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Enhancing the Electrocardiogram Signal Quality by Applying Butterworth Infinite Impulse Response Filter 8th Order

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ABSTRACT The electrocardiogram (ECG) of the human body is an important basis in heart function as well as the diagnosis of cardiovascular diseases, which has a very vital role in clinical diagnosis. Obtaining high-quality ECG signals with a portable remote ECG acquisition system is a big challenge given limited resources. According to the World Health Organization (WHO), disorders of the cardiovascular system still rank high, causing about 31% of deaths globally. This is because the symptoms of cardiovascular disease cannot be seen directly, but rather by conducting an electrocardiograph (ECG) examination. The purpose of this research is to develop and analysis the ECG signal by comparing the 2nd order AD8232 module analogue filter with the 8th order Butterworth digital filter by applying infinite impulse response. This research uses a multiplexer circuit for switching leads, AD8232 ECG module, 50Hz notch filter circuit, non-inverting amplifier, adder, Arduino Mega 2560, USB module, and an application to display digital signals, namely Delphi 7. Signal acquisition is done by monitoring for one minute. Data collection was carried out with 5 respondents 5 times on each lead. The results of the data collection can be concluded that 80% of digital filters display smoother signals for ECG signals than analogue filters.

NDEX TERMS Electrocardiograph, Analog Filter, Digital Filter

I. INTRODUCTION

The heart is one of the most vital organs in the body. The heart is a muscle that can contract. Every muscle contraction will always cause electrical changes known as action potentials. The action potential that arises in the heart muscle (myocardium) and the heart transmission network is what gives the electrical picture of the heart or cardiac conduction. Due to conduction, the heart can generate electrical impulses in a rhythmic manner that causes rhythmic contractions of the heart muscle called heart rhythm, sending action potentials through the heart muscle and causing the heart to beat. Health problems with disorders of the cardiovascular system still rank high, according to data from the World Health Organisation (WHO) reports that there are about 31% of causes of death globally are cardiovascular diseases [1][2][3].

From these data, disorders of the cardiovascular system cannot be underestimated. The high mortality rate is due to the fact that the symptoms of this disease cannot be seen directly, but by conducting an examination using an electrocardiograph (ECG). That's why the development of electrocardiographs (ECG) is needed to help identify abnormalities in the heart so that medical treatment can be carried out by medical personnel or by heart specialists [4][5][6][7].

Electrocardiogram (ECG) is a signal that is formed as a result of the electrical activity of the heart indicated by P-Q-R-S and T waves. Small changes in the amplitude and duration of the ECG describe certain heart abnormalities so that we can identify abnormalities in the heart with P-Q-R-S, T waves ECG recordings are taken by placing electrodes at certain points on the patient's body. The ECG signal has a specific shape so that it can be used as a reference to determine heart health conditions by cardiologists. ECG signals are recorded using a device called an electrocardiograph. Therefore, the placement of the electrodes to get good recordings on the electrocardiograph is very important so that the diagnostic results are obtained properly [8][6].

