Jurnal Teknokes
International: Rapid Review: Open Access Journal **Vol. 15, No. 2, June 2022, pp. 81-87** **ISSN: 2407-896**

RESEARCH ARTICLE **OPEN ACCESS**

Manuscript received February 10, 2022; Revised March 17, 2022; accepted May 1, 2022; date of publication June 30, 2022
Digital Object Identifier (DOI): https://doi.org/10.35882/teknokes.v15i2.132

How to cite Wahyu Caesarendra, Triwiyanto Triwiyanto, Her Gumiwang Ariswati, Rizki Masnulula, Nashucha Mutiara Firdaus, M, "Development of Cardiac Monitor Through Carotid Pulse, Phonocardiography and Electrocardiography", Jurnal Teknokes, vol. 15, no. 2, pp. 81–87, June. 2022.

Development of Cardiac Monitor Through Carotid Pulse, Phonocardiography and Electrocardiography

Wahyu Caesarendra[1], Her Gumiwang Ariswati[2], Rizki Masnulula[2], Nashucha Mutiara Firdaus[2]

[1] Faculty of Integrated Technologies, Universiti Brunei Darussalam, Brunei Darussalam
[2] Department of Medical Electronics Technology, Poltekkes Kemenkes, Surabaya, Indonesia

Corresponding author: Triwiyanto (e-mail: ariswatihergumiwang@gmail.com).

ABSTRACT Heart disease is a hazardous disease. Even today in Indonesia, the disease ranks first as a cause of death. This study aims to design Electrocardiograph (ECG), Phonocardiograph (PCG), and Carotid Pulse on a personal computer using Delphi7 programming. The contribution of this research is that the carotid signal can be displayed on a personal computer monitor so that it can be viewed simultaneously with ECG and PCG signals. In order to intercept the carotid signal on the carotid artery on the surface of the neck, a piezoelectric sensor is used. In this study, the carotid pulse signal was recorded in the left upper neck area of the carotid artery with the help of a piezoelectric sensor. The primary circuit of the cardiac monitor consists of the non-inverting amplifier, low passes filter 100hz, high pass filter 0,1 Hz, summing amplifier, and Arduino microcontroller. Carotid Pulse Showed that the correlation between the pattern of the dicrotic notch (the D wave) in the carotid pulse and second heart sound (S2) occurred simultaneously or just before the D wave pulse from the carotid pulse for each respondent. The results of data collection from 10 respondents were measured from the correlation between the Dicrotic Notch (pattern D) on the carotid pulse and S2 on the phonocardiograph occurred just before the dicrotic notch from the carotid pulse. The correlation measurement data obtained from an average of 10 respondents showed that the interval between S2 and Dicrotic Notch was ±0.063 s.

INDEX TERMS Carotid Pulse, Piezoelectric, Microcontroller, Personal Computer

I. INTRODUCTION

Cardiac monitoring is an important tool for monitoring patients that identified as having heart abnormalities. One method for early detection of heart disease associated with abnormal heart valves can be done by an auscultation technique. Auscultation is a technique of listening to heart sounds using an electric stethoscope [1][2]. The electrical and mechanical activity of the heart also involves the process of blood pressure in flowing blood through the heart valves to the chambers of the heart and lungs. In this research, the blood pressure is represented by the carotid pulse [3][4][5]. The carotid pulse records carotid artery pressure signals; the record is done by placing a sensor on the neck and is an alternative to seeing blood pressure signals [6][5]. This carotid pulse is also useful for phonocardiograph (PCG) and can help identify a second heart (S2) and its components. Carotid Pulse provides information about indications of variations in blood pressure signals in the arteries and the volume of each heartbeat [7][8]. A carotid pulse can also help a clinician to analyze the differences between normal and abnormal heart conditions (a type of aortic stenosis heart defects). This condition can be done by displaying the heart sound signal (S2) and carotid pulse signals (Dictotic Notch) simultaneously. Therefore, making a diagnosis is not enough to see the heart signal, but also other parameters such as heart sound signals (PCG) and blood pressure signals represented by carotid pulse. In 2013 Vashisth [3][9].

