A Study on Design and Construction of Non-invasive Cholesterol Sensor

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Abstract

This project aimed to study on the design and construct a non-invasive cholesterol sensor based on the principle of light absorption. The design and construction of our device composed of 4 main parts; 1*)* the input part that consists of two different wavelengths of LEDs for the light source, reference light, and the detector circuit; 2*)* the signal conditioning part that consists of current to voltage, AC amplifier, and inverting amplifier circuit; 3*)* the processing part that uses a microcontroller to convert Analog signals to digital and performs signal processing, and 4*)* the display part that includes Liquid Crystal Display *(*LCD*)* to display blood cholesterol levels in mg/dL. The result of functional testing as compared to the clinical blood sampling method by the Faculty of Medical Technology, Rangsit University, found that the average error was 2.52%.

Keywords: *Non-invasive Cholesterol Sensor, Cholesterol Sensor.*

1. Introduction

Currently, a factor that causes of Cardiovascular disease is atherosclerosis. Atherosclerosis is a condition that changes in inner blood vessels to become thickness by fat. The fat accumulates between the blood vessels that is a cause of high cholesterol (Blesso & Fernandez, 2018; Soliman, 2018). Normally cholesterol is in many healthy cell functions if it is higher than the normal level, the body will have harm (Huff & Jialal, 2019). The level of cholesterol in the blood is divided into three levels; a normal level that should be at least 200 milligrams per deciliter (mg/dL), moderately high level that is between 200 to 239 mg/dL, and high level of over 240 mg/dL (Cox & García-Palmieri, 1990). There are a large number of people who have high cholesterol (Dyslipidemia) in which the population is at risk for high blood pressure and risk for disorder continuously. According to the Thai Registry in Acute Coronary Syndrome (TRACS) study, it is found that the common risk factors in Thai people who are treated with coronary heart disease, Dyslipidemia is as high as 83.2%. Dyslipidemia is a disease that can cause many complications such as obesity, coronary heart disease and ischemic heart disease (Nelson, 2013). There are important causes of hyperlipidemia such as Genes, Diabetes and consuming food with high fat. The preventive for Dyslipidemia from consumption of food, we can control Dyslipidemia by reduced fat in food. For the patients with Dyslipidemia, it is necessary to often test blood Cholesterol to control lipid in blood in a normal range and adjust food that is suitable for them.

Currently, the standard method used to measure blood cholesterol level are two methods; 1) Conventional measuring by blood collection and 2) Measuring cholesterol by strip test at the fingertip. However, these methods are invasive into the body that caused an injury, and some of the patients are afraid of blood collection. Both methods may affect the feelings of the patient for continuous treatment (Fradet et al., 1990). Besides, these two methods of blood collection tests have infectious waste as well.

Presently, Near-infrared light is used to measure blood cholesterol concentrations by using the principle of light absorption (Yusoff et al., 2015). When the light penetrates through the solution, the molecules of the substance absorb light energy in proportion to the molecular quantity of the substance. This phenomenon occurs by properties of light waves when travelling through the solution that is the absorbance of each substance and is its unique property according to the Beer-Lambert Law. Cholesterol is a substance that has absorbance value and has unique properties as well. Due to the research of using infrared light near the wavelength of 1000 - 1800 nm to detect cholesterol compared with other substances found that at 1200 nm cholesterol absorbs more light than other substances (Fleming et al., 2015).

Therefore, the research aims to study the design and construct a non-invasive cholesterol sensor at fingertip by using light absorption principles in the near-infrared range at a wavelength of 1,200 nm because cholesterol can be absorbed better than other substances. The developed sensor uses with the patient who can measure blood cholesterol by himself or herself in anytime and anywhere. It will be used with patients who are afraid of blood collection, reduced patient's injury, reduced infection due to blood collection and reduced infectious waste.

2. Objectives

The research aims to study to design and construct a non-invasive cholesterol sensor at fingertip by using light absorption principles in the near-infrared range at a wavelength of 1,200 nm.