In 2006, Daniel Lucani et al. conducted ECG research about mobile ECG monitoring machine with the addition of Bluetooth and Holter as a telemedicine application. In this study, the researchers made a 3 lead 3 channel ECG with data transmission in the form of Bluetooth. However, this study has a drawback, namely the frequency generated from wireless telephones and WiFi networks can have a negative impact on data transmission because it is via Bluetooth at different distances [9][10][11]. In 2012, Parin Dedhia et al. conducted ECG research about using low cost solar ECG with bluetooth transmitter. In this study he wrote ECG data is sent via Bluetooth to be displayed on the LCD. In this study, it has the advantage that the device is efficient in detecting arrhythmias[12][13][14]. In 2015, Agustiawan et al. wrote about computer based 12 lead ECG data acquisition instrumentation system. In this study he wrote it still has drawbacks, namely, the data taken is not real-time on the 12 leads used. In the same year, Dwiky Wicaksono conducted a study about electrocardiograph (ECG) 12 leads on PC (Frontal Field). In this research, he discussed about 12-lead ECG which is then connected to a serial USB RS232 to display the results on a computer, but in this study it still has a drawback that it is not equipped with storage for the ECG signal analysis process[15][16][17][18][8]. In 2016, researchers named Yan lin and Mana Sriyudthsak made a 12 Lead ECG study entitled Design and Development of Standard 12-Lead ECG Data Acquisition and Monitoring System. This study discusses 12 lead ECG with 3 channel data transmission. In this study, it has a drawback, namely the absence of a memory card for data storage, the advantage of this tool is that it is made portable and compact so that it can be carried and used at various times.[19][3][20][16]. In 2021, Rizki Aulia Rachman conducted a study about development of a low-cost and efficient ECG devices with IIR digital filter design. In this study, he wrote about using Butterworth, Chebyshev I, Chevbyshev II, and Elliptic digital filters. The author states that the Butterworth digital filter with order 8 is more ideal than Chebyshev I, Chevbyshev II, and Elliptic. This study has the advantage of discussing four types of IIR filters, namely Butterworth, Chebyshev I, Chebyshev II, and Elliptic. However, it also has a drawback, namely, it is not equipped with a complete number of leads and views on the channel[21][22]. In 2021, Mohamat Frisdyanata Dwi Huda conducted research about improvement of leading electrocardiograph signals in palms and feet using digital filters. The digital filter used is a Butterworth digital filter. In this study, the patient's heart signal was detected using electrodes attached to the patient's palms and soles of the feet. This study also tried to collect data using a phantom ECG with the aim of comparing the ECG signal from humans with the ECG signal from the Phantom ECG. This study has a drawback, namely the resulting frequency is not in accordance with the filter design used as many as six orders. The advantage of this research is that the output signal generated by the ECG is clearer because it is processed using FFT[23][24][25].

An electrocardiogram is a common diagnostic test used to evaluate heart function. The test records the electrical activity of the heart, and to some extent and identifies if there is any abnormal circulation or blood flow. The EKG gives a good picture of the size and shape of the heart. The heart is one of the largest muscular organs and is divided into four chambers. The upper chambers are called the right and left atria, and the lower chambers are the right and left ventricles. The electrocardiograph must provide results that are representative of the patient's heart condition. To see the complete state of the heart, leads are needed inferior (leads II, III, aVF), lateral (leads I, aVL, V5, V6), septal (V1 and V2), anterior (V3, V4) and aVR.[26][27][13][28]

From the identification of the problems above, the purpose of this study is to develop a simple and low cost ECG monitor based on personal computer using infinite impulse response (IIR) to enhence the ECG quality. In this design, the author proposed a 12 Lead ECG (Lead I, II, III, AVR, AVL, AVF). In this design, the AD8232 module was used to record the ECG signal from human body. Furthermore, an analog filter, butterworth type IIR digital filter using fc between 0.5-100 Hz on order 8 in 12 Lead ECG for Lead I, Lead II, Lead III, aVR, aVL, aVF. This study aims to develop and analysis the ECG signal by comparing the 2nd order AD8232 module analogue filter with the 8th order Butterworth digital filter by applying infinite impulse response. The personal computer unit was used to show the ECG signal directly using Delphi programming application [29][30][27]. The contributions of this study are as follow:

1) The ECG monitoring proposed design can be built with a low cost and portable
2) The machine can monitor the ECG in real-time by using a personal computer.
3) The implemented IIR digital filter 8^{th} orde able to improve the ECG quality.

II. MATERIALS AND TOOLS

This research was conducted as experimental research. The author proposes to analyze the comparison of signal output from the AD8232 module, analog filter output, and butterworth type IIR digital filter on the ECG 12 Lead in lead 1, lead 2, lead 3, aVR, aVL and aVF displayed in Delphi. Materials and methods will be explained in the following sections.

A. DATA COLLECTION

In this study, module testing was carried out on respondents using a 12 Lead ECG cable with clamp and bulb electrodes as a heart signal recording and with the sample criteria taken by teenagers aged 18-24 years, male sex and weight 50-70 kg. In the ECG module each signal obtained is the result of the leads of two or more electrodes mounted on the surface of the body. Each ECG signal represents the orientation of the heart vector at each lead point. If the tapping point has been determined, then the electrode is installed. This lead was taken from lead 1, lead 2, lead 3, AVR, AVL, and AVF in patients. The patient was placed on a clamping electrode and smeared with gel on the tip of the lead and the patient was expected to relax during data collection.

