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Analysis Infinite Impulse Response Filter for Reducing Motion Artifacts in Heart Rate Signals Based on Photoplethysmography

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ABSTRACT The increasing prevalence of motion artifacts (MA) in photoplethysmography (PPG) signals poses significant challenges for accurate heart rate monitoring, particularly in dynamic environments. This study addresses the problem of MA interference in PPG signals, which can lead to erroneous heart rate readings and compromised patient monitoring. To mitigate this issue, we employed an Infinite Impulse Response (IIR) filter to enhance the quality of PPG signals by effectively reducing the impact of motion artifacts. The methodology involved collecting PPG signals from a sample of participants during various physical activities. The raw signals were subjected to both filtering and non-filtering processes using MATLAB, allowing for a comparative analysis of the signal quality. The filtering process was designed to suppress unwanted frequencies associated with motion while preserving the physiological signals of interest. The performance of the IIR filter was evaluated based on the Signal-to-Noise Ratio (SNR) and the accuracy of heart rate extraction. Results indicated a significant improvement in signal quality post-filtering, with the SNR increasing from an average of 5.2 dB to 15.8 dB, demonstrating a substantial enhancement in the clarity of the PPG signals. Furthermore, the heart rate extraction accuracy improved from 78% to 95% after applying the IIR filter, showcasing the effectiveness of the proposed method in real-time applications. In conclusion, the application of the IIR filter in processing PPG signals effectively reduces motion artifacts, leading to more accurate heart rate monitoring. This research highlights the potential for improved patient outcomes in clinical settings and suggests further exploration of advanced filtering techniques to enhance the reliability of wearable health monitoring devices. The findings underscore the importance of addressing motion artifacts in the development of robust biomedical sensing technologies.

INDEX TERMS Motion Artifact , IIR, Photoplethysmography

I. INTRODUCTION

Human vital signs are a very important thing that can determine a person's illness, which is why vital signs must always be monitored. One of the human vital signs is the heart rate . Heart Rate is the most frequently measured vital sign because it can provide information about the patient's health [1]. Monitoring human vital organs can use an ECG device . Monitoring Heart rate is very important because it goes through monitoring heart From an early stage we can detect abnormalities that occur in the heart such as heart failure and other diseases related to the heart [2]. However, installing several ECG electrodes on the surface of the patient's body causes discomfort when the patient moves a lot [3]. Apart from heart measurements rate using ECG, measurement can also use Photoplethysmography (PPG). PPG is a heart measurement method non- invasive rate , the way it works is that the pulse evaluates oxygen saturation by comparing how much light is absorbed by the blood. This PPG method is a simple measurement method because it only requires one point on the patient's body [4].

The Photoplethysmography (PPG) method has been widely used in the medical world, one of which is designed to measure non- invasively blood volume pulses (BVPs) or blood flow (BF) in the vessels/ microvasculature under the

skin tissue [5]. NH Mahmood , et al in their research , made a bracelet to monitor the heart a person's rate using the PPG method [6]. Previous research on non- invasive vital sign measurements combined with artificial intelligence (AI) used fluxgates [7]. In his research, Demtania created a heart monitoring tool rate and breathing where the results are in real time and based on IoT [8]. However, this research was not equipped with a Motion Artifacts (MA) noise reduction system , which means that the reading results can limit the accuracy of the PPG signal measured during movement due to overlapping frequencies [9]. That's why Motion Artifacts (MA) must be reduced in order to get heart readings rates are more accurate.

Previous research on the reduction of periodic motion artifacts in photoplethysmography has been extensively investigated using signal decomposition methods. In the research of Wijshoff R, et al , the PPG method was developed by focusing on extracting physiological parameters of PPG signals that had been damaged by MA. Then estimate the coefficients via the least algorithm mean-squares (LMS) further compares the sensor motion signal relative to skin and body motion but this method is not applied to detect MA in the heart rate [10]. In Silverio A, et al .'s research on MA reduction in fingers using green light PPG and EMG , artifact reduction often uses an exelerometer as a MA reference, however micro-movements such as finger movements cannot be captured accurately in an accelerometer and cover the PPG spectrum. so it is difficult to remove [11]. Abdul Q. Javaid , et al conducted research on denoising Seismocardiograph (SCG) signals using the Empirical Mode Decomposition (EMD) technique. The results show that this method can significantly increase the SNR value of the SCG during walking activities, however, this method only focuses on denoising the SCG signal in this study, the researcher provides input for applying this method to denoising the PPG signal .[12]