Agnia Nerlika created personal computer-based electrocardiography (ECG) tool in 2008, but it only displays ECG signal graphs. In this study, the author used a disposable electrode to collect the ECG signal using standard lead I. The ECG signal was transferred into the computer via serial communication based on an asynchronous interface. In this design, an author needs a long and secure cable to protect from lost data. However, the study was only performed using an ECG simulator or phantom and has not been verified using humans. Another study that related to the cardiac monitor was conducted by Dian Hera et al. They made a personal computer-based phono-cardiography (PCG) apparatus. Still, it only displays PCG signal graphs and has a weakness, namely that the signal displayed on the computer unit is not real-time data but data that has been buffered and then displayed. Furthermore, from the weakness of other researchers, Federico et al. developed a personal computer-based cardiac monitor PCG and ECG parameters by simultaneously displaying both signals. Still, there were no carotid pulse parameters [10][11]. The carotid pulse is essential to monitor the heart value. Thus, in 2017 Samsul Anwar made a BPM tool on a computer unit-based carotid artery via Bluetooth, but the signal produced still contains noise [12] [9][13]. A signal with high noise will disturb the existence of the original.

Further research was conducted by Rosyida & Risa. They developed a cardiac monitor ECG, PCG, and carotid pulse parameter design. In the study, those parameters were able to display the signal simultaneously with the carotid pulse signal; however, the previous design was not portable [14]. A portable device is needed for mobile measurement of the patient [15][16] [17].

Therefore, this study aims to develop an apparatus of cardiac monitor based on piezoelectric, disposable ECG electrode, and mic condenser to measure and analyze the relation among the parameter of carotid pulse, ECG signal LEAD II, and phonocardiograph. Furthermore, in this study, the parameters will be simultaneously displayed on the computer monitor. This proposed design is to obtain more accurate and faster diagnostic results and data on cardiac examinations with a portable design.

II. MATERIALS AND METHODS

A. EXPERIMENTAL SETUP

This study uses subjects with free criteria. For statistics purposes, the sampling population is done randomly. The inclusion criteria in this study is that respondent was only selected with no previous problem with the heart. Moreover, the respondent was selected in the age range between 20 to 25 years old. The exclusion criteria are that the respondent has no problem with high blood pressure. In order to find average error of each parameter measurement, each parameter were performed five times for each respondent.

1. MATERIALS AND TOOL

This study used a piezoelectric sensor that are attached to the carotid artery on the neck surface. This location was used to measure the carotid pulse. Disposable electrodes were attached as standard lead II placement. Furthermore, a mic-condenser in the stethoscope was placed in the left chest area. The mic condenser is used to measure the phonocardiograph signal from the heart sound. The main circuit used Arduino nano as a microcontroller and a USB cable to send the data to the personal computer (PC).

2. EXPERIMENT

In this study, the researchers conducted the carotid pulse signal from the human body with ten respondents. Carotid pulse and PCG signal were then analyzed to show the correlation between Dicrotic Notch (pattern D) in the carotid pulse with a random S2 from human heart sound and an average of carotid pulse width for each respondent. In this study, the researchers measured the heart ECG signal and sound as many as ten times. This study will investigate the

