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Analysis of the Effect of Red LED and Infrared Flip Flop Frequency on SpO2 Measurement Accuracy

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ABSTRACT Oxygen saturation is a vital parameter for the early detection of advanced oxygen deficiency. Spo2 is a tool that measures the amount of oxygen in the blood non-invasively. This equipment consists of ophotodiodeiode as a sensor as well as red and infrared LEDs with a flip flop driver circuit that has a certain frequency. In this case, several research projects and equipment on the market have various flip flop frequencies. This research aims to find the best frequency setting value for red and infrared led drivers on SpO2 devices. In this research, a SpO2 that can be adjusted with a flip flop frequency of 400 Hz to 1400 Hz was designed. The SPO2 reading from the sensor is presented on the OLED LCD panel using Arduino Mega as a data processor from the driver frequency output controller. Frequency adjustment for sensor drivers is also at 400 Hz to 1400 Hz. This tool was further used to measure the frequency variation of the flip flop. The measurement results on the subject's finger were then compared with the results of the standard SpO2 tool to see the effect of the frequency value on the level of accuracy of the tool. The results of the comparison data processing showed that the largest error of 0.35% occurred in the SPO2 measurement using the 600 Hz sensor frequency driver, and the smallest error value of 0.07%, occurred in the use of the driver frequency at 1400Hz. These results can be used in the initial design of the production of SpO2 equipment, the higher the frequency, the more accurate it will be. This study only discusses the frequency, whereas the intensity parameters of the red and infrared LEDs also vary. In future research, it would be better to involve the LED light intensity parameter to determine its effect on the accuracy of the tool.

INDEX TERMS SpO2, Frequency, Infrared, Red Led

I. Introduction

Oxygen is an essential gas for human survival. To survive, humans need sufficient oxygen levels in their bodies [1] [2]. Measurement of blood oxygen levels is also important for human survival. Sensors for oxygen levels in the blood function as monitoring [3][4]. SpO2 is a critical measure for the early detection of oxygen insufficiency [5][6]. The amount of oxygenated hemoglobin in the arteries is called oxygen saturation; Normal oxygen saturation is between 95% and 100% [7][8][9][10]. A pulse oximeter is a medical device that produces a photoplethysmograph (PPG) by noninvasively and continuously monitoring the patient's oxygen saturation level in the blood and changes in blood volume due to blood vessels in the skin [11][12][13][14][15]]. When blood flows through the arteries in the finger, the photodiode as a detector detects the absorption of the human finger against the light with wavelengths of red (660 nm) and infrared (940 nm) [16][17][18][19][20]. In practice, optical sensors are used to collect electrical signals generated by light sources that pass through or are reflected due to changes in blood flow during cardiac activity. The photoplethysmograph method generates a signal that is used to measure the level of blood oxygen saturation [21] [22]. The signal generator block generates the timing signal. Each LED is switched on and off for 250 seconds, so both LEDs are active within 1 millisecond [23][24][25]. Therefore, this research examined the frequency of light emitted by the finger sensor using a signal generator followed by an analysis to improve the accuracy of SpO2 measurement.