FIGURE 2. Data Collection on Respondents

The process of digital ECG signal filtering is by applying an infinite impulse response (IIR) type digital filter. The IIR filter has an architecture consisting of two parts feed forward and feed back. In accordance with FIGURE 1, the IIR filter utilizes current and past inputs and outputs to produce an output. Based on the Z transformation, the feed forward and feed back block transfer function values are obtained as shown in Eq (1). Where, coefficient b is the feed forward process coefficient, further coefficient a is the feed back process coefficient. In general, the transfer function Eq. (1) can be realized in the form of a discrete equation as shown in Eq. (2).

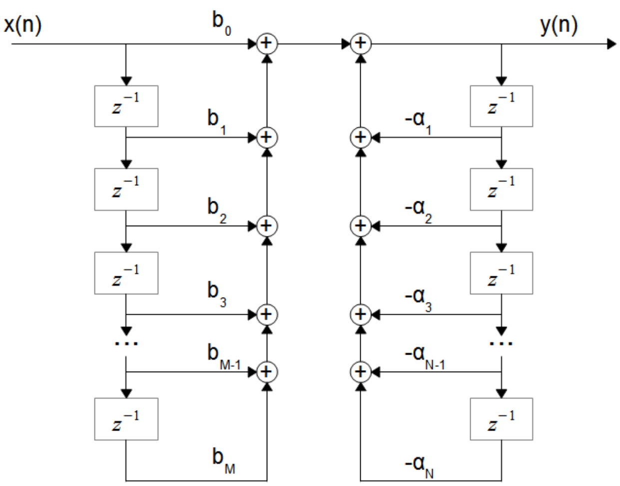

FIGURE 1. IIR filter direct form I architecture

$$H(z) = \frac{\sum_{i=0}^{M} b_i z^{-i}}{1 + \sum_{i=1}^{N} a_i z^{-i}} \quad (1)$$

$$y(n) = \sum_{i=0}^{M} b_i x(n-i) - \sum_{i=1}^{N} a_i y(n-i) \quad (2)$$

where y(n) shows the output of digital filter (IIR), M=N indicates the filter order, bi shows the feed forward coeficient, ai indicates the feef back coeficients. Number of data is shown by n value. Equation (2) can be represented by using Eq. (3) for programming implementation.

$$\begin{aligned} y(n) &= b_0 x(n) + b_1 x(n-1) + \ldots + b_M x(n-M) \\ &-a_1 y(n-1) - .. - a_N y(n-N) \end{aligned} \quad (3)$$

The data analysis was carried out to determine the final results and to determine the level of accuracy of the tools that have been made. The data to be analyzed is the data from the ECG signal which is converted into an analog signal and a digital signal and displayed on Delphi. Then the data is saved in txt format. and processed in Microsoft Excel to form a signal graph. From this data, it can be seen which output signal is better or the signal that produces less noise. Leads on a 12 lead ECG generally consist of:

1. FRONTAL LEAD (LIMB LEAD)

In this frontal lead, the Einthoven triangle method is used which produces ECG signals, namely Lead I, Lead II, and Lead III [17]. Heart signals are tapped from three points of the body, namely the right hand (RA), left hand (LA), and left foot (LL). The mathematical equation for the frontal lead is as follows:

- Lead I = LA – RA (1)
- Lead II = LL – RA (2)
- Lead III = LA – RA (3)

2. UNIPOLAR EXTREMITY LEAD (AUGMENTED LIMB LEAD)

This lead compares the stress at one point of the body to the average stress at the other two points of the body. The results of these unipolar extremity leads are AVR, AVL, and AVF. The resistors used to obtain leads aVR, aVL, and aVF have the same value, so that the average voltage of the two body points is obtained [2]. The mathematical equation for the unipolar extremity lead (augmented limb lead) is as follows: $= RA - +LL$ 2 (4) $= - RA+LL$ 2 (5) $aVF = - RA+LA$ 2 (6).

3. PRECORDIAL LEAD

The precordial leads are intended to obtain the electrical activity of the heart viewed from the horizontal plane. The precordial leads are derived from a comparison between the