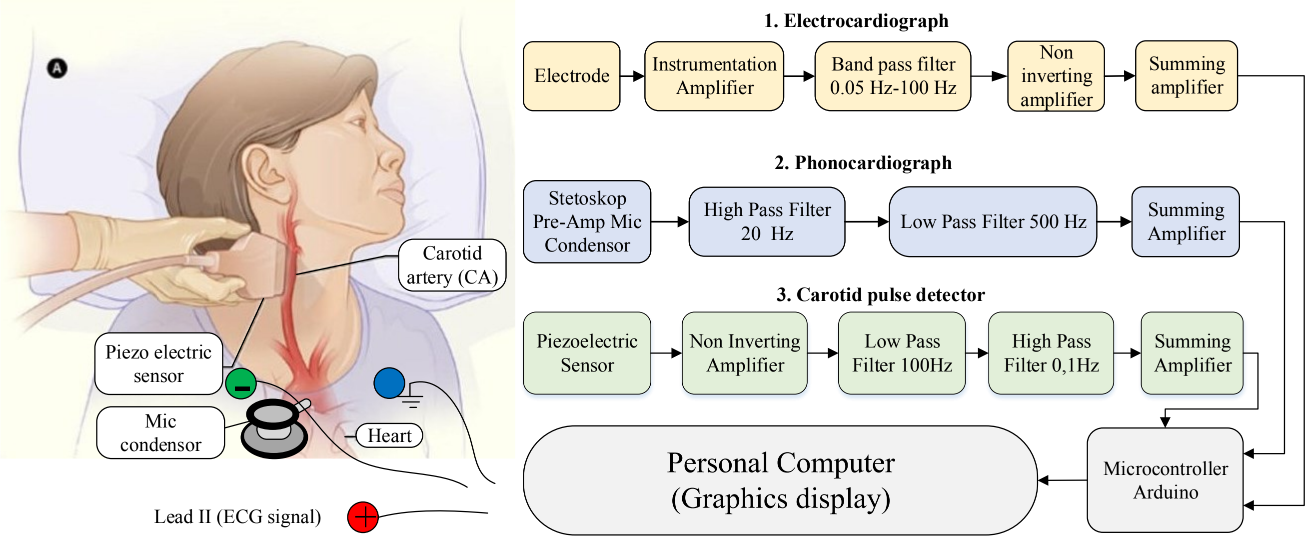

FIGURE 1. Diagram Block of ECG signal, phonocardiograph and carotid pulse detector measurement

ECG and PCG relation. In this case, a correlation between peak R on ECG and random S1 human heart sound will be shown in this case. Furthermore, carotid pulse and PCG signals showed a correlation between dichromic notches (D patterns) in carotid pulses with random S2 human heart sounds and average wide carotid pulse rate for each respondent.

B. THE DIAGRAM BLOCK

In this study, as shown in FIGURE. 1, a piezoelectric sensor was used as a carotid pulse signal interceptor. The output of the piezoelectric sensor enters the amplifier and filter circuit further, and Arduino Nano will process it. ADC pin in the Arduino was activated to collect the analog signal. Arduino Nano output will be sent using a USB cable and then displayed on a computer using Delphi 7 application.

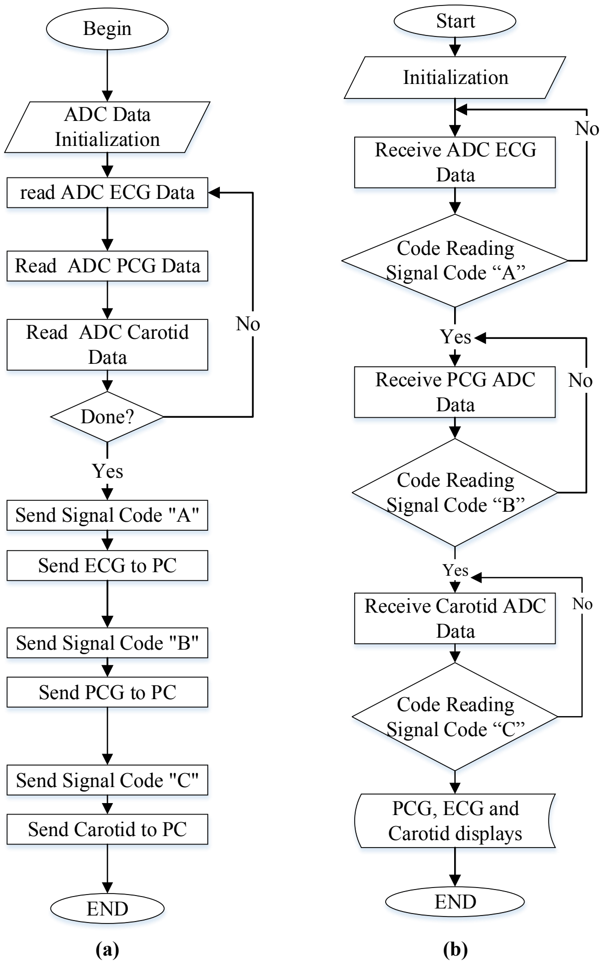

FIGURE 2. The flowchart of the acquisition system on (a) Arduino, (b) Delphi Programming on the computer unit.

