Technokes Journal
International: Rapid Review: Open Acces Journal Vol. 17, No. 4, December 2024, pp. 164-169 e-ISSN 2407-8964; p-ISSN 1907-790

RESEARCH PAPER OPEN ACCES

Manuscript received September 19, 2024; accepted October 10, 2024; date of publication December 25, 2024
Digital Object Identifier (DOI): https://doi.org/10.35882/teknokes.v17i4.2

How to cite: Helenora Maria Bernardina Toan, Endang Dian Setioningsih, and Sumber, "Improving the Performance of Holter ECG Monitor with Digital Filter Comparison Method for Motion Artifact Reduction, Jurnal Teknokes, Vol. 17, No. 4, December 2024, pp. 164-169.

Improving the Performance of Holter ECG Monitor with Digital Filter Comparison Method for Motion Artifact Reduction

Helenora Maria Bernardina Toan, Endang Dian Setioningsih, and Sumber

Department of Medical Electronics Technology, Poltekkes Kemenkes Surabaya, Surabaya, Indonesia

Corresponding author: Helenora (e-mail: helentoan4@gmail.com)

ABSTRACT A portable device that continually records heart activity, the Holter ECG monitor is prone to motion artefact interference, which lowers the quality of the ECG signal. By contrasting how well Infinite Impulse Response (IIR) and Finite Impulse Response (FIR) digital filters reduce motion artefacts using Butterworth and Window techniques at different orders, this study seeks to enhance Holter Monitor's performance. To assess the signal quality based on Signal-to-Noise Ratio (SNR), the Fast Fourier Transform (FFT) was used. With an average SNR of 10.3282 at order 8, the results demonstrated that FIR filters with higher orders (6 and 8) generated more reliable and consistent signals. high orders (6 and 8) produced more stable and consistent signals, with an average SNR of 10.3282 at order 8. On the other hand, with an average SNR of 12.0281 at order 2, the IIR filter performs best at low orders (2 and 4). However, at high orders, the IIR filter exhibits instability, leading to a considerable distortion of the signal. These findings demonstrate that both filters effectively reduce motion artefacts when compared to the minimum SNR criterion of 10 for ECG signal processing; nevertheless, the selection of the filter is contingent upon the particular requirements of the application. Better signal analysis for cardiovascular diagnosis is made possible by the use of this research, which increases the Holter Monitor's accuracy in identifying cardiac signals during patients' regular activities. Additionally, the method allows for effective data transfer via SD card without requiring patients to remove the device, which is convenient for them. The primary obstacle is the FIR filter's requirement for more processing power, which can be addressed through algorithm optimisation. It is anticipated that this research will promote the creation of portable cardiac monitoring devices that are more dependable and effective.

INDEX TERMS Holter Monitor, FIR, IIR, Motion Artifact, Digital Filter FIR & IIR, FFT, SNR

I. INTRODUCTION

The human heart is a vital organ that pumps oxygen-rich blood throughout the body. Impaired heart function, such as arrhythmia or other cardiovascular diseases, can lead to serious complications and even death. To help with early diagnosis, Holter Monitor is used as a non-invasive device capable of recording the patient's heart activity continuously for 24-48 hours or more. However, utilization of the Holter Monitor is often compromised by motion artifacts resulting from the patient's physical activities, such as walking, sitting or standing. These artifacts affect the quality of the electrocardiogram (ECG) signal, which may lead to data misinterpretation or the need for repetition of diagnostic procedures. In a clinical context, motion artifacts have significant implications, such as the risk of misdiagnosis of cardiac conditions, including atrial fibrillation, ventricular arrhythmias, and myocardial ischemia. Therefore, the development of methods to reduce motion artifacts is a top priority to improve the reliability of Holter Monitor data in support of cardiovascular diagnoses. Various previous studies have evaluated digital filtration methods to resolve ECG signal noise. Finite Impulse Response (FIR) filters are known for their linear phase stability, while Infinite Impulse Response (IIR) offers better computational efficiency. Previous research, such as by V. Vital Reddy et al. (2023), demonstrated the use of minimal order FIR and IIR filters with Window and Butterworth methods to improve ECG signal quality. Meanwhile, Xian An et al. (2020) compared FIR, IIR, and adaptive filters, concluding that adaptive filters are more effective for reducing noise in abnormal ECG signals. However, not many studies have evaluated the performance of FIR and IIR in depth under various physical activity conditions of patients of different orders, especially in the context of a portable Holter Monitor. In this study, we