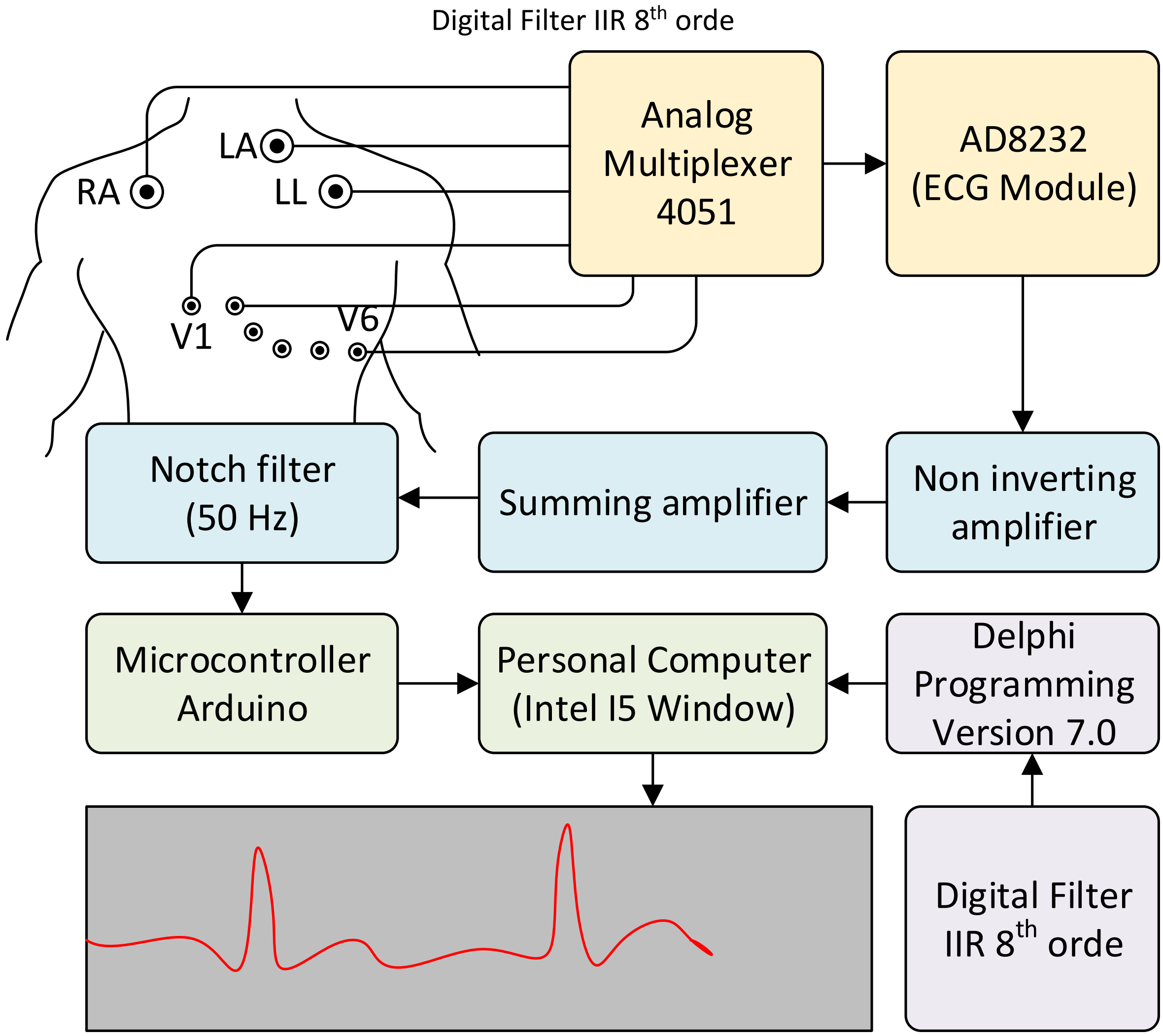

FIGURE 3. Implementation of digital filter based on infinite impulse response algorithm using orde 8