A stethoscope electronics with a build-in mic condenser was used to measure phonocardiograph and record the heart sound. An analog filter and amplifier processed the signal to gain the phonocardiograph signal.

Additionally, the ECG signal was detected by using the ECG electrodes. In this case, the ECG signal was collected from LEAD II mode. In order to get the original ECG signal, the ECG was filtered using a band pass filter with a frequency cut of 0.05 and 100 Hz. All three parameters were then transferred into the computer using serial communication. The detailed communication between the microcontroller and computer system was shown in FIGURE 2.

C. THE FLOWCHART

In this study, the communication between the microcontroller and computer was synchronized using a different code for each parameter. The flowchart was divided into two parts that are a flowchart for microcontroller and Delphi programming (FIGURE 2). In the microcontroller flowchart (FIGURE 2(a)), in the beginning, the microcontroller will initialize the system to prepare for data collection. The three analog voltages from ECG, carotid pulse, and phonocardiograph were recorded sequentially in the data collection process. If the system has detected three sensors, then the Arduino application will send the data into the computer using serial communication. A code followed each parameter, for example, code “A”, “B’, and “C” for ECG, PCG, and carotid pulse, respectively. This program will loop forever, read analog, and send the data to a computer via serial communication. On the other hand, the Delphi programming flowchart was used to receive the analog data from the microcontroller. The program will detect the code to decide whether the data is ECG, PCG, or carotid pulse. All the data was displayed on the computer monitor sequentially and in real-time.

D. ANALOG CIRCUIT

1) NON INVERTING AMPLIFIER

The non-inverting amplifier circuit, as shown in APPENDIX**,** amplifies the signal without reversing the signal phase. The gain was calculated using Eq. (1).

$$Acl = 1\frac{Rf}{Rin} \quad (1)$$

Rf is a feedback resistor in the operational amplifier, and Rin is the input resistor.

2) LOW PASS FILTER

This low pass filter circuit, as shown in APPENDIX is used to limit the frequency according to the defined cut-off frequency. In this case, the low pass filter will pass the signal with a frequency below the cut-off frequency. The gain and cut-off frequency can be calculated using Eq. (2) and (3), respectively [18][19].

$$Acl = \frac{1}{\sqrt{1+4\omega^4 xR^4 xC^4}} \quad (2)$$

$$Fc = \frac{1}{2\pi RC} \quad (3)$$

where ω, is the input of angular velocity, R is the value f resistance, and C is the value of capacitance. A different low pass filter was applied to the hardware circuit. The cut-off low pass filter 100 Hz, 500 Hz, and 100 Hz was used for the ECG amplifier, phonocardiograph, and carotid.

3) HIGH PASS FILTER

The high pass filter is a circuit (APPENDIX) used to suppress amplitude at low frequencies and will pass the higher frequency than the cut-off frequency. The gain of the second-order of the high pass filter can be calculated using Eq. (4). The Cut off frequency is calculated based on Eq. (5).

$$Acl = \frac{1}{\sqrt{1+\frac{4}{4\omega^4 x R^4 x C^4}}} \quad (4)$$

$$Fc = \frac{1}{2\pi RC} \quad (5)$$

where ω, is the input of angular velocity, R is the value of resistance, and C is the value of capacitance. The cut-off low pass filter 0.05 Hz, 20 Hz, and 0.1 Hz was applied for the ECG amplifier, phonocardiograph, and carotid, respectively [20][21].

4) SUMMING AMPLIFIER

A summing circuit amplifier is a circuit (APPENDIX) that serves to raise the signal voltage level where a portion of the signal rises to a positive whole. The equation to adjust the gain is shown in Eq. (6). Therefore the output of the circuit can be calculated using Eq. (7) [22].

$$Acl = \frac{1+Rf}{Rg} \quad (6)$$

$$Vout = (\frac{Rf}{Ri} + 1).\left(\frac{V1+V2}{2}\right) \quad (7)$$

Rf is a feedback resistor in the operational amplifier, and Rin is the input resistor.

III. RESULTS

The research objective is to design a cardiac signal data acquisition by measuring ECG, PCG, and carotid pulse with real-time monitoring on a computer monitor. Measurements were carried out using healthy respondents with variations in the number of samples between 5 to 10. More details related to the shape of the signal and its characteristics will be shown in the following explanation.