3. Materials and Methods

A study on the design and construct of a non-invasive cholesterol sensor at fingertip was to use the principle of light absorption principles in a near-infrared wavelength of 1200 nm and red light and the principle of electronics. There were two parts, 1) Design and construction of non-invasive cholesterol sensor and 2) Testing and calibration of the cholesterol sensing device.

3.1 Design and construction of a non-invasive cholesterol sensor

The design and construct of a non-invasive cholesterol sensor consisted of 4 parts. A) the signal detector by using the sensor which consisted of Near-Infrared LED and Red Light-Emitting Diode as a transmitter and photodiode as a receiver. B) the signal conditioning by using LM324. C) the signal processing by using Arduino Nano 3.0. D) the display by using the LCD. The diagram illustrating a study on the design and construct a non-invasive cholesterol sensor was shown in Figure 1**.**

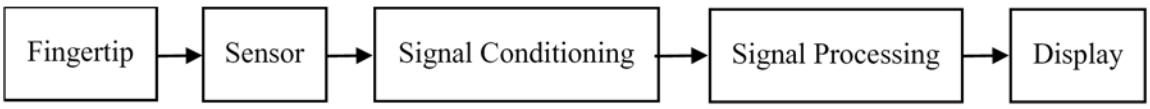

Figure 1 Diagram illustrating of a non-invasive cholesterol sensor

a. Signal detector part

The design and construction of signal detector part consisted of a light transmitter and a light receiver inside the sensor that was set in the finger clip probe. The light transmitter consisted of two different lights. The first light was the near-infrared wavelength 1200 nanometer which can be absorbed by blood cholesterol and the second light was the red light that used as the background due to the red light does not affect the absorption of cholesterol in the blood. The light receiver was used as a photodiode.

For the sensor circuit used Arduino Nano 3.0 which was the digital of microcontroller port as the power supply (Vs) and used resistor R1 to limit current pass through the near-infrared LED and used resistor R2 to limit current pass through the red LED in the circuit to prevent damage to the light sources. The sensor circuit in part A1 was as shown in Figure 2 and could be calculated the resistance R1 and R2 value to use in the circuit as the equation (1).

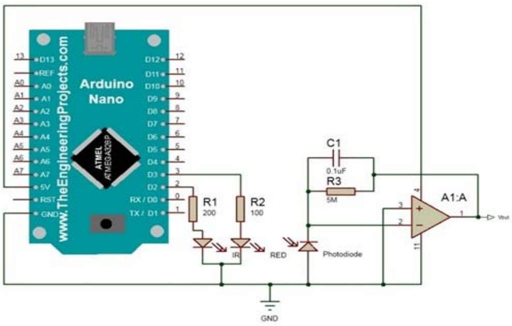

Figure 2 Signal detector part

$$R_{IR} = \frac{(V_S - V_{IR})}{I_{IR}} \quad (1)$$

Where R_{IR} was the resistance that used to limit current on the near-infrared light, V_S was the voltage of power supply, V_{IR} was the bias voltage of near-infrared light and I_{IR} was the bias current of near-infrared light.

$$R_R = \frac{(V_S - V_{RED})}{I_{RED}} \quad (2)$$

Where R_R was the resistance that used to limit current on the near-infrared light, V_S was the voltage of power supply, V_{RED} was the bias voltage of red light and I_{RED} was the bias current of red light.

The power supply (V_s) from Arduino Nano 3.0 port was 5 Volts. From the description of the near-infrared LED light, it showed that there would be V_{IR} was 1 Volt and I_{IR} was 20 milliamperes when substitute in equation (1), the resistance R_1 was 200 ohms. From the description of the red LED light, it showed that there would be V_{RED} was 3 Volts and I_{RED} was 20 milliamperes when substitute in equation (2), the resistance R_2 was 100 ohms. Therefore, the resistances R_1 and R_2 used in a sensor circuit were 200 ohms and 100 ohms.