electrodes placed on the chest and the Wilson Central Terminal (WCT) circuit. The electrode is used as a positive voltage while the WCT circuit is used as a negative voltage. The result of this precordial lead is V1, V2, V3, V4, V5, dan V6. FIGURE 3 describes a block diagram consisting of input, process, and output. Heart signals in patients are detected using electrodes attached to the patient's body. Then the heart signal goes to the AD8232 ECG module. Furthermore, the signal will be selected alternately (switching) using a multiplexer to select the signal to be sent to the Microcontroller. Prior to the selection signal on the multiplexer, the output of the AD8232 ECG module will be filtered using a notch filter to reduce 50 Hz noise on the PLN grid after which it will be amplified through a non-inverting circuit and to increase the voltage reference it will then enter the adder circuit. After the adder circuit there is a notch filter notch filter to reduce 50 Hz noise on PLN grids. Furthermore, the output of the circuit will be adjusted to the reference value so that it can be read by the microcontroller. Before being displayed, the output of the AD8232 module will be changed using an analog filter and a Butterworth type digital filter with an order of 8 in order to get a better signal and display it on a PC using Delphi. Lead initialization is carried out to retrieve the ECG signal in the body using electrodes then lead selection is carried out using a multiplexer circuit. After the lead selection, the analog signal is processed at the ADC and converted into a digital signal and the data is processed using a digital filter program. The processed signal is displayed by Delphi 7. The lead selection is selected using the buttons on the Delphi program display. FIGURE 4 shows the flowchart of the proposed system. The system consists of two sections, namely microcontroller system and computer-based system as shown in FIGURE 4(a) and FIGURE 4(b). In the microcontroller section, the program will initialize several functions such as serial communication and analog to digital converter. Microcontroller will detect whether any command from computer system to select the ECG LEAD (I, II, III, AVR, AVL, and AVF) through serial communication. The command will select the ECG channel using an analog multiplexer 4051. After the selection, the A/D converter will convert from analog voltage to digital

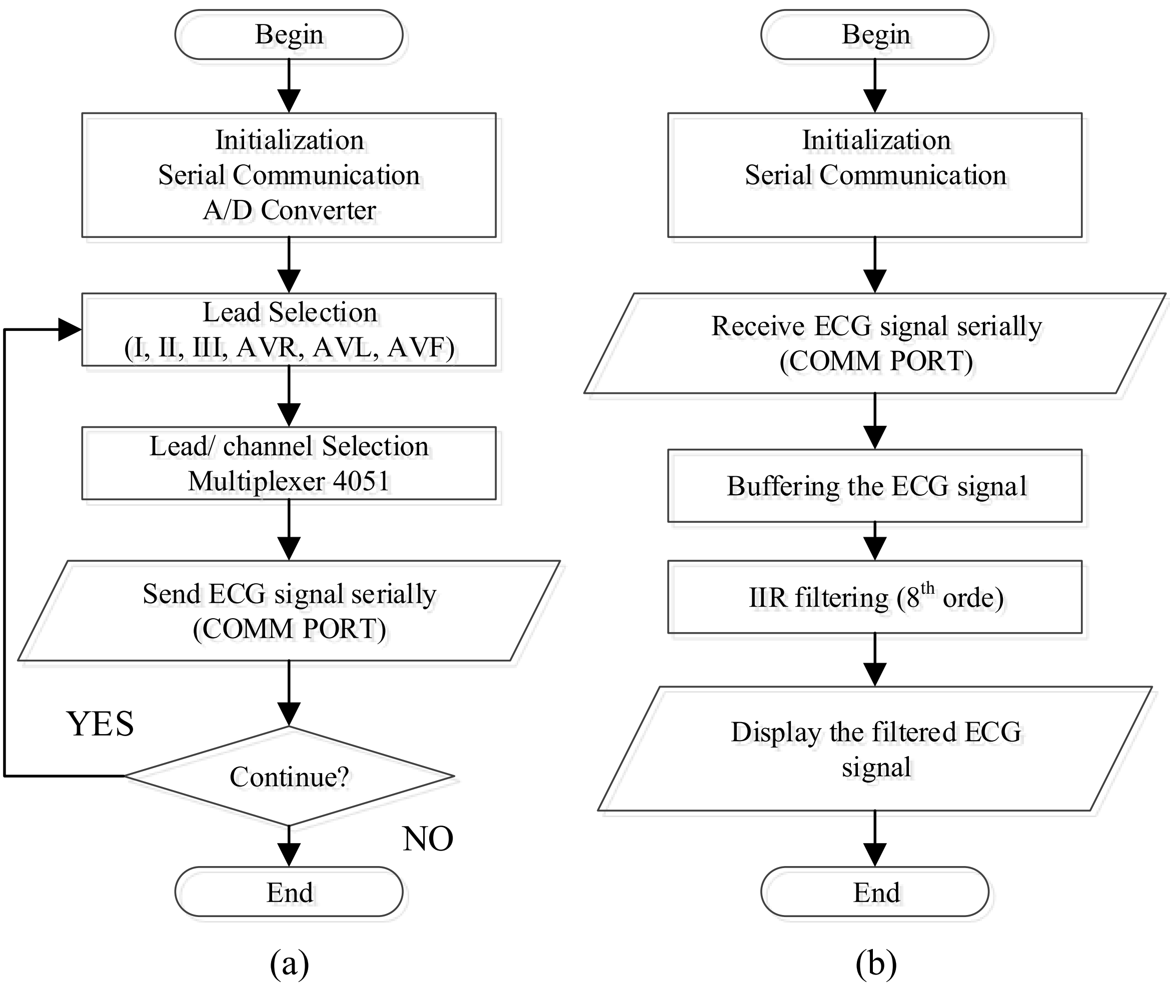

FIGURE 4. (a) ECG data acquisition using microcontroller Arduino, (b) receiving the ECG data using serial communication and filtering using IIR 8th order