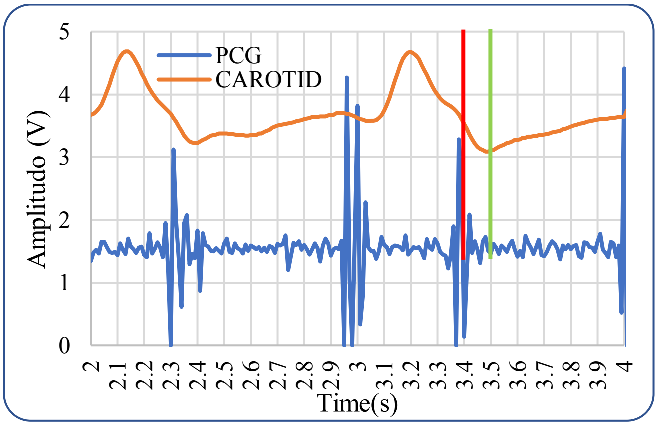

FIGURE 3. The plotting of carotid and PCG signals (red line indicates the S2 pulse, and the green line indicates the dicrotic notch)

Phonocardiography and carotid pulse are shown in FIGURE3. There is a relationship between the PCG and carotid. The carotid pulse always appears at the beginning before the PCG signal. Additionally, FIGURE 3 shows that the correlation between the dicrotic notch (pattern D) on the carotid pulse and S2 on the phonocardiograph occurred just before the dicrotic notch from the carotid pulse. The phonocardiograph signal shows the S1 and S2 sequentially. The distance between the S1 and S2 is approximately 0.6 seconds. Furthermore, the carotid pulse has a length of 1.1 seconds.

TABLE 1
The result of measurement of correlation

Data	S2 on PCG (s)	Dicrotic Notch on Carotid Pulse (s)	Interval S2 and Dicrotic Notch (s)
1	3,37	3,46	0,09
2	3,34	3,41	0,07
3	3,37	3,45	0,08
4	3,30	3,49	0,09
5	3,38	3,43	0,05
Average			**0,076**

In TABLE 1, the measurement results from respondent 1 show that the mean interval S2 on the phonocardiograph and Dicrotic notch (pattern D) on the carotid pulse is 0.076s.

TABLE 2
Result Of Measurement Of S2 And Dicrotic Notch Intervals In 10 Respondents

Respondent	Interval S2 and Dicrotic Notch (s)
1	0,076
2	0,064
3	0,07
4	0,058
5	0,068
6	0,056
7	0,064
8	0,064
9	0,048
10	0,064
Average	**0,063**

TABLE 2 shows the results of the measurement of the correlation between the Dicrotic Notch pattern (pattern D) on the carotid pulse and S2 on the phonocardiograph. Measurements on respondents were carried out with five measurements, each of which showed that the Dicrotic Notch (D pattern) on the carotid pulse and S2 on the phonocardiograph occurred before the D pattern on the carotid pulse. From the correlation measurement data, the average of 10 respondents, the interval between S2 and Dicrotic Notch is ±0.063s. This study used subjects with free criteria. Sampling was done randomly or randomly with data collection of 10 patients with 5X measurements. In FIGURE

4, you can see the correlation result of ECG and PCG signal, that is, when the first heart sound (S1) occurs right or before the R ECG pulse.