Sanjeetha Sara John and P. Anatha Christhu Raj conducted study in 2013 on a pulse oximeter using PSoC and a Nellcor DS100A sensor. A transimpedance amplifier converts the photodiode output current into a voltage signal, and a programmable gain amplifier completes the amplifier portion (PGA). The signal was then fed to an analog to digital converter with a trans-impedance amplifier for converting the photodiode output current into a voltage signal and a programmable gain amplifier (PGA) for further signal amplification. In this case, the required PPG signal is in the range of 0.5Hz to 5Hz, and a suitable filter circuit consisting of an LPF and an HPF configured for the required cut-off range. Since PSoC 1 only has one ADC, both signals were routed through a multiplexer. The results were shown on the onboard LCD (16x2) and a time signal was generated in the signal generator block. Each LED was turned on and off for 250 seconds, so both LEDs are active in 1 millisecond. The signal generator module was made up of a dead band PWM generating block. This system's key benefit is that it is less expensive and more durable than other microprocessor systems. It has lower dimensions and can be utilized as a modern outpatient device [19]. In 2014, Desak Putri with three colleagues researched pulse oximetry with a priority alarm system as a non-invasive method of vital monitoring of patients using the principle of absorption of red (660 nm) and infrared (940 nm) wavelengths of light detected by photodiodes as a detector when blood is flowing through the blood vessels at the fingertips. A Nellcor DS100A oxygen sensor, an ATmega 8535 microcontroller as a data processor, and an LCD as a display of measurement data were used to detect blood saturation and pulse rate. The sensor's data were then transmitted to the microcontroller for processing before being shown on the LCD. This study added a priority alert system as a marker of unfavorable conditions in the patient, allowing for continuous monitoring of the patient's status. This added to the value of the study. However, the oxygen saturation value recorded by pulse oximetry was still inaccurate because it only reached 98 percent. Therefore, it has to be examined on the tool's output, and the frequency results given by the sensor employed have not been tested further [3]. Lim Chun Keat et al. studied pulse sensors in real-time with a system-on-chip architecture that included a microprocessor system technique connected to an ADC and pulse sensors built-in FPGA hardware in 2016. Experiments were conducted to assess system performance by running the data acquisition system in real-time on a variety of test data. According to the test results, the system performs well when compared to direct readings using an oscilloscope. In particular, for the pulse sensor output signal, a greater sampling rate results in better measurement resolution. This study solely looks at the microprocessor system's power; no further testing of the frequency results given by the sensor has been done [20]. Shifat Hossain et al. published a study in 2019 that compared different wavelengths for estimating SpO2 using the beer-lambert law and photon diffusion with the PPG method to detect changes in blood volume in the subcutaneous region from the periphery (fingertips, earlobe, esophagus). Finally, because the violet (378nm-417nm) and red/near IR (679nm-730nm) pairs have the largest ratio, we will have the best resolution and accuracy when estimating SpO2. The Red-Green duo (660nm-525nm) has the highest ratio among commercially available light sources. For photon diffusion, it can also be seen that the transmission and reflection systems are not that dissimilar. This study has the advantage of comparing all types of light with varying wavelengths, but the disadvantage is that the results of the sensor employing a signal generator are unreliable [12].

Based on the summary above and the four studies shown in paragraph 2, some of the weaknesses of the above research require further research. The drawback is that no further testing of the frequency results obtained by the sensor uses a signal generator. The purpose of this study is to analyze the effect of red led and infrared flip-flop frequency on spo2 measurement accuracy. The author of this study wanted to use a signal generator to adjust the frequency of the light generated by the finger sensor to improve the accuracy of SpO2 measurement. In this study, SpO2 measurements were carried out with a finger sensor placed on the fingertip. Then, using a signal generator, separate the sensor performance values. The next measurement result will be displayed on the character LCD. Comparing the measurement results received from the SpO2 sensor using a signal generator, then analyzing them to improve the accuracy of the SpO2 measurement. In the end, we find the best frequency setting value for red and infrared led drivers on SpO2 devices.

This article consists of an introduction which is presented in section 1, Materials and Methods which are described in section 2, the results is shown in section 3, the discussion is described in section 4, and the conclusion of Kn is described in section 5, and finally, a list of references are filled in.

II. Materials and Methods

A. Experimental Setup

The respondents in this study are two ordinary persons. For every change in driver frequency, data from each respondent were collected for 10 times.

1) Materials And Tools

The designed SpO2 can be adjusted with a flip-flop frequency of 400 Hz to 1400 Hz. The SPO2 reading from the sensor is presented on the OLED LCD panel using Arduino Mega as a data processor from the driver frequency output controller. The Nellcor DS100A SPO2 sensor was used in this study, with data processing carried out on Arduino. Portable SpO2 was used as a standard tool.

2) Experiment

Following the completion of the module design, the researcher collected data or directly assessed the accuracy of the SPO2 module with adjustments in the frequency of the SPO2 sensor driver in this study. Frequency adjustment for sensor drivers was also at 400 Hz to 1400 Hz. This tool was used to measure by setting the frequency variation of the flip-flop. The measurement results on the subject's finger was then processed to be compared with the results of the standard SpO2 tool to see the effect of the frequency value on the level of accuracy of the tool. FIGURE 1 describes the procedure of data collection.

