



Design and Construction of Medical Pulse Oximeter

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Abstract

Pulse oximetry is a noninvasive method for monitoring a person's oxygen saturation. It is an electronic device and instrument that measures the electrical impulse of the of human heart and the number of beats per minute at which the heart pumps blood into the body. An average man, school or hospital should be able to easily afford a pulse oximeter for personal, teaching and emergency purposes, respectively. This is not the case due to the cost of this device and this is the reason this project was embarked upon. This work builds a low power, low cost, reliable and non-invasive monitoring device that accurately measures the level of SPO_2 and pulse rate in the blood of a patient or an individual. LM358 was used in this project and the electrodes in the transmitter senses the heart electrical impulse and sends the information to a receiver in the form of a watch, to obtain and record results which were found to be accurate and within normal range and standards. The results and readings are as obtained from some patients in the medical ward of University of Ilorin Teaching Hospital. This type of proximity device is essential for a patient suffering from hypertension, asthma and other various heart diseases. In spite of the successful design and construction of the device, battery failure (life cycle), deterioration of the components, among others, are some of the challenges associated with the device. Recommendations on how to improve the system have been given.

Keywords: Pulse oximeter, human heart, low cost, monitoring, electrical impulse.

1. Introduction

All tissues in the body depend on oxygen for survival. Oxygen makes up approximately 21% of the gases in the air we breathe. Heart rate and blood oxygen saturation are indicators of heart functionality, in other words, they are vital indicators of life. A short interruption in the supply of oxygen will impair cellular function, and a sustained interruption will rapidly cause cellular injury and eventually death. Detection of reduced oxygen levels in the blood is therefore a key indicator of patients requiring immediate intervention (Petersen, 2013).

Heart rate is the speed of the heartbeat measured by the number of contractions (beats) of the heart per minute (bpm). The heart rate can vary according to the body's physical needs, including the need to absorb oxygen and excrete carbon dioxide.

Heart rate is formerly measured by placing the thumb over the arterial pulsation, and counting the pulses usually in a 30 second period. Heart rate is then found by multiplying the obtained number by 2. This method although simple, is not accurate and can give errors when the rate is high. In clinical environment, heart rate is measured under controlled conditions like blood measurement, heart voice measurement and electrocardiogram (ECG). ECG is one of the frequently used and accurate methods for measuring the heart rate. But ECG is not economical and can be afforded only by few (Esrat, 2014).

The heart rate of a healthy adult at rest is around $75(\pm 15)$ (or greater for females) beats per minute (bpm). Athletes normally have lower heart rates than less active people. Babies have a much higher heart rate at around 120 bpm, while older children have heart rates at around 90 bpm. Heart rate varies significantly between individuals based on fitness, age and genetics (Esrat, 2014).



The commercial pulse oximeters available in the market are expensive. An average man should be able to afford a pulse oximeter for regular use at home and in cases of emergency. Pulse oximeters should also be available for teaching purposes in schools. In order to achieve this, the pulse oximeter should be portable, lightweight and easy to operate. Oxygen in the air is breathed into the lung and carbon dioxide is breathed out. Blood is oxygenated in the lungs and is then pumped by the heart to the tissues.

In arterial blood, 98% of hemoglobin is saturated with oxygen, hence, fully saturated. This gives it its bright red colour. Venous blood from the tissues has delivered some of its oxygen to the tissues. Normally only 75% of the hemoglobin of venous blood is saturated with oxygen, hence reduced. This gives it its dark red colour. The hemoglobin in the arterial blood is called oxidized hemoglobin (oxyhemoglobin), denoted as HbO₂. The hemoglobin in the venous blood is called reduced-oxygen (deoxyhaemoglobin), denoted as Hb. The oxygenation level of hemoglobin in arterial blood is estimated by the oxygen saturation in arterial blood (SaO₂), which is defined as the ratio of the concentration of oxygenated hemoglobin to the concentration of total hemoglobin in the blood. The SaO₂ provides information about the performance of the respiratory system. Normal values of SaO₂ are 94–98% for healthy adults at sea level.