Accredited by the Director General of Higher Education, Research, and Technology
Decree No: 10/C/C3/DT.05.00/2025, dated March 21, 2025
Journal homepage: http://teknokes.org/

focus on comparing FIR and IIR filters of various orders using Butterworth and Window methods to reduce motion artifacts in Holter Monitor. The analysis is performed using Fast Fourier Transform (FFT) to evaluate the frequency changes due to motion artifacts. This research aims to provide a practical solution for medical personnel in analyzing ECG signals with high accuracy without compromising the comfort of patients, who can still perform their daily activities while using the Holter Monitor. Furthermore, this research also has the potential to support the development of Internet of Things (IoT)-based cardiac monitoring technology, enabling real-time monitoring of heart conditions for telemedicine and remote care applications. With this, it is hoped that a more effective, efficient and accurate heart monitoring system can be created for the future.

II. MATERIALS AND METHODS

The research system is composed of four main components: the AD8232 sensor, Arduino Mega 2560 microcontroller, TFT LCD, and SD card module. The system block diagram, shown in Figure 1, illustrates the overall workflow—from signal acquisition to data storage. In this study, the respondents were human participants. Electrodes were attached to the body at standard lead points: Right Arm (RA), Left Arm (LA), Right Leg (RL), and Left Leg (LL). During the data collection process, each participant was instructed to perform two types of activities:

1. Sitting Still - The participant remained relaxed without any body movement.
2. Sitting to Standing – The participant performed a light movement from a sitting to a standing position to simulate motion artifacts.

Signal data were recorded for 10 seconds for each activity and stored in CSV format for further analysis.The image below illustrates the placement of the sensors on the body during the data collection process.