B. The Diagram Block

FIGURE 1 shows the finger sensor shown in the block diagram of the system is made up of infrared and red LEDs and photodiodes. The photosensor will collect the light generated by infrared and red LEDs. The amplifier circuit will then amplify it, and the filtering procedure will take place in the filter circuit part. After that, the analog to digital converter circuit was used to process the data. Furthermore, SpO2 data were created and presented on the character LCD. The signal generator block generated the timing signal. Each LED was turned on and off for 250 seconds, so both LEDs were active in 1 millisecond. A PWM generator block made up the signal generator module.

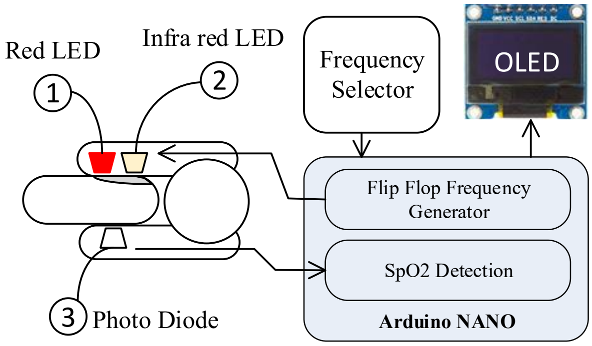

FIGURE 1. A block diagram of this research system. The Nellcor finger sensor was used to measure oxygen saturation in blood non-invasively on human fingers. In Arduino, the frequency generator was programmed as the flip-flop frequency driver of the red and infrared LEDs. The frequency selector is a button connected to one of the Arduino's pins. The measurement results are displayed in the OLED LCD.

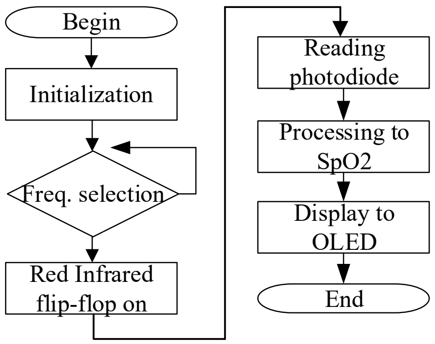

FIGURE 2. A flow diagram of the tool starting from initialization, detecting changes in the frequency of the flip flop, to processing data on the photodiode and displaying the results on the LCD

C. The Flowchart

FIGURE 2 shows the flow diagram of the tool. When the device is turned on, the Arduino starts operating with the initialization process. The tool will detect whether the frequency setting will change. If so, it will change the infrared and red LED flip flop frequencies, as well as the detection frequency. After the photodiode receives a signal from the infrared and red LEDs that pass through the measured finger, the tool will detect SpO2. Then it starts counting how much light is captured by the photosensor or photodiode. The data will be processed to produce signal data when the Infrared is on and when the red LED is on. These two signals will be divided into two data each, an ac signal and a dc signal. The data above is processed by EQUATION (1) and EQUATION (2) [6], resulting in the value of SpO2. The SpO2 value is displayed on the OLED LCD.

$$R = \frac{AC\ red/DC\ red}{AC\ ired/DC\ ired} \quad (1)$$

$$SpO_2 = 110\text{-}25 \times R \quad (2)$$

III. Result

A. Spo2 Module Design

FIGURE 3 shows the Arduino Mega serves as both a data processor and a sensor module for the SPO2 sensor, allowing the value to be shown on the OLED LCD.

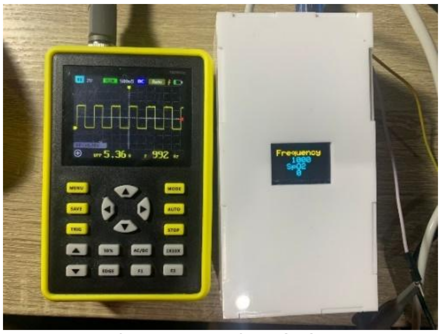

FIGURE 3. The results of the design of the SpO2 tool with an OLED LCD, on the right. Meanwhile, the left is a digital oscilloscope which is used to determine the capability of the flip-flop frequency generator

In order to obtain accurate data, the results of module measurements with standard measurement tools were compared. FIGURE 4 shows the experimental design of data collection. The procedure was described in that figure.

FIGURE 4. Demonstrating methods of data collection, and concurrent measurement using designed modules and standard tools. The index finger of the right hand was measured with the module and the index finger of the left hand was measured with a standard instrument.