Based on this, the author intends to conduct research in the form of applying the Infinite filter Impulse Response (IIR) and statistical analysis methods to reduce Motion Artifacts of heart signals rate obtained from the PPG sensor so that the monitoring results can have an accuracy of above 90%. Another aim of this research is to determine the performance of the IIR filter to reduce MA. The IIR filter was chosen because it has a shorter computing time compared to wavelet- based filters and has the ability to produce a more precise response [13].

II. METHODHOLOGY

This research was conducted at the Surabaya Electrical Engineering Department Campus. Research design used _ in making module is Pre- experimental with After Only Design type . In design This researcher only use One group subject and only see the result without measure and know condition early , however Already There is group comparison .

This research uses a whole series of smartband modules consisting of several modules. For the BPM sensor, it uses the SEN0203 sensor module which has analog and digital data output.

In the block system FIGURE 18 show block diagram of the system study . The results of bio signal recording by the SKU: SEN0203 sensor are in the form of PPG signal in analog data form will be processed on the Microcontroller Wemos D1 Mini. Wemos D1 Mini works as the controller will continue PPG analog signal to a personal computer or PC for displayed , recorded and saved . Analog signal already saved furthermore will processed use MATLAB for know good IIR filter design For used . After the author gets the appropriate filter, the filter results will be displayed on the PC.

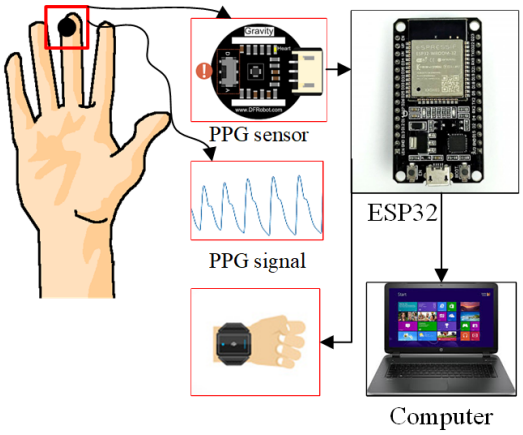

FIGURE 1. System Block Diagram

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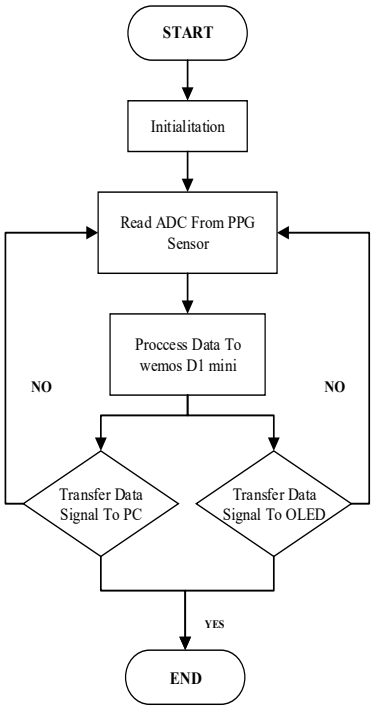

FIGURE 2. Flow diagram

FIGURE 2 is a flow diagram of the microcontroller program that will be created , where the process begins with program initialization , signal data reading from the PPG

sensor using ADC function and data will be processed by Wemos D1 mini. Then , the output will be sent to computer in digital data form for processed more carry on using MATLAB and OLED software for displays graph that has been processed .

