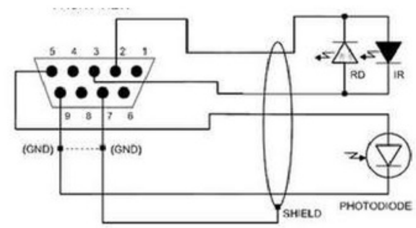


Fig. 5. Pulse oximeter sensor and signal conditioning circuit block diagram

(a)



(b)

Fig. 4. A Nellcor DS100a pulse oximeter sensor [9], a) top view, b) internal schematic [15]

TABLE I. WEMOS D1 PIN CONFIGURATION

Pin	Connection	Function
D2	Driver Red LED	To control ON/OFF Red LED
D3	Serial clock I2C (SCL)	To send data to LCD
D4	Serial data I2C (SDA)	To send data to LCD
D5	Driver Yellow LED	To control ON/OFF Yellow LED
D6	Driver buzzer	To control ON/OFF buzzer
D7	Driver Green LED	To control ON/OFF Green LED
D8	The output of the signal conditioning circuit	To read pulses of the heartbeat signal from signal conditioning circuit output.
A0	The output of DC voltage sensor	To read analog voltage from DC voltage sensor output.

The pulse rate correlates with the heart rate. The comparator converts the peaks of the analog signal into pulses signal. It compares two level of voltage to the input voltage to perform hysteresis. The function of this feature is to decrease the possibility of converted noise signal into pulse signal. The upper threshold is designed at 1.9V, and lower threshold is at 0.7V. The hysteresis characteristic is shown in Fig. 6. Any input signal with peak voltage level equal to or higher than 1.9V when input signal in rising transition will be converted to high logic (4V). And any input signal with peak voltage level equal to or lower than 0.7V when input signal transitioning down will be converted to low logic (0V) [16]. However, the input signal with the peak voltage level outside the range of 0.7V to 1.9V will stimulate another transition.

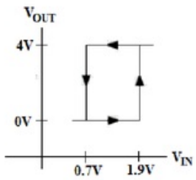


Fig. 6. Comparator hysteresis characteristic [16]

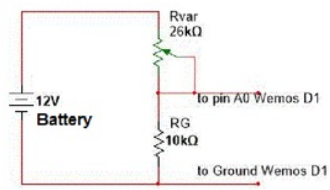


Fig. 7. DC voltage sensor

C. DC Voltage Sensor

DC voltage sensor is used to determine the voltage level of the 12Vdc battery as the power source of the device. The voltage level will then converted into battery capacity percentage that will be displayed on a 2x16 characters liquid crystal display (LCD). DC voltage sensor circuit is actually a voltage divider circuit as shown in Fig. 7. It is consists of a variable resistor (Rvar) connected in series with a 10kΩ-2W ground resistor (RG). The circuit is connected in parallel to the battery. The point between Rvar and RG is the output of the DC voltage sensor, which is connected to analog input pin channel A0 of the microcontroller on the Wemos D1 module. The output voltage generated from this sensor is a DC voltage ranging from 0 to 3.3V, as required by the analog input voltage range of the ADC.

IV. Software Design Method

There are two pieces of software that have been designed, for programming the microcontroller and the Android application. The microcontroller system is based on the battery capacity that power up the device wearing by the patient.The software using C programming language is designed for programming the microcontroller, while the Android application is designed using the Blynk platform. The microcontroller system will deal with the process related to the heart rate as long as the battery capacity higher than 10%. The system will count the heart rate in BPM based on the input pulses to the microcontroller input pin. Then, it will decide whether the instantaneous heart rate is in normal condition, tachycardia, or bradycardia. The decision will stimulate LEDs and buzzer to on or off. Otherwise, the system will indicate that the battery is in low power condition, and will also stimulate a particular LED to light. The battery capacity data, the heart rate condition, and LEDs status are then sent to the Blynk server through the Internet.

The information displays on LCD and Android application are different.