For the light receiver used a photodiode that received light energy and changed into a voltage by using the current to voltage converter in part A1. The current to voltage converter was used zero voltage biasing and requires a V_{out} of 5 millivolts, the current of a photodiode (I_d) was 1 nano-ampere, and the resistance in the circuit was calculated by the Ohm law. Therefore, the resistance in current to voltage circuit R_3 was 5 Megaohms.

b. Signal conditioning part

Due to the signal from the detector was a small signal, and there was an interfering signal, this project was used the processing part to improve the signal to reduce the interfering signal and enlarge the signal. The signal conditioning part used the AC amplifier circuit, which consisted of a high pass filter, non-inverting amplifier, and low pass filter. The diagram illustrating of processing part was shown in Figure 3.

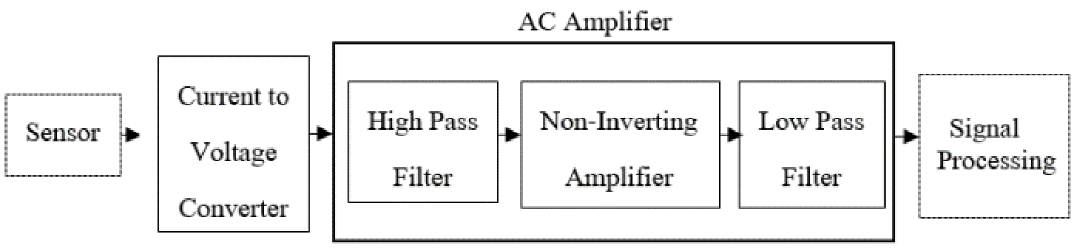

Figure 3 Diagram illustrating of signal conditioning part

The AC amplifier circuit was used in the processing part as non-inverting circuit due to the properties of the circuit which can be specified cut-off frequency range (f_c) in high pass filter circuit and low-pass filter circuit. The AC amplifier circuit in part B1 was as shown in Figure 4.

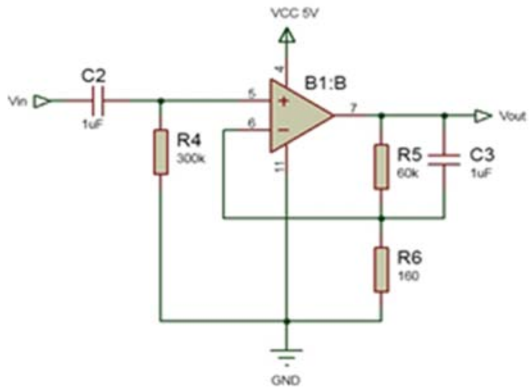

Figure 4 AC amplifier circuit

The processing part used the high pass filter which was used cut off frequency 0.5 Hertz, and a capacitor (C_2) has capacitance 1 microfarad. The resistance R_4 was calculated by equation (3).

$$R = \frac{1}{2\pi f_c C} \quad (3)$$

Where $R = R_4$,

$$R_4 = \frac{1}{2\pi \times 0.5\ \text{Hz} \times 1\ \mu\text{F}} = 300\ \text{k}\Omega$$

From the signal amplifier circuit in part B1 obtained the input voltage (V_{in}) was 5 millivolts by determining the output voltage from non-inverting amplifier circuit V_{out} in positive was 2 volts because the circuit used a single-phase of the power supply is positive and the voltage gain (Av) was 400. The current was used in op-amp was calculated by equation (4).

$$I = 100 I_{B(max)} \quad (4)$$

Where $I_{B(max)}$ = 300 nano-amperes, therefore the current in equation (4) was 30 microamperes.