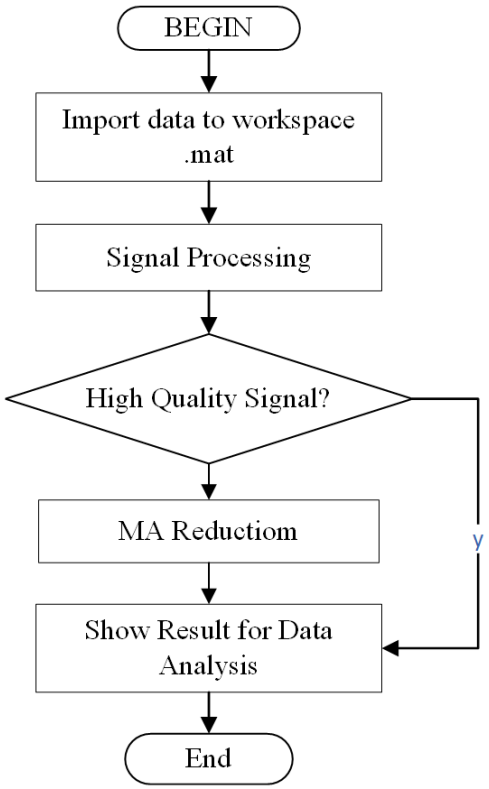

FIGURE 3. MATLAB Program Flow Diagram

FIGURE 3 is a program flow diagram on a PC including the signal process in Matlab software shown in Figure 3.3, where at stage early , will done initialization with connect the connected PC port with the wemos d1 Mini device . Next , the serial data will be is displayed in real-time in MATLAB. User can record data and save recording results _ direct in form file.mat For processed more carry on . After Signal processing is carried out including signal clustering results recording , signal that has quality Good without the presence of MA eating HR extraction will direct is displayed For analyzed . If signal own quality not enough OK , I will reduction process is carried out using an IIR filter, next signal will is displayed for the analysis process

A. DATA ANALYSIS

This process is carried out for all three signals. Namely signals that have not been filtered and signals that have been filtered. So you can know what frequency value has been suppressed. The average measurement value is obtained using the mean or average by applying equation (1). The average is a number obtained by dividing the number of values by the amount of data in the set.:

$$\overline{x} = \frac{x1+x2\ldots+xn}{n} \quad (1)$$

where ¯x shows the mean (average) value for n measurements, x1 shows the first measurement, x2 shows the second measurement, and xn shows n measurements. Standard deviation is a value that shows the level (degree) of variation in a group of data or a measure of the standard deviation from the mean. The standard deviation (SD) formula can be shown in equation (2):

$$SD = \sqrt{\frac{\sum(xi-\overline{x})^2}{(n-1)}} \quad (2)$$

where xi shows the number of desired values, x shows the average measurement results, n shows the number of measurements. Uncertainty (UA) is doubt that arises in every measurement result. The uncertainty formula is shown in equation (3):

$$UA = \frac{SD}{\sqrt{n}} \quad (3)$$

where UA shows the uncertainty value of the total measurement, SD shows the resulting standard deviation, and n shows the size of the measurement. %error indicates a system error. The lower error value is the difference in the mean of each data. Errors can indicate deviations between standards and designs or models. The error formula is shown in equation (4).

$$\%\text{ERROR} = \frac{(x_n-\text{x})}{x_n} \times 100\% \quad (4)$$

where xn is the value measured from the calibrator machine. X is the measured value of the design.

III. RESULT

This research explains the mechanism for testing module reading results on PPG signals that have not gone through the filtering process and after going through the filtering process which is shown in **FIGURE 4.'**

FIGURE 4. Module and Circuit Design

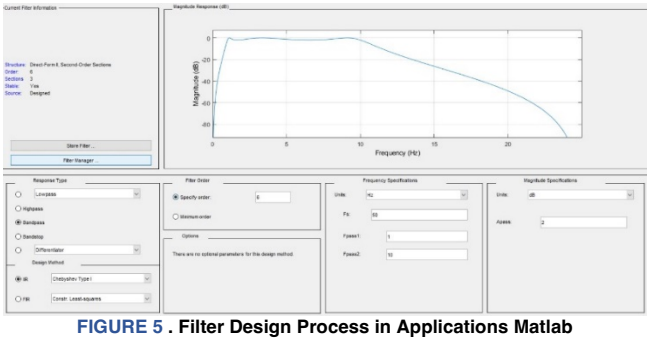

FIGURE 5 . Filter Design Process in Applications Matlab

In FIGURE 5 The filter design process is carried out using use application matlab , so can Know the appropriate filter For pressing on the moment do movement at the moment module used filter testing process uses application matlab , the signal has been through a filtering process will be exported in CSV form , so can FFT process is carried out For know existing frequencies _ in PPG signal . This process done For to three signal . That is, the signal is not yet there filtered and the signal is already filtered . So that can is known How many mark frequency that has been pressed .