Aside the introduction section, the remaining sections of this paper are organized such that Section 2 gives a review of related previous works. Section 3 describes the methodology and implementation of the pulse oximeter system. Results and discussion are presented in Section 4, while conclusion is drawn in Section 5.

2. Related Works

In this section, some of the related works on medical pulse oximeter have been considered. Wang and Chen (2017) designed a pulse oximetry circuit and its sensing system based on the standard complementary metal-oxide-semiconductor (CMOS) technology of 0.18 μm . Ali and Serdar (2016) proposed the use of a wireless microcontroller based pulse oximeter to measure the oxygen delivered to patient through the oxygen flowmeter. The pulse oximeter telemetry system presented in the study was fast, easy to set up and use. It also reduced the associated medical risks involved in such activity, but the device cannot be said to be cheap.

Petersen, et. al. (2013) developed an ultra-low-cost pulse oximeter that interfaced a conventional clinical finger sensor with a mobile phone through the headset jack audio interface.

Nitzan, et. al. (2014) presented a calibration-free pulse oximetry for measurement of SPO₂, based on photoplethysmography (PPG) pulses of two nearby wavelengths in the infrared. PPG is an optical measurement of the change in blood volume in the arteries. By neglecting the difference between the path-lengths of the two nearby wavelengths, SPO₂ was derived from the PPG parameters with no need for calibration.

Hay, et. al. (2018) presented the fact that because commercial pulse oximeters require empirical calibration which is based on SaO₂ measurement in extracted arterial blood, they are still prone to error, since the path-lengths difference between the two wavelengths varies among different subjects. Jianchu & Steve (2005) stated that due to its non-invasive nature, high precision in its operational range, and reasonable cost, pulse oximetry is widely adopted as a standard patient monitoring technique.

Against this premise and bearing in mind some of the open issues as highlighted, this work is an attempt to design and construct a relatively cheaper, accurate, easy to use, as well as efficient medical pulse oximeter for applications at home by individuals, in schools by teachers, and at the hospitals by medical practitioners for emergencies and other medical related needs.

3. Methodology

This section deals with the details of the research methodology and implementation. The Pulse Oximeter system consists of SPO₂ sensor, signal generator, amplifier, filter, ADC, SPO₂ and pulse rate detection module and LCD. The operational amplifier is the key component in the circuit which converts the light signal, processes it and produces an output value of the measured variables of a patient SPO₂ and pulse rate.

3.1 The Pulse Oximeter Measurement Circuit

In Figure 1, the circuit diagram of the pulse oximeter is shown. The pulse oximetry sensor, i.e. DCM03, is used to detect the pulse oxygen saturation, which has the advantages of small volume, low power consumption and high precision. The key to measure the blood oxygen saturation is to get the pulse waveform. The pulse signal of human body is a physiological signal of low frequency and low amplitude, which is about 0.5 mV.

In theory, the whole measurement system needs to be enlarged more than 200 times to achieve the requirement of ADC conversion voltage. The pulse frequency is concentrated in 0.5 Hz ~ 5 Hz, and the maximum is less than 40 Hz. In the process of signal acquisition, the movement of the body and mental stress will produce baseline drift and noise. At the same time, there will inevitably be power frequency interference and electromagnetic interference. This requires the suppression of the base drift circuit and the two filter circuit to filter the interference.