The design required $R_i = R_6$ and $R_f = R_5$ resistance R_5 and R_6 was calculated by Ohm's law and the voltage gain as equation (5) and (6)

$$R_6 = \frac{5mV}{30\mu A} = 160\Omega \quad (5)$$

$$Av = 1 + \frac{Rf}{Ri} \quad (6)$$

$$R_5 = 160\Omega(400 - 1) = 60k\Omega$$

In the low pass filter in part B1 used to cut off frequency 2.5 Hertz and a capacitor (C_3) has capacitance 1 microfarad. The resistance R_5 in the circuit was 60 kΩ and the capacitance was calculated by equation (7).

$$R = \frac{1}{2\pi f_c C} \quad (7)$$

$$C_3 = \frac{1}{2\pi \times 2.5\ \text{Hz} \times 60\text{k}\Omega} = 1.06\ \mu\text{F}$$

Therefore, the design of AC amplifier circuit used $R_4 = 300\ \Omega$, $R_5 = 60\ k\Omega$, $R_6 = 160\ \Omega$ and $C_3 = 1.6\mu F$ but in this project, we used $C_3 \sim 1.0\ \mu F$.

For the signal amplifier circuit in part B1 had remained an interfering signal at high frequency. In this project used low pass filter to prevent the effect in signal processing part which was used cut off frequency 2.5 Hertz, a capacitor (C) has capacitance 1 microfarad, the voltage gain (Av) was 1, the resistor R_7 used in low pass filter and R_8 used for the suitable of the amplifier signal so that the resistance R_7, R_8 was equal. The resistance R_7, R_8 was calculated by equation (8).

$$R = \frac{1}{2\pi f_c C} \tag{8}$$

Where $R = R_7 = R_8$,

$$R_7 = R_8 = \frac{1}{2\pi \times 2.5\ Hz \times 1\ \mu F} = 63\ k\Omega$$

Therefore, the design of low pass filter used $R_7 = 63\ k\Omega$, $R_8 = 63\ k\Omega$.

c. Signal processing part

In the project use microcontroller Arduino Nano 3.0 which has enough resolution to process the signal in the desired range well. There is an analog signal converter circuit into a digital signal, and there is the highest voltage from the input part equal to 5 volts.

From the signal conditioning, the output from op-amp was an analog signal which converted to a digital signal by using the analog to digital converter. Then, the equation of the relationship between the concentration of cholesterol in the blood in milligrams per deciliter and digital output values was used to writing a signal processing program into a microcontroller.

d. Display part

A 16 x 2 LCD screen was chosen in the display part to show the user's blood cholesterol level in milligrams per deciliter (mg/dL). When measured blood cholesterol levels, the signal from the signal processing part was commanded by a microcontroller that sent to the display part and showed the alphabets and numbers on the LCD screen.

The design and construction non-invasive cholesterol sensor circuit described above are shown in Figure 5.

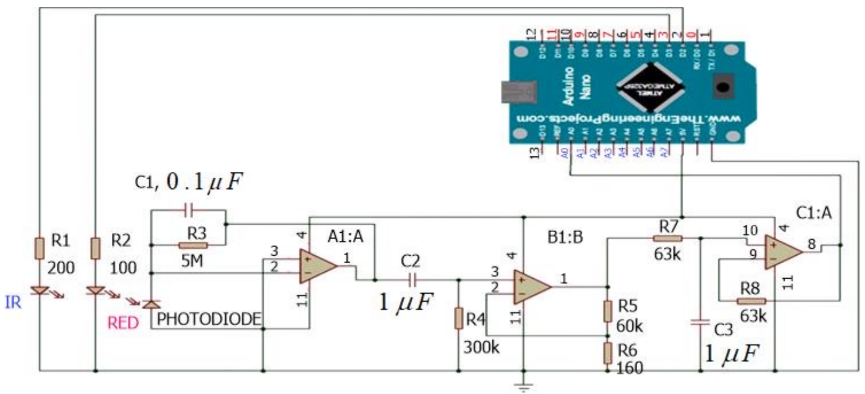

Figure 5 Non-invasive cholesterol sensor circuit

3.2 Testing and calibration of the cholesterol sensing device

In order to develop the non-invasive cholesterol sensor device for practical use, it was necessary to establish of the calibration curve the cholesterol sensing device and find the percentage error of Non-invasive cholesterol sensor compared with cholesterol from blood collection.