data further send the data to the computer system through the serial communication. The data will be sent with baud rate of 115200 BPS. Furthermore, in the computer system part (FIGURE 4(b)), the system will prepare first for serial communication initialization. The data serial receive procedure will detect any activities in the serial communication continuously. If the data is detected then the data will be processed for digital signal processing. In the digital signal processing, the ECG data will be buffered in the specific variabel. The digital filter which implemented the infinite impulse respons conducted by using the Delphi programming application (Delphi, Version 7, Borland corporation, United State). The eight (8) order IIR filter was implemented in this algorithm.

B. DATA ANALYSIS

The data analysis carried out aims to determine the final result and to determine the level of accuracy of the tool that has been made. The data to be analyzed is the data from the ECG signal which is converted into an analog signal and a digital signal. The output signal from the AD8232 ECG will be selected alternately (switching) using a multiplexer circuit, a notch filter to reduce 50Hz noise on the PLN grid, amplified by a non-inverting amplifier circuit and the reference value adjusted by the adder circuit, then a notch filter is added to reduce noise 50Hz on the PLN grid will then be sent into the Arduino Mega 2560 to be processed into analog signal data, which of the data will be sent to a PC to appear in the Delphi application. As for the digital filter, it uses an IIR digital filter with a Butterworth type of order 8, where from the output signal of the AD8232 module it will be processed in Delphi with a digital filter program so that it can be displayed on a PC with the Delphi application. Then the results that will appear on the PC are the AD8232 module signal output, the analog filter signal and the digital filter signal to analyze which output is a better signal or a signal that produces less noise.

III. RESULT

In the 12-lead ECG data acquisition, the ECG signal were collected from LEAD 1, LEAD 2, LEAD 3, AVR, AVL, and AVF from the patient body. FIGURE 4 shows the ECG recording from LEAD II and LEAD III for raw and filtered ECG signal. FIGURE 5(a) and (c) show the raw ECG signal