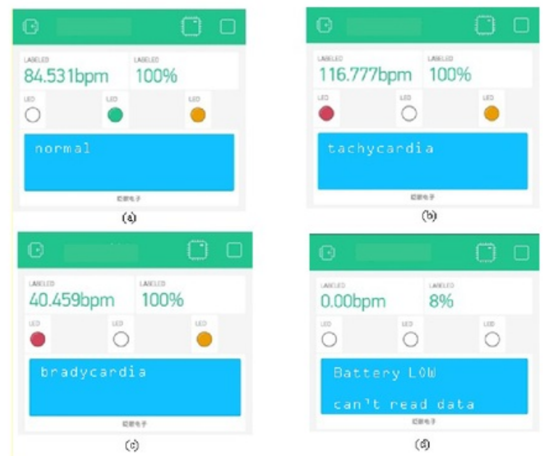


Fig. 8. The Monitoring Display on Android application based on heart rate condition and battery capacity, a) normal heart rate, b) tachycardia, c) bradycardia, d) battery low power

The information displays on LCD are information that important to patient and people around the patient. The 2x16 character LCD will continuously display the heart rate in bpm as long as the battery capacity is higher than 10%. Otherwise, the LCD will only display the information that the battery is low until the power is lost. This information to alert the patient or close by a person that the device power supply needs to be recharged and can not be used.

Fig. 8 shows the monitoring display on Android application based on heart rate condition and battery capacity. The goal of this application is to make the family member able to monitor remotely. And the more important is to alert if there is any potential danger to the patient condition due to arrhythmia. There are three types of displays based on heart rate condition; they are when the detected heart rate in normal condition, tachycardia, and bradycardia.

Otherwise, when the battery is in low power condition, it will only show the battery condition and zero bpm heart rate since the process to count the heart rate has stopped. Red LED light to indicate arrhythmia, green LED light to indicate the normal heart rate, and yellow LED light to indicate battery capacity higher than 10%.

V. Results and Discussions

A. DC voltage sensor measurement and testing

The accuracy of DC voltage sensor will define the accuracy of battery capacity information. The circuit is tested with stable DC input voltage from a laboratory DC power supply. DC input voltage range is 0 to 12V, and will be scaled to 0 to 3.3V by the DC voltage sensor circuit and converted to digital signal by 10-bit ADC. The microcontroller will then recalculate ADC output to dc voltage back to the range of 0 to 12V and displayed on LCD.

Fig. 9 shows the graph of thirteen measured battery voltages (input line) in the range of 0-12V, compare with scaled voltage at the output of DC voltage sensor (output line), and with the displayed voltage on LCD (displayed line). The graph shows that the lowest accuracy of the designed device to process input DC voltage to LCD compare with the measured DC input voltage is 95.4%.

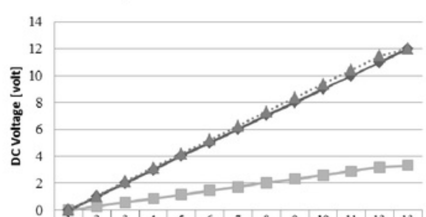
B. Comparator hysteresis response test

Fig. 10 shows the comparison of comparator circuit response to an unstable peak of the pulse oximeter output signal. This circuit can generate square pulses with the limitation of the input heart pulse signal peak as low as 0.7mV at the current to voltage converter (I-to-V) circuit output since the total signal amplification of the circuit design is 2695 times. And it also limits the electric current received from the pulse oximeter sensor as low as 7nA based on the I-to-V circuit design.

C. Microcontroller software and Android application responses test

The purpose of this step is to test whether the device can detect and calculate heart rate accurately, and the device can give responses by controlling the LEDs and buzzer as expected. The input pulses signal to the microcontroller is generated by a function generator (GW-GFG 8210) to simulate the heart pulses. The pulses frequency range of the sample signal is in the range of bradycardia, normal beat, and tachycardia. The graph of the test results can be seen in Fig. 11. It shows that the system accuracy can reach as high as 100%.

The slope of pulse waveform might be different for each person [8]. Heart rate could be calculated from the period of two pulses; it can be the period between two rising edges or falling edges [16]. Fig. 10 shows that the period between two pulses might be different if calculated the period of two rising edges compares to the falling edges. The chosen method to calculate this period will affect the heart rate calculation error. It indicates that the device can trigger responses of LEDs and buzzer activation exactly as expected to the three conditions as proposed; bradycardia, normal beat, and tachycardia. The data of heart rate classification, pulse rate, battery capacity, LEDs and buzzer status that sent to the Android application also have been tested. The responses of the application are exactly as expected as shown in Fig. 8.