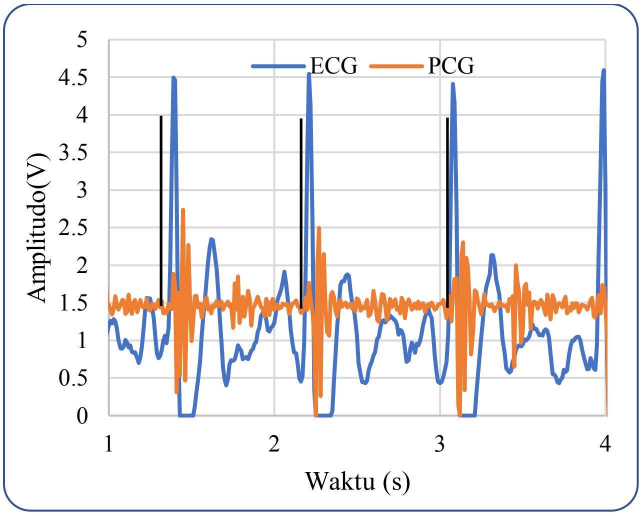

FIGURE 4. Graph of ECG and PCG signal plotting results

TABLE 3
measurement results using ECG phantom or simulator

No.	Standard (BPM)	Design (BPM)	Error (BPM)
1.	30	29.7	1
2.	60	58.82	1.96
3.	120	120	0
4.	180	179.425	0.31
5.	240	241.15	0.48
Average			0.75

In TABLE 3, it can be seen the average result of comparison calculation using modules and phantom obtained error results as ± 0,75

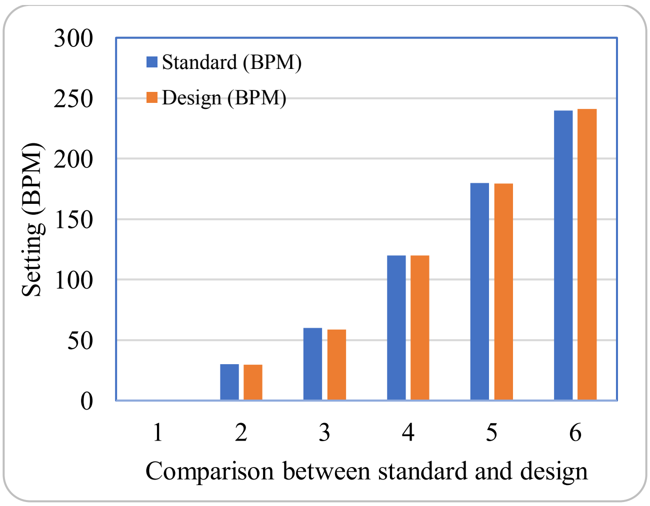

FIGURE 5. BPM measurement between standard and design

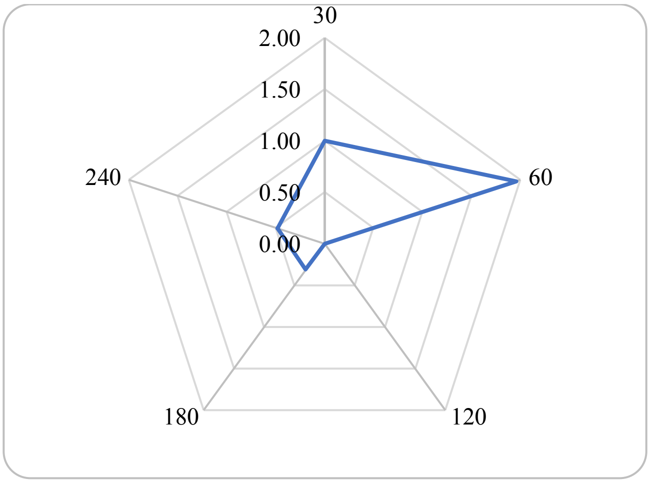

FIGURE 6. BPM error measurement between standard and design

FIGURE 5 shows the measurement comparison of BPM for several BPM settings (30, 60, 120, 180, and 240 BPM). The results show that the BPM values between the design and calibrator are almost the same. The radar graph shows that each BPM setting has different error values. In this case, the lowest value was found in the BPM setting of 120 (FIGURE 6).

TABLE 4
Comparison results of module measurement with oxymetry

Respondents	Comparison (BPM)	Module (BPM)	Error Value %(±)
1	87,2	88,6	1,60
2	84,6	85,6	1,18
3	98	96,2	1,84
4	83,2	85	2,16
5	99	97,6	1,41
6	73	74	1,37
7	87	86,2	0,91
8	74,8	76,6	2,40
9	85,8	86,8	1,16
10	75,4	76,6	1,60
Average	84,8	85,32	0,613207547

TABLE 4 shows the average comparison of BPM values in oxymetry and Modules in each patient. The most significant error value in the measurement was ±2.16, and the slightest error value was ±0.91, with an average error value of ±0.61.