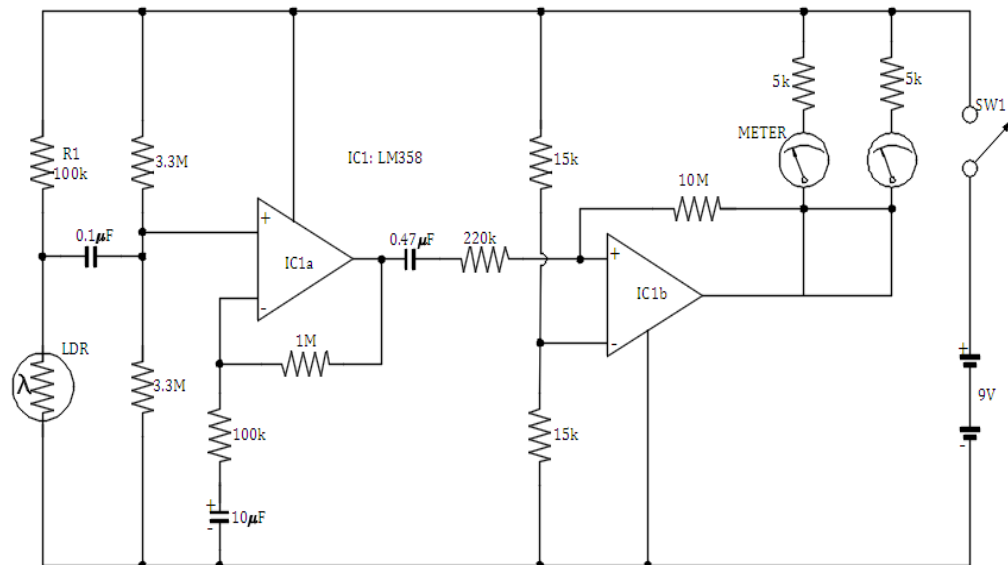


Figure 1: The circuit diagram of the pulse oximeter

The pulse signal collected by the pulse sensor is very weak, the signal amplitude is 20 mV ~ 50 mV. In order to achieve the conversion voltage of ADC, the input signal of the circuit module should be increased by 50 ~ 80 times. In order to improve the anti-interference performance of the circuit, to avoid the distortion of the pulse signal caused by a large gain, the pulse oximeter measurement circuit is composed of preamplifier circuit and two-stage amplifier circuit. The preamplifier circuit uses differential amplifier. The differential amplifier circuit has a capability of strong common mode rejection (82.5 dB), which can suppress the temperature drift, voltage drift and effectively offset the random noise.

After the signal is amplified, it needs to filter the interference. The band-pass filter circuit is designed to eliminate the interference and noise, including low-pass filter and high-pass filter. Low pass filter circuit uses two-order Butterworth low-pass filter circuit. This type of active circuit can not only remove the interference effectively, but also reduce the signal attenuation. At the same time, the signal can be amplified to some extent. The pulse signal, after the low-pass filter circuit, is composed of DC signal and AC signal. Among them, the DC signal is the volt level, while the AC signal is millivolt level. Therefore, it is necessary to amplify the AC signal individually. In this way, the AC and DC signals should be isolated, and then the AC signal can be amplified, some low-frequency interference can also be filtered out. Finally, the AC signal is fed into the two stage amplifier to obtain the value of AC I, DC I.

The pulse oximetry sensor system based on CMOS is composed of four modules: the reflective pulse oximetry module, data processing module, RFID transceiver module and the PC interface. In the process of data transmission, this system involves two kinds of communication modes including wired communication and wireless

communication. The communication between sensor and MCU, MCU and the tag, the reader and PC are all through the wired communication mode. The transmission of sensor data between RFID tag and RFID reader is accomplished by wireless communication. The data processing module will not only process the pulse and blood oxygen information collected by the sensor, but also establish a connection with the RFID tag. At the same time, the pulse and blood oxygen data collected and processed are transferred to the register of the RFID tag. The data transmission between the sensor and the data processing module is through the serial port connection, and the data transmission between the data processing module and the RFID tag is communicated through the SPI interface.