	1	2	3	4	5	6	7	8	9	10	11	12	13
Output	0	0.28	0.58	0.86	1.16	1.45	1.73	2.03	2.31	2.6	2.89	3.18	3.33
Input	0	1	2	3	4.04	5.01	6.01	7.04	8.01	9.01	10	11	12
Displayed	0	1.03	2.1	3.13	4.21	5.24	6.26	7.31	8.34	9.39	10.4	11.5	12
% Accuracy	100	97.4	95.4	95.9	95.8	95.4	95.9	96.2	95.9	95.8	95.9	95.8	100

Fig. 9. The result of DC voltage sensor measurement and its conversion to the displayed voltage on LCD

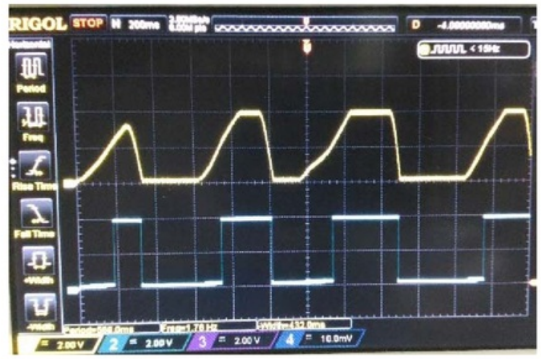


Fig. 10. Pulses waveform vs comparator output waveform

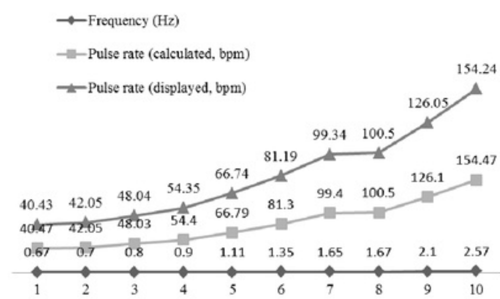


Fig. 11. Software performance to count pulse rate

D. Hardware system testing

The designed hardware worn by the patient has been tested compared with a fingertip pulse oximeter. The purpose of this test is to determine the accuracy of the device to count the heart rate (BPM) of the patient. There were twelve healthy male volunteers aged 19 to 23 with different mass, height, and skin color those acting as the patients. The position of the pulse sensors on subject fingertips are shown in Fig. 12. The pulse sensor of the designed device is positioned on the index fingertip of the left hand, and the fingertip pulse oximeter is positioned on the middle finger of the left hand.

To achieve an accurate heart rate results, the subject should not do any heavy physical activity at least 15 minutes before the measurement began [9,13]. During the measurement process, the subject must be at rest. The measurement is taken once every minute, and the total time is 5 minutes for each subject. Fig. 13 shows the graphical result of one-time measurement of each person. It shows the heart rate data displayed by the designed device compared with those displayed by the fingertip pulse oximeter. The performance accuracy of the designed device is 96.9% and mostly higher. The difference of mass, height, and skin color did not give meaningful effect to the designed device performance since the error is approximately less than 3%.

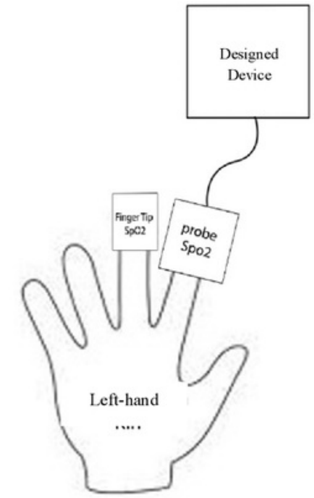
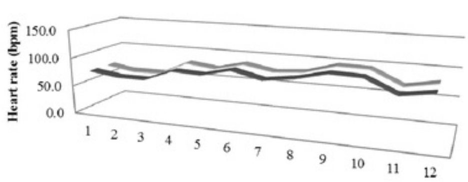


Fig. 12. The position of fingertip pulse oximeter and the sensor of the designed device on the left-hand fingertips



	1	2	3	4	5	6	7	8	9	10	11	12
■ Designed	75.9	69.1	69.0	88.4	86.3	98.5	86.5	93.8	106.4	104.8	81.5	90.1
■ Pulse Oximeter	75	67	68	91	85	97	88	92	107	106	82	92
% Accuracy	98.8	96.9	98.5	97.1	98.5	98.4	98.3	98.1	99.4	98.9	99.4	98.0

Fig. 13. The comparison of heart rate measurement result: the designed device vs the fingertip pulse oximeter

VI. Conclusion

The DC voltage sensor 8 the input source to calculate the battery capacity has input voltage range of 0-12V and output voltage range of 0-3.3V. The lowest accuracy of the designed device to read and display the battery voltage is 95.4%.

The accuracy of the designed device to calculate the pulses rate can reach as high as 100% when using the square wave to simulate heart pulses. Its accuracy can decrease as low as 96.9% when tested on human subjects. Since the heart rate calculation error is approximately less than 3%, it could be concluded that the difference of sex, body mass, and skin color do not give meaningful effect to the designed device.

The Android application can give excellent responses due to the sent data from the designed device. However, the response speed depends on the internet connection quality, and also the Blynk server performance.

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