B. Comparison To Standard Device.

TABLE 1 shows the findings of the researcher's data collection to determine the accuracy of each frequency employed. Based on the data obtained on repeated measurements of respondents, various values that describe the condition of the module's level of accuracy are compared with the values of the standard SpO2 tool. A different test was carried out on the two measurement values to determine the frequency closest to the standard tool. Based on the results of the 1200Hz frequency difference test, it is close to the standard value with a two-tail value of < 0.05

TABLE 1

The average results of ten measurements of the instrument were designed with various frequency settings ranging from 400 Hz to 1400 Hz. These results were compared with the average measurement results using Standard SpO2 equipment.

Frequency	SpO2 Design	SpO2 Standard	Error Average
400 Hz	97.79	97.95	0.16334865
600 Hz	97.68	98.03	0.00357034
800 Hz	97.77	98.1	0.00336391
1000 Hz	97.76	97.52	0.00246103
1200 Hz	97.91	98.01	0.0010203
1400 Hz	97.86	97.93	0.0007148

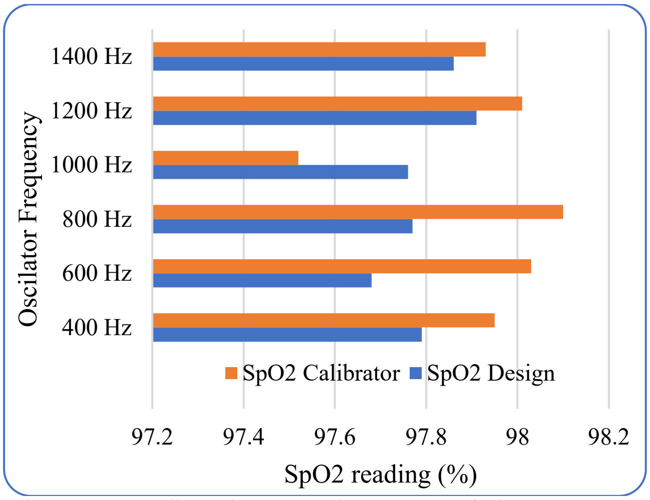

FIGURE 5. The effect of oscilator frequency on SpO2 reading. The assessment was performed on standard SpO2 calibrator and proposed design. There are six test oscilator frequency in this proposed design.

The SpO2 reading on calibrator and proposed design shows different values for each oscillator frequency selection as shown in FIGURE 5. Furthermore, the reading errors for each oscillator frequency selection are also differ for each as shown in FIGURE 6. In the oscilator frequency selection of 1400 Hz, the error was the smallest.

IV. Discussion

The accuracy of the spo2 measurement was found to be affected by changes in the frequency signal conditioning on the spo2 sensor driver. The highest difference in spo2 value readings is discovered when using the 600 Hz frequency with an error rate of 0.35 percent, while the smallest difference in spo2 value readings is found when using the 1200Hz and 1400 Hz frequency drivers with error rates of 0.10 percent and 0.07 percent, respectively. The form or pattern of the spo2 signal data is also affected by changes and discrepancies in the values acquired. Since the spo2 value processing on the Arduino implements data collection of signals from the photodiode 25 times, then the collected data was reprocessed as data updating the spo2 value every 30 times cycle to increase the accuracy of readings from the spo2 sensor. The higher the frequency, the faster and more spo2 output data that can be processed.

Based on the results of data collection, it shows that the smallest error values of 0.07 percent and 0.10 percent. This makes this research better than previous studies [3][12][23]. The implication of this research is that these results can be used in the initial design of the production of SpO2 equipment, the higher the frequency, the more accurate it will be. There is a weakness in this study, namely that a better data processing module has not been used to minimize the process of stopping the program suddenly due to the limited reading ability of the data processing module. This study only discusses the frequency, whereas the intensity parameters of the red and infrared LEDs also vary.