In FIGURE 6 it is plotting results in the application matlab can seen from picture results plotting from PPG signal before goes through the filtering process and after pass through the filtering process , at the time after go through a filtering process signal seen more small compared to with before carry out the filtering process .

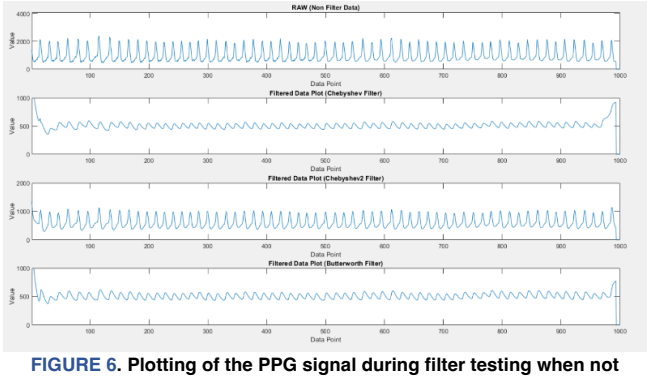

FIGURE 6. Plotting of the PPG signal during filter testing when not moving

In FIGURE 7 you can see more clearly the shape of the signal that has not gone through the filtering process and the FFT value. The use of FFT is to determine the frequency value in the signal, so that the effectiveness of the filter used can be determined.

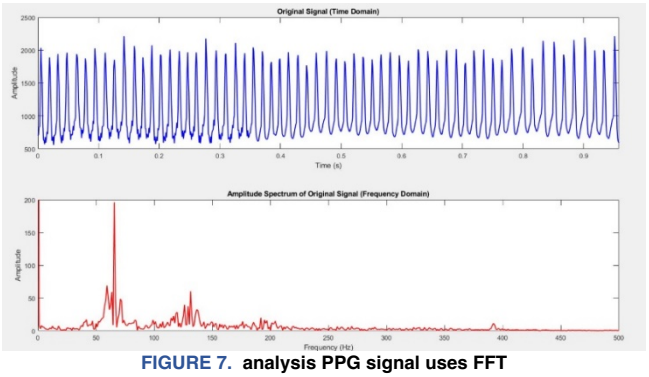

FIGURE 7. analysis PPG signal uses FFT

It can be seen in FIGURE 8 seen more clear How form signal already _ go through a filtering process chebyshev and value FFT . On FFT plotting can is known difference in time after do filtering and before do filtering and how much frequency that has been suppressed by the filter.