To create the equation for the relation between the concentration of cholesterol in the blood in milligrams per deciliter with the digital output of the 12 subjects from College of Biomedical Engineering, Rangsit University, Pathumthani, Thailand. The process of testing that recorded the concentration of cholesterol in-unit milligram per deciliter (mg/dL) by blood collection at Medical Technology clinic, Rangsit University, after that recorded the digital output with non-invasive cholesterol device at fingertip and plot graph between the digital output and the concentration of cholesterol in-unit mg/dL. The multiple regression analysis was used to analyze the data record between digital output with the concentration of cholesterol in the blood.

To find the percentage error of Non-invasive cholesterol sensor testing with five subjects in the College of Biomedical Engineering, Rangsit University, Pathumthani, Thailand. The data obtained from cholesterol from blood collection of each subject at the Medical Technology clinic, Rangsit University compared with the average cholesterol from 3 times of measuring by placing the finger of each subject into the probe of non-invasive cholesterol sensor, as shown in figure 6.

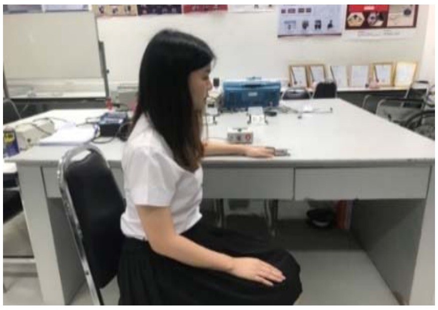

Figure 6 Non-invasive cholesterol sensor test

4. Results and Discussion

A study on design and construction of Non-invasive cholesterol sensor has two light sources; the wavelength is 1200 nm and red light by using light absorption and electronic principles. It was used to measure cholesterol in blood at the fingertip and showed the concentration of cholesterol in the blood in milligrams per deciliter (mg/dL). The prototype of the device was shown in Figure 7.

Figure 7 Prototype of device

The effectiveness of the non-invasive cholesterol sensor was calculated from the calibration equation that came from the relation between the digital output and the concentration of cholesterol in mg/dL of 12 subjects. The data record was shown in Table 1.

Table 1 Data of concentration of Cholesterol and digital output

Subject	Cholesterol Concentration (±5 mg/dL)	Digital Output
1	186	99.67
2	189	155
3	190	221.33
4	192	265
5	193	300
6	196	350
7	210	414
8	213	438.33
9	226	466.33
10	247	494.33
11	284	520
12	287	525.67

The relation between digital output and cholesterol concentration in blood in mg/dL was shown in figure 8.

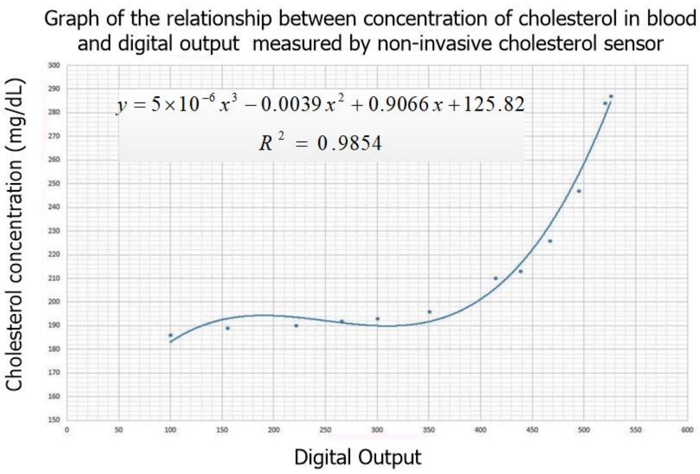

Figure 8 Graph of the relation between the concentration of cholesterol in the blood in-unit mg/dL and digital output

When plotting the graph between the concentration of cholesterol in the blood in the y-axis and the digital output in the x-axis (Figure 8), it was found that the calibration equation was $y = 5x10^{-06}x^3 – 0.0039x^2 + 0.9066x + 125.82$ and coefficient of determination was 0.99.