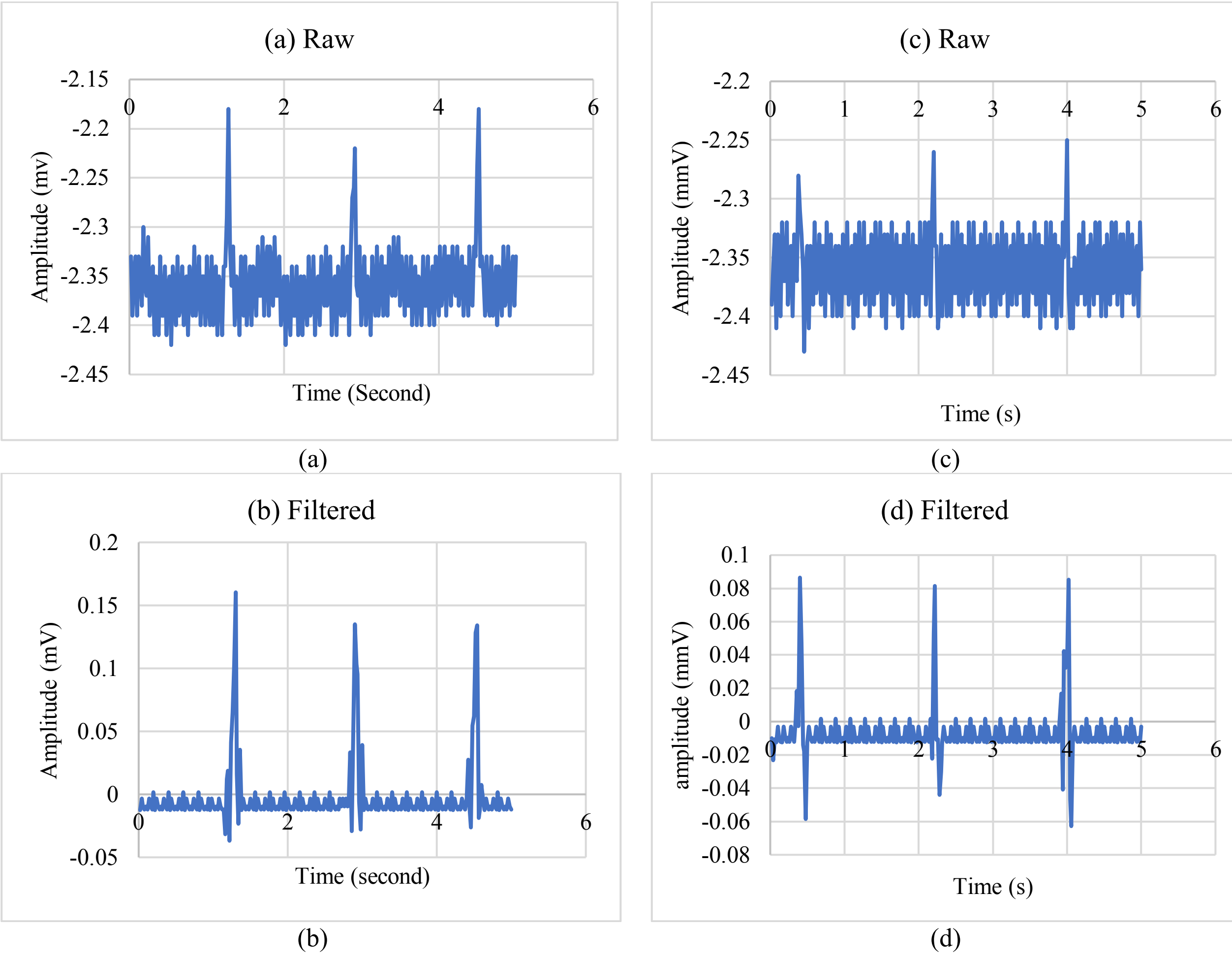

FIGURE 5. **The ECG recording from computer system (a) the raw ECG signal from LEAD II, (b) the filtered ECG signal from LEAD II, (c) the raw ECG signal from LEAD III, and (d) the filtered ECG signal from LEAD III.**

Table 1. The performance analysis for raw and filtered ECG signal using t-Test (α=0.05)

	Lead1	Lead2	Lead3	AVR	AVF	AVL
Error (%)	-1,84642937	-2,064602	-2,728395	-1,4332	-1,918	-1,78061
p-value	1,08419E-36	1,975E-34	3,504E-56	2,2E-26	1E-29	5,67E-32

TABLE 1 explains the difference between the original data signal before being filtered and the results after being filtered using the T-test. The comparison between analog and digital filter show error in % -1,846, -2,064, -2,728, -1,433, -1,918, and -1,780 for LEAD I, LEAD II, Lead III, AVR, AVF and AVL, respectively. The p-values show that there is significant difference of performance between the analog and digital filter (p-value<0.05).

IV DISCUSSION

In lead 2 shown in FIGURE 8, it can be seen that the signal from the ECG module still contains a lot of noise. When the ECG signal is converted into an analog filter, it can be seen that the signal still contains noise but a little. When the ECG signal is converted into a digital filter, it can be seen that the signal results in less noise than the analog filter[24][19]. In lead 3 shown in FIGURE 8, it can be seen that the signal from the ECG module still contains a lot of noise. When the ECG signal is converted into an analog filter, it can be seen that the signal still contains noise but a little. When the ECG signal is converted into a digital filter, it can be seen that the signal results in less noise than the analog filter.

V CONCLUSION

The purpose of this research is to develop an ECG device to read more signals by utilizing 12 leads. The contribution of this research is to create 12 leads using digital filter by displaying the output signal of ECG module, analogue filter signal and digital filter signal using Delphi application. We found that the smallest error was found from LEAD I (% error: -1,846). This research has found that it is possible to create a 12 lead 1 channel ECG module using a Butterworth type digital filter of order 8. In summary, this ECG module has the best output results on digital filter signals where these results are obtained from comparing 3 outputs. Further experimental research is needed to develop this module by displaying the BPM value on the computer screen, using high quality materials to produce a better signal, processing the signal on the computer to stabilize the signal reference point up and down, making a device with a good grounding system so that the ECG signal is not affected by 220V.

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