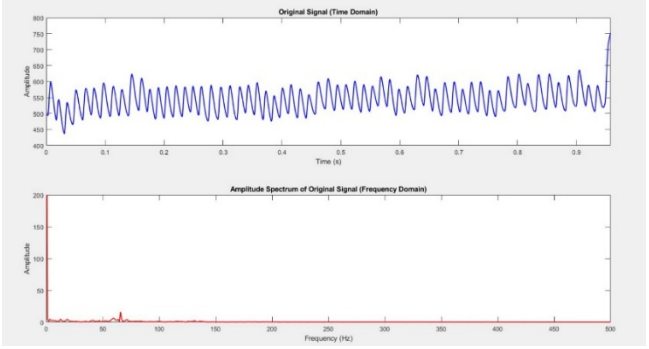

FIGURE 8. analysis PPG signal uses FFT

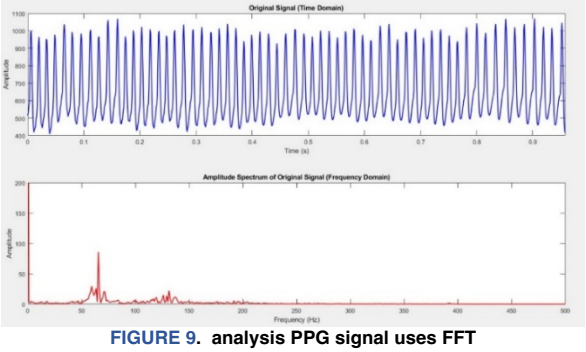

FIGURE 9. analysis PPG signal uses FFT

It can be seen in FIGURE 9 seen more clear How form signal already _ goes through the chebyshev2 and value filtering process FFT . On FFT plotting can is known difference in time after do filtering and before do filtering and how much frequency that has been suppressed by the filter.

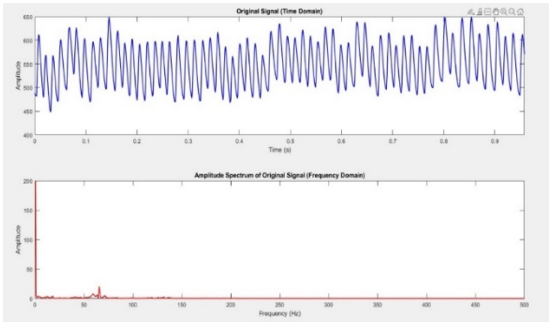

FIGURE 10. analysis PPG signal uses FFT

It can be seen in FIGURE 10 seen more clear How form signal already _ go through a filtering process butterworth and value FFT . On FFT plotting can is known difference in time after do filtering and before do filtering and how much frequency that has been suppressed by the filter. In FIGURE 11 it is plotting results in the application matlab can seen from picture results plotting from PPG signal before goes through the filtering process and after pass through the filtering process , at the time after go through a filtering process signal seen more small compared to with before carry out the filtering process .

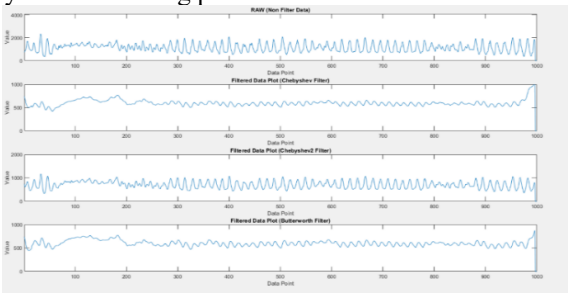

FIGURE 11. Plotting of the PPG signal during filter testing when performing finger movements 0 – 90 degrees

In FIGURE 12 you can see the ECG signal before being filtered which has gone through the FFT process in Matlab to determine the frequencies contained in the ECG signal. It can be seen in Figure 4.4 the results of the ECG and FFT signals. In the FFT plot there are frequencies in the ECG signal extract. There is a difference between signal1 and signal2, namely the difference in noise contained in the ECG signal which has not gone through the Kalman filtering process.

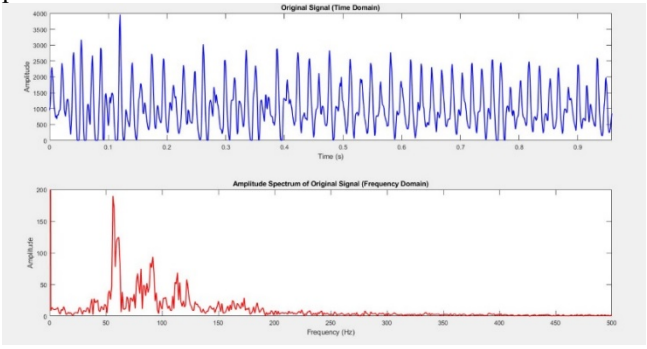

FIGURE 9. analysis PPG signal uses FFT

It can be seen in FIGURE 13 that there are ECG signal from the first and most recent data collection through a filtering process Kalman . And below it is plot results from FFT , got it seen from the FFT plot there is the frequency that has been suppressed by the filter. The frequency represented by the red graph shows at what point the Kalman filter is suppressed.