RFID transceiver module includes the RFID active tags and the RFID reader. The RFID tag and the reader achieve the data transmission based on GEN ISO/IEC 18000-6C protocol. Based on the communication between the data processing modules, the whole communication process: MCU transmits the data in the register to the RFID tag through the SPI interface. The reader communicates with the tag in accordance with the radio frequency communication protocol and reads the data in the internal register of the RFID tag. Finally, the RFID reader read the data in the RFID tag through wireless communication (Chan, et. al., 2013), and display the data on PC interface.

3.2 Mode of Operation of the Pulse Oximeter

The principle of operation of the pulse oximeter is as a result of a high gain circuit, based on a dual operational amplifier I.C. which can either be low power LM358 or the JFET TL072. However, in this project LM358 was used. The LDR is connected in series across 9 V battery supply via a look resistor (RI) and the minute signal causes the non-inverting (+) input, pin 3, of IC via a 0.1 uF capacitor. Pin 3 is biased by a high impedance voltage divider consisting of two 3.3 mΩ resistor. The feedback resistors to pin 2 set the gain to eleven times. The output of IC, is connected through a 0.4 μF capacitor and 20 KΩ resistor to ICIB. This is configured as an inverting OP-AMP of 45 J so that is the total circuit gain is about 500 J. The output of ICIB is used to drive two analogue meters, one measuring (indicating) pulse rate and the other measuring SPO₂ (Hossain, et. al., 2010).

Measurements taken in a well lit room preferably in daylight increases the effectiveness of the reading of pulse oximeters. To check patient or individual pulse rate, carefully place or position a thumb or finger over the LDR and count the meter fluctuations for a period of 15seconds. Then multiply the result by four to obtain pulse rate. However, the circuit cannot be used if one is walking or running. It must be stable, i.e. put on a table or desk etc. The mode of operation of the pulse oximeter is represented in Figure 2.

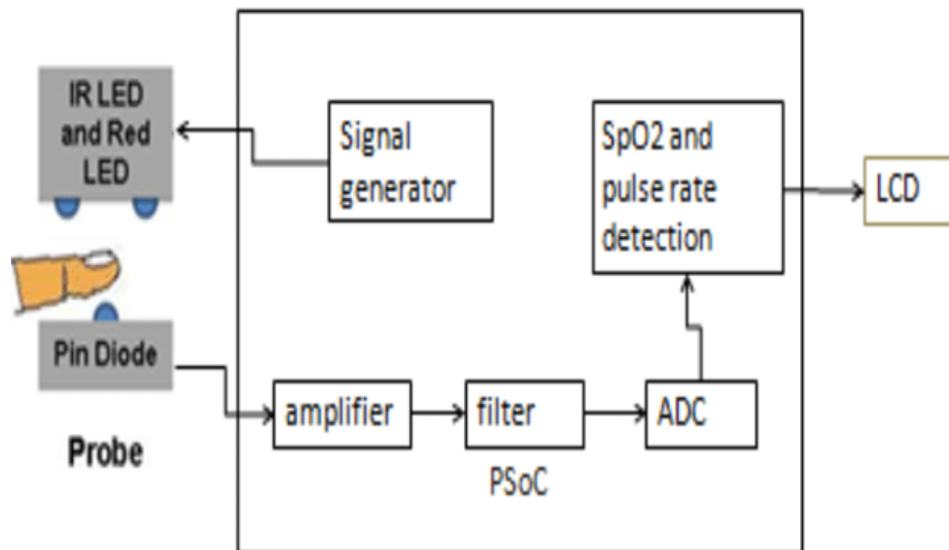


Figure 1: Functional Block Diagram

3.3 Process of the Data Transmission



After the reader and tag are connected, the pulse oximeter system is tested. The pulse oximeter sensor is connected with the host computer through the USB interface, which can directly display the red light and infrared light PPG signal measured by the sensor.

According to the principle of dual wavelength detection, the PPG signal can be transformed into digital signal, which can be used for further transmission of the data. In the pulse oximetry system, the pulse oximeter is connected with the data processing module through the UART interface. The data processing module is connected with the RFID tag through the SPI interface. Then the data in the register of data processing module is transferred to the internal register of the tag.