The result of Non-invasive cholesterol sensor testing with five subjects was shown in Table 2.

Table 2 Result of Non-invasive cholesterol sensor testing

Cholesterol Level by blood Collection (mg/dL)	Cholesterol Level by Non-invasive blood cholesterol sensor (mg/dL)			Average Cholesterol Level by Non-invasive blood cholesterol sensor (mg/dL)	Standard Deviation	Percentage Error
	1	2	3			
174	169.81	173.21	170.26	171.10	1.84	1.67
194	193.64	191.97	193.09	192.90	0.85	0.56
202	193.08	201.39	192.66	195.71	4.92	3.11
204	203.51	193.15	191.95	196.32	6.36	3.76
213	209.68	194.09	212.79	205.52	10.02	3.51

Sensors were designed and constructed that used near-infrared light with a wavelength of 1200 nanometer. When light 1200 nm penetrates cholesterol, the transmission of light is decreased that is following Beer-Lambert Law. Therefore, it is possible to use near-infrared light that has a wavelength of 1200 nm to measure non-invasive blood cholesterol levels.

The design and construction non-invasive cholesterol sensor used two wavelengths that were near-infrared 1200 nanometer as the light source and the red light as the background and used a photodiode that responds to the wavelengths from 500 - 1700 nm as a receiver which was able to convert the light signal into an electrical signal. The electrical signal passed through the signal conditioning circuit and signal processing which used microcontroller Arduino Nano 3.0 to convert an electrical signal to the digital output.

When creating the equation of the relation between the concentration of cholesterol in the blood in milligrams per deciliter with the digital output of 12 subjects who had cholesterol levels in the range of 186-287 mg / dL, it was found that the equation to correlate the concentration of cholesterol in the blood with digital output was $y = 5x10^{-06}x^3 – 0.0039x^2 + 0.9066x + 125.82$, where y was the concentration of cholesterol in-unit mg/dL, x was digital output, and the coefficient of determination was 0.99. This equation was a calibration graph to be used to determine the concentration of cholesterol in the blood in milligrams per deciliter (mg / dL).

For accuracy testing of non-invasive cholesterol sensor by comparing the value of cholesterol from Non-invasive cholesterol sensor with the cholesterol by blood collection at Medical Technology Clinic of Rangsit University found that the average percentage error was 2.52%. The measured value was greater than 200 mg / dL to have discrepancy because the number of subjects that used to make a calibration equation was too small and the subjects had cholesterol levels within the limited range of 186-287 mg / dL. If this project is improved accuracy in future work, it should be obtained many subjects who have the cholesterol less than 200 mg/dL (normal Cholesterol), in range 200-230 mg/dL and greater than 240 mg/dL that cover the range of cholesterol,

5. Conclusion

A study on the design and construct of a non-invasive cholesterol sensor was able to create non-invasive blood cholesterol sensors using near-infrared absorption principle and display in milligrams per deciliter (mg / dL). It can create a calibration equation between blood cholesterol concentrations with digital output. The test results from the samples are in the range of 186 - 287 milligrams per deciliter (± 5 mg / dL), the equation is obtained between the blood cholesterol concentration (mg / dL) and the value digital output measured from sensor which was $y = 5x10^{-6}x^3 - 0.0039x^2 + 0.9066x + 125.82$ and $R^2 = 0.9854$ and when non-invasive cholesterol sensor testing, it found that the average percentage error of 2.52% when to compare with results of cholesterol by blood collection.

6. Acknowledgements

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