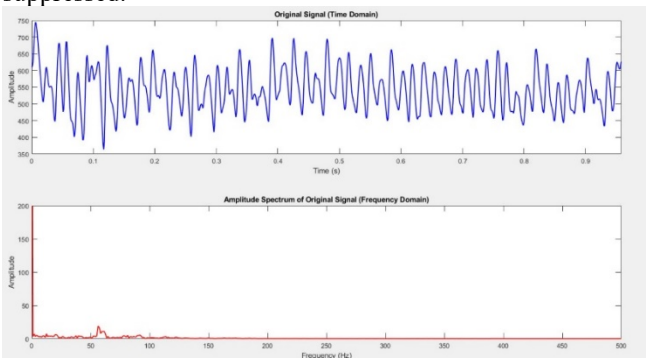

FIGURE 12. analysis PPG signal uses FFT

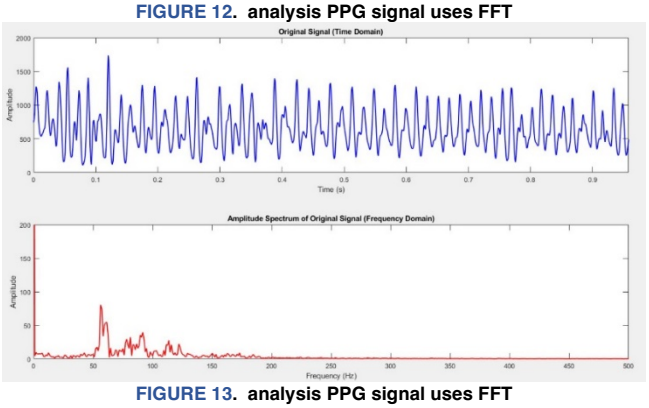

FIGURE 13. analysis PPG signal uses FFT

It can be seen in FIGURE 14 ECG signal from the first and most recent data collection through a filtering process Kalman . And below it is plot results from FFT , got it seen from the FFT plot there is the frequency that has been suppressed by the filter. The frequency represented by the red graph shows at what point the Kalman filter is suppressed.

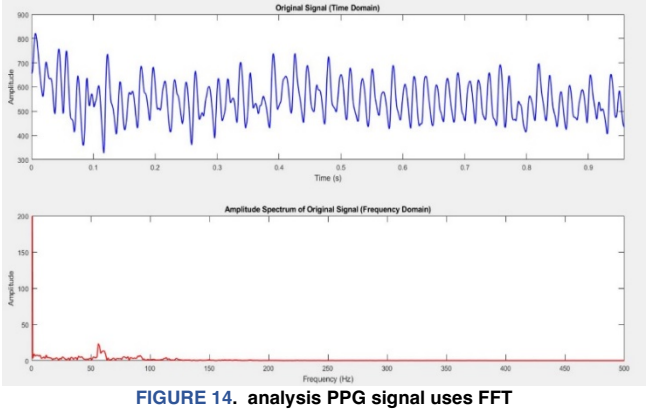

FIGURE 14. analysis PPG signal uses FFT

It can be seen in FIGURE 15 seen more clear How form signal already _ go through a filtering process butterworth and value FFT . On FFT plotting can is known difference in

time after do filtering and before do filtering and how much frequency that has been suppressed by the filter. In **FIGURE 15** it is plotting results in the application matlab can seen from picture results plotting from PPG signal before goes through the filtering process and after pass through the filtering process , at the time after go through a filtering process signal seen more small compared to with before carry out the filtering process.