The RFID reader and RFID tags constitute the RFID transceiver module. It works in the 860 – 960 MHz frequency range. The data transmission is based on the EPC C1 GEN2/ISO 18000-6C protocol (Petersen, 2013). The reader interface and the reader starts working after clicking on the connection button. Click on the label and open a single label cycle recognition mode, the reader will identify the tag within the working range. The data window displays the label number, storage area and storage address of the tag identified by the reader. The contents of the data window in the graph are the tag information identified by the reader and the data in each storage area.

The reader is connected with the host computer through the USB interface, which can display the value and waveform of the pulse and oxygen saturation in the computer interface. The pulse oximeter information is displayed on the computer interface. By clicking on the record, the pulse and oxygen saturation data received by the host computer can be saved in the form of text. The real time data detected by the pulse oximeter system is shown. Users can check their information on a regular basis. By analyzing and processing the real time data of pulse and blood oxygen saturation, we can know the health status and the development trend. It can play a good role in monitoring the health of the user.

3.4 Accuracy

In critically ill patients with SaO₂ values of 90 % or higher, the mean difference between SpO₂ and SaO₂ (that is, bias) measured by a reference standard (CO-oximeter) is less than 2 %; the standard deviation of the differences between the two measurements (that is, precision) is less than 3 % (Jubran & Tobin, 2020). The bias and precision of pulse oximetry readings, however, worsen when SaO₂ is lower than 90 %. Although pulse oximetry is accurate in reflecting one-point measurements of the SaO₂, it does not reliably predict changes in SaO₂, particularly in intensive care unit (ICU) patients (Rustam, 2017).

4. Result and Discussion

Table 1 shows the test result recorded after examining some patients in the medical ward of the University of Ilorin Teaching Hospital. The readings were taken before and after the keep fit exercise organized monthly by the hospital management.

Table 1: Samples of patients tested in the wards

S/N	TEST	SPO ₂	PULSE RATE
1.	Patient from age 1-20	Before exercise 96%	72
		After exercise 98%	76
2.	Patient from age 21-40	Before exercise 98%	78
		After exercise 100%	82
3.	Patient from 41 and above	Before exercise 98%	75
		After exercise 100%	79

Analogue pulse oximetry device is an easy and invasive instrument. As shown in Table 1, a patient from age one to twenty have a pulse oximetry before exercise of 96% and pulse rate had 72 which is normal than after exercise of 98% and pulse rate of 76%. Patients from age 21-40 pulse oximetry was 78% which is normal for that age and after exercise was 100% and that of pulse rate is 82%. The patient from 41 and above before exercise was 75 and after was 100% for pulse oximetry and 75% for the pulse rate. At home and health care setting, a pulse oximeter is an essential device to diagnose patients with low level of oxygen in their blood when they breath due to

malfunctioning of the heart or cardiac problems. it is therefore advisable for a patient with breathing disorder to have it at home so as to measure oxygen level from time to time so that supplementary oxygen amount can be adjusted as needed to be.



Figure 3: A patient being tested with the pulse oximeter

5. Conclusion and Recommendations

The pulse oximetry circuit and its sensing system is designed based on the CMOS technology. The principle of pulse oximetry circuit is analyzed, and the corresponding circuit is designed to realize the acquisition and amplification of pulse oximeter signal. It can realize the function of real-time monitoring of pulse oximetry in the middle and far distance with the combination of microprocessor and wireless sensor technology. The experimental results show the feasibility of the proposed scheme, and the system has the advantages of stable operation, high precision and low power consumption. With the development of science and technology and the continuous improvement of the medical level, the characteristics of miniaturization and wireless monitoring have a good prospect in the field of wearable medical research. Future development of this project, i.e. portable and of low-cost pulse oximeter, is recommended for individuals, clinics, maternity and hospital.

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