IV. DISCUSSION

The results of measurements of the correlation between the patterns of the dicrotic notch (pattern D) on the carotid pulse and S2 in the phonocardiograph were measured. The measurements in respondents were carried out with five trials, each of which showed the value between dicrotic notch (pattern D) on the carotid pulse and S2 in phonocardiograph occurring together or S2 in phonocardiograph occurred before the D pattern on the carotid pulse. The measurement obtained that the average value from 15 respondents of the interval between S2 and the dicrotic notch was ±0.063s. This research's weakness is the piezoelectric sensor's design, which is not attached to the neck surface. The use of sensors that must be pressed in order to intercept the carotid pulse signal. The benefit of this study is that we can know the shape of the carotid signal in the carotid artery and that the carotid signal has a correlation with the second heart sound (S2) [23].

After measuring ten respondents with five trials, the error result was ±2.16 for BPM measurements obtained from a comparison tool (Oxymetry) with a Module (Heart Monitor). The average BPM value obtained in the comparison tool is 84.4 and in the Module 85.32 with a difference of ±0.9 BPM. Tool results are also compared with the Fluke MPS450 phantom ECG and Oxymetri tools. The error value obtained from the measurement between the module and the Phantom ECG Fluke MPS450 tool, the error value is 1%(30 BPM), 1.96%(60 BPM), 0%(120 BPM), 0.31%(180 BPM), 0,48%(240 BPM). This BPM error follows the permissible tolerance limit of ± 5% which is based on the instrumentation health quality standard issued by the Indonesian Ministry of Health. The results of plotting the ECG and PCG signals show that the R beat on the ECG has a correlation with the first heart sound (S1) on the PCG. The R beat occurs just before the first heart sound (S1) occurs [10].

In the research, the recording results are strongly influenced by the placement of the sensor (electrode & stethoscope mic condenser) [24][24][25], as well as the position of the respondent. If the electrode placement is not right and the patient's position is not relaxed, the recording results will be noisier. The benefit of this research is that it can be easier to monitor the condition of the heart condition, and the results of the recording can be saved in the form of Bitmap and excel.

V. CONCLUSION

This study aims to develop an apparatus for the cardiac monitor using piezoelectric, disposable ECG electrode, and mic condenser to measure and analyze the relation among the parameter of carotid pulse, ECG signal LEAD II, and phonocardiograph. The measured parameters was sent to the computer unit using a serial communication program via a USB cable. The electrodes (ECG) placement and the mic-condenser stethoscope significantly affect the recording results. From the data obtained, it can be seen that there is a correlation between ECG and PCG signals. The ECG R pulse occurs just before the first heart sound (S1) occurs. The results of the BPM measurement between the module and the oximetry resulted in an error of +-2.16%. In the future, this design research can be developed by choosing a data transmission method using wireless and improving the filter used using a digital filter.

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International: Rapid Review: Open Access Journal Vol. 15, No. 2, June 2022, pp. 81-87 ISSN: 2407-896

APPENDIX

Attachment

a. Schematic:
https://drive.google.com/file/d/1Y0MLJcNwz2S_b5d2rRGc3ZlefIA74ggq/view?usp=sharing

b. Listing Program Arduino:
https://drive.google.com/file/d/12ufPyyPwPy3X0cp_0E3JAIc3nyjAEo27/view?usp=sharing

c. Cardiac Monitor Application:
https://drive.google.com/file/d/12ufPyyPwPy3X0cp_0E3JAIc3nyjAEo27/view?usp=sharing