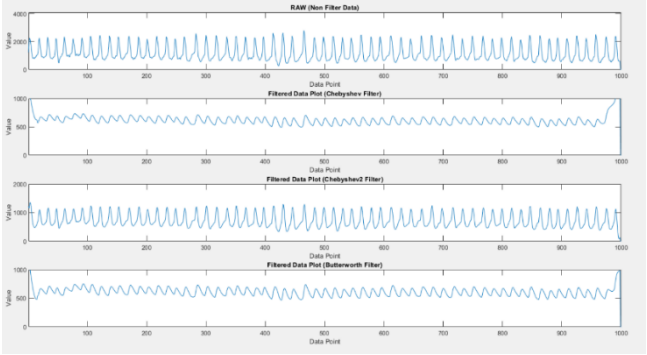

FIGURE 16. Plotting of the PPG signal during filter testing when making finger waving movements

In **FIGURE 16** you can see the ECG signal before being filtered which has gone through the FFT process in Matlab to determine the frequencies contained in the ECG signal. It can be seen in Figure 4.4 the results of the ECG and FFT signals. In the FFT plot there are frequencies in the ECG signal extract. There is a difference between signal1 and signal2, namely the difference in noise contained in the ECG signal which has not gone through the Kalman filtering process.

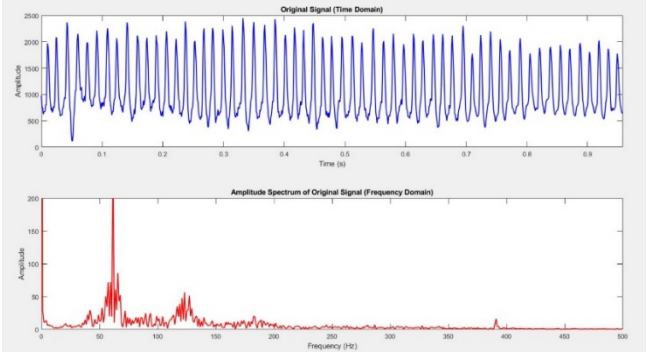

FIGURE 17 . analysis PPG signal uses FFT

It can be seen in **FIGURE 17** that there are ECG signal from the first and most recent data collection through a filtering process Kalman . And below it is plot results from FFT , got it seen from the FFT plot there is the frequency that has been suppressed by the filter. The frequency represented by the red graph shows at what point the Kalman filter is suppressed.

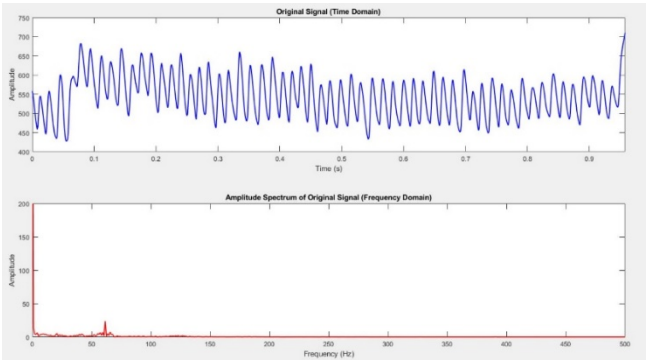

FIGURE 18. analysis PPG signal uses FFT

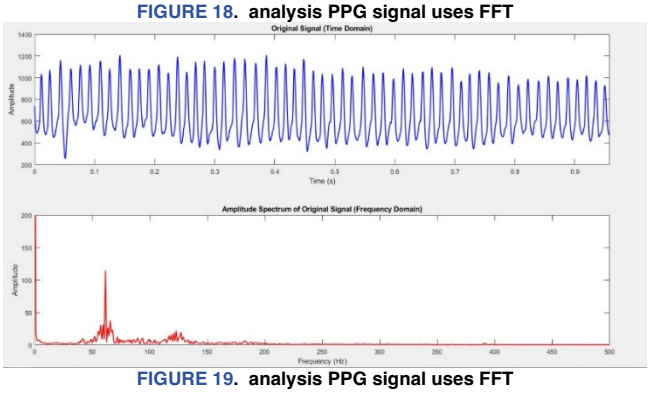

FIGURE 19. analysis PPG signal uses FFT

It can be seen in **FIGURE 18** ECG signal from the first and most recent data collection through a filtering process Kalman . And below it is plot results from FFT , got it seen from the FFT plot there is the frequency that has been suppressed by the filter. The frequency represented by the red graph shows at what point the Kalman filter is suppressed.