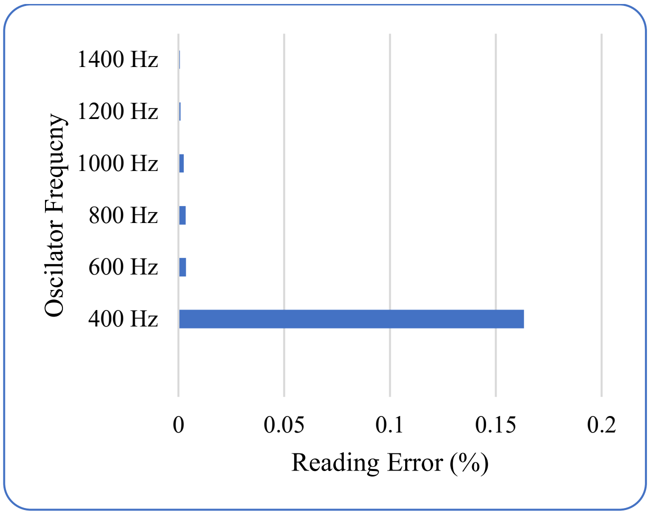

FIGURE 6. The effect of the oscillator frequency in error reading of the SpO2 design. There are six oscillator selection in this experimental.

V. Conclusion

The purpose of this study's analysis is to compare the measurement results received from the SpO2 sensor using a signal generator and to improve the SpO2 measurement's accuracy. The form or pattern of the spo2 signal data was also affected by changes and discrepancies in the values acquired. Since the spo2 value processing on the Arduino implements data collection of signals from the photodiode 25 times, the collected data was reprocessed as data updating the spo2 value every 30 times. The highest difference in spo2 value readings was discovered when using the 600 Hz frequency with an error rate of 0.35 percent, while the smallest difference in spo2 value readings was found when using the 1200Hz and 1400 Hz frequency drivers with error rates of 0.10 percent and 0.07 percent, respectively. Further research is suggested to use a better data processing module to reduce the process of the program abruptly ending due to the data processing module's inadequate reading ability. In future research, it would be better to involve the LED light intensity parameter to determine its effect on the accuracy of the tool.

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APPENDIX

1) Spo2 Data Processing Program.

```
void rising() {
  digitalWrite(REDLed, HIGH);
  digitalWrite(IRLed, LOW);
  //filter();
}
void falling() {
  digitalWrite(REDLed, LOW);
  digitalWrite(IRLed, HIGH);
  //filter();
}
void rcalculation() {
  readsIRMM[ptrMM] = lastIR;
  readsREDMM[ptrMM] = lastRED;
  ptrMM++;
  ptrMM %= maxperiod_siz;
  samplesCounter++;
    samplesCounter = 0;
    IRmax = 0; IRmin = 1023; REDmax = 0; REDmin
= 1023;
    for (int i = 0; i < maxperiod_siz; i++) {
      if ( readsIRMM[i] > IRmax) IRmax =
readsIRMM[i];
      if ( readsIRMM[i] > 0 && readsIRMM[i] < IRmin )
IRmin = readsIRMM[i];
      readsIRMM[i] = 0;
      if ( readsREDMM[i] > REDmax) REDmax =
readsREDMM[i];
      if ( readsREDMM[i] > 0 && readsREDMM[i] <
REDmin ) REDmin = readsREDMM[i];
      readsREDMM[i] = 0;
    }
    R =  ( (REDmax - REDmin) / REDmin) / ( (IRmax
- IRmin) / IRmin ) ;
  }
  if (R > 0) {
    SpO2 = -19 * R + 112;
  }
  if (R == 0) {
    SpO2 = 0;
  }
}
void SPO()
{
  sensor = lastRED;
  sensor = sensor * 5 ;
  if (ref < sensor) {
    ref = sensor;
  }
  else {
    ref = ref;
    hold = (ref - 3);
```

```
  }
  waktu = millis() - waktureset;
  if (sensor > hold)
  {
    beat = 1;
  }
  if (sensor < hold)
  {
    if (beat == 1) {
      beat2++;
      beat3++;
      //hold = 0;
      beat = 0;
    }
  }
  if (beat2 == 2) {
    bpm = 120000 / waktu;
    beat2 = 0;
    ref = 0;
    waktureset = millis();
  }
  if (beat3 == 18) {
    beat3 = 0;
  }
```

2) The Sensor Driver's Output Frequency Is Set By The Software.

```
SetPinFrequency(11, 400);
  SetPinFrequency(10, 400);
  pwmWrite(11, 128);
  pwmWrite(10, 128);
}

void loop() {
```

ATTACHMENT

- Schematic and Board : https://drive.google.com/drive/folders/1mjVksvbXy0bSLxtY09d7QziKsph9wR8B?usp=sharing
- Listing Program : https://drive.google.com/drive/folders/1mjVksvbXy0bSLxtY09d7QziKsph9wR8B?usp=sharing