d. Delphi7 Application:
https://winworldpc.com/product/delphi/70

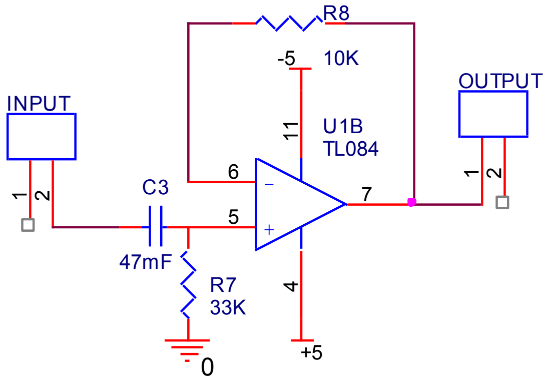

FIGURE 6. **Non Inverting Amplifier Circuit**

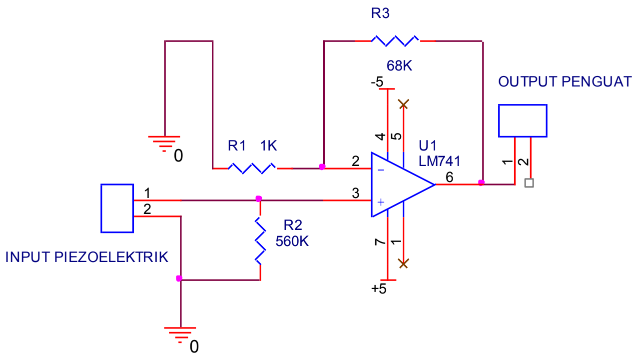

FIGURE 4. **Non Inverting Amplifier Circuit**

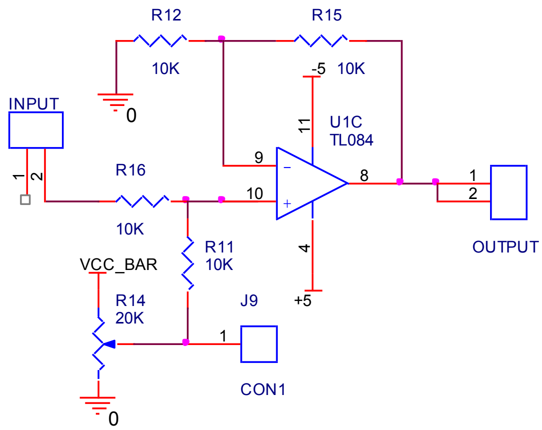

FIGURE 7. **Summing Amplifier Circuit**

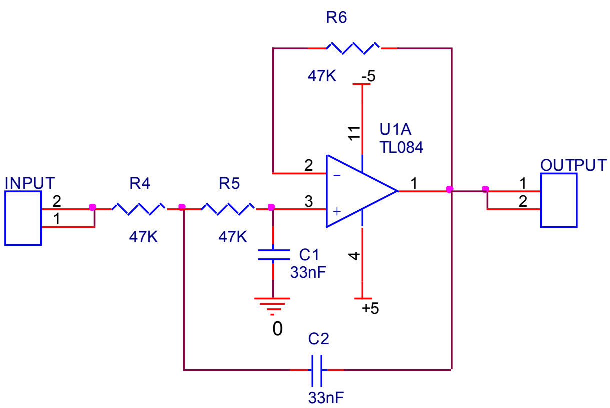

FIGURE 5. **Low Pass Filter Circuit**

A. The Listing Program for Arduino

Pseudocode: 1. The arduino program above functions for reading and sending ADC from Carotid Pulse.

```
unsigned int dataadc1, dataadc2, dataadc3;
unsigned char nilai1,nilai2;
void setup() {
  Serial.begin(9600);
}
void loop() {
  Serial.print('y');
  dataadc3=analogRead(A2);
  nilai1=dataadc3/100;
  nilai2=dataadc3%100;
  Serial.print(char(nilai1));
  Serial.print(char(nilai2));
  Serial.print('z');
  delay(1);
}
```

B. Result of Delphi7 Program

Pseudocode: 2. this program serves to display the Carotid Pulse signal via ComDataPacket. Carotid Pulse signal appears in Series 3.

```
procedureTForm1.ComDataPacket1Packet(Sender:
TObject; const Str: String);
Var
 ECG,  PCG, CAROTID: double;
 E, a, b, dataECG, dataPCG, dataCarotid: Integer;
 tampilmemo1,tampilmemo2,tampilmemo3 : string;
 begin
  dataECG:=(Ord(Str[1])*100)+Ord(Str[2]);
  dataPCG:=(Ord(Str[3])*100)+Ord(Str[4]);
  dataCarotid:=(Ord(Str[5])*100)+Ord(Str[6]);

  ECG    :=(dataECG*0.0008058608058);
  PCG    :=(dataPCG*0.0008058608058);
  CAROTID:=(dataCarotid*0.0008058608058);
 End;
```