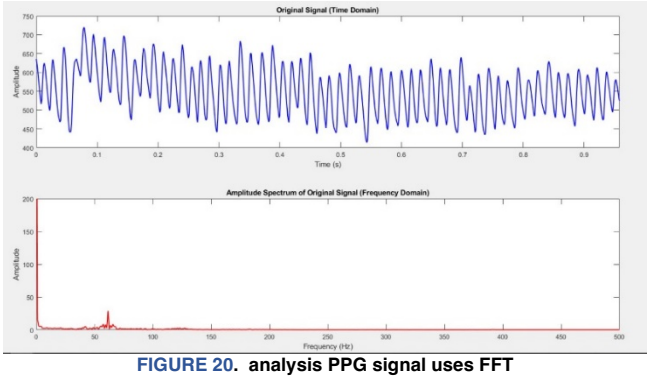

FIGURE 20. analysis PPG signal uses FFT

It can be seen in **FIGURE 20** seen more clear How form signal already _ go through a filtering process butterworth and value FFT . On FFT plotting can is known difference in time after do filtering and before do filtering and how much frequency that has been suppressed by the filter.

IV. DISCUSSION

After done testing about mechanism testing results reading module to PPG signals that have not gone through the filtering process and after go through a filtering process.

filter testing process uses application matlab , the signal has been through a filtering process will be exported in CSV form , so can FFT process is carried out For know existing frequencies _ in PPG signal . This process done For to three signal. That is, the signal is not yet there filtered and the signal is already filtered . So that can is known How many mark frequency that has been pressed.

PPG is method non-invasive way of measuring heart rate it works that is credit evaluate saturation oxygen with compare How many Lots light absorbed by blood. This PPG method is method simple measurements _ Because only need One point in the body patients [4].

Study previously about Subtraction artifact motion periodic in photoplethysmography has researched in a way extensive with use method decomposition signal . On research Wijshoff R, et al PPG method was developed with focuses on the extraction of physiological parameters the PPG signal has been damaged by MA. Then estimate coefficient through The least mean-squares (LMS) algorithm is next compare signal relative motion sensor to skin and movement body but method This No applied For detecting MA in heart rate [10]. In the research of Silverio A, et al about MA reduction in fingers hand use ray green PPG and EMG reduction artifact often use accelerometer as MA reference, will but movement micro like movement finger No can arrested in a way accurate in accelerometer and cover PPG spectrum so difficult For omitted [11]. Abdul Q. Javaid, et al do study for denoising the signal Seism cardiograph (SCG) uses Empirical Mode Decomposition (EMD) technique . The results show that method This can in a way significant raise SNR value of SCG during activity walk however, method This only focuses on SCG signal denoising in research this , researcher give input For apply method this is on PPG signal denoising [12].

Based on matter the author mean for do study form application of Infinite Impulse Response (IIR) filters and methods analysis statistics For reduces Motion Artifacts of the heart rate signal obtained from the PPG sensor so results monitoring can own accuracy above 90%. Another aim of this research is to determine the performance of the IIR filter to reduce MA. The IIR filter was chosen because it has a shorter computing time compared to wavelet-based filters and has the ability to produce a more precise response [13]. There are several shortcomings in the module that has been made, including that further research has not been carried out for use on other microcontrollers, further research needs to be carried out to use other signals, and finally the display on the module is still relatively small.

IV. CONCLUSION

This research was conducted to study and prove the use of Chebyshev, Chebyshev2, Butterworth filters to suppress noise when moving. When the hand is still it does not produce *motion artifacts* . However, when moving the finger 90 degrees, *a motion artifact occurs* at a frequency of 1.1Hz. After analyzed using PSD, differences signal between *raw* data and filtered visible in the amplitude of the *raw* data amounting to 41,630. Chebyshev filter 1 is effective in reduce *motion artifact* , produces amplitude 7.266. When _ hand waving , there is *motion artifact* at a frequency of 0.78Hz after done PSD analysis . Difference signal between *raw* data and filter results can be seen in the amplitude of the *raw* data amounting to 15,501. Chebyshev filter 1 was successful reducing motion artifacts, with amplitude to 2,231 .

There is a number of possible development _ developed in research This . To apply filters to the microcontroller. To test each filter for use in other signal applications. For use more view _ big like nextion For form more signal _ big

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