A.The Diagram Block

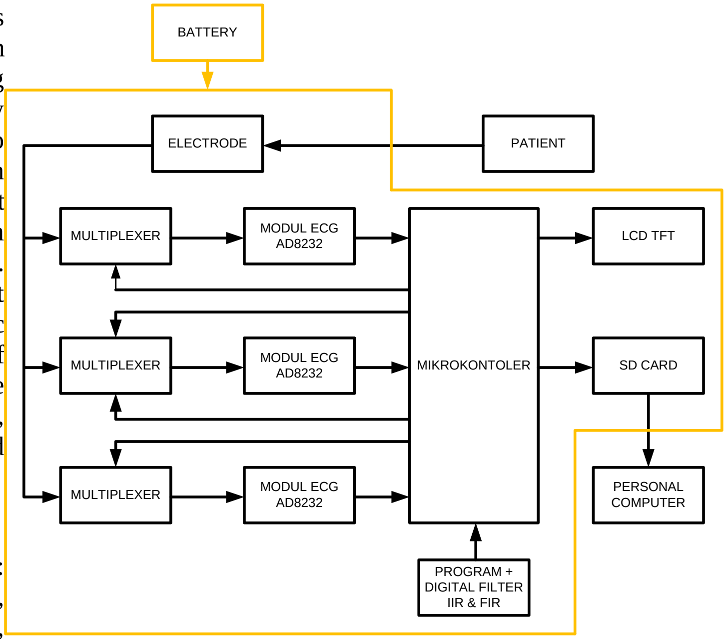


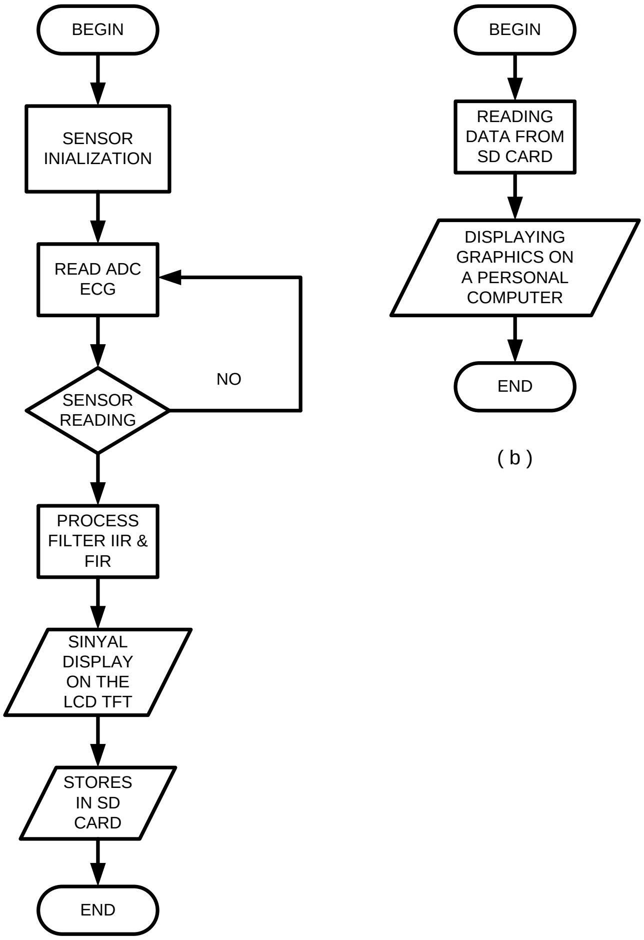
Figure 1. Diagram Block of the Measurement Module

Based on FIGURE 1 is Diagram Block from ECG Holter Device. The research system is built using four main components: the AD8232 sensor, Arduino Mega 2560 microcontroller, TFT LCD, and an SD Card module. The system architecture is illustrated in Figure 1, which shows the workflow from signal acquisition to data storage.

B. THE FLOWCHART

FIGURE 2 is shows the system flow diagram of the signal acquisition process involves Signal Amplification: The raw data from the sensor is first amplified using an operational amplifier (Op-Amp) circuit before being converted into a digital signal by the Arduino. The ECG signal will be filtering and processed using digital FIR and IIR filters of orders 2, 4, 6, and 8. These filters are designed in MATLAB to reduce noise and improve signal clarity. Fast Fourier Transform (FFT) is applied to analyze the dominant frequency components of the ECG signals and assess the performance of the filtering methods. And the filtered signals are stored on an SD card and simultaneously displayed in real-time on a TFT LCD screen.

Accredited by the Director General of Higher Education, Research, and Technology
Decree No: 10/C/C3/DT.05.00/2025, dated March 21, 2025
Journal homepage: http://teknokes.org/



(a) (b)

Figure 2. (a) Flowchart of tool workflow (b) Flowchart of data reading on sd card

C. DATA ANALYSIS

Data analysis was performed using descriptive statistics to calculate the average SNR value of each filter order. The calculation is done using the following equation:

$$SNR=10\cdot\log10\ (Pnoise\ /\ Psignal)$$

The SNR results were compared with the minimum standard of 10 for a clean ECG signal. All calculations were performed using MATLAB, and the results were used to determine the effectiveness of each filter in reducing motion artifacts.

III. RESULT

In this study, In this study, the Holter ECG Monitor device will record heart activity and detect motion artefact interference. The form of ECG Holter module is as follows: On this device in Figure 3 there is an ON / OFF button, TFT LCD which will display settings such as filter selection, also equipped with 4 electrode cables that will be attached to the patient.

Figure 3. ECG Monitoring Module Equipped with 4 Electrodes

This device in Figure 4 has several components that support the running of the system consisting of arduino mega pro mini, battery, AD8232 sensor and multiplexer.

Figure 4. Inside of the Module

The data collection method is carried out in a sitting and moving state with the following steps:

1. Open the Arduino application and serial monitor programme that has been designed.
2. Attach the electrodes to the patient's/respondent's body in accordance with the predetermined tapping points
3. Make sure the patient / respondent is sitting relaxed and not moving the body
4. Switch on the device by pressing the switch button and make sure the TFT is on
5. Set the selection settings that will be used
6. By executing the created serial read application, measurements are taken.
7. After measuring for 10 seconds, save the data by clicking file then save workspace as.
8. End the programme by pressing the cross on the serial read display.

Measurements are made to determine whether the filter can work to reduce motion artifact noise.

Table 1 Average Results of Measurements Using FIR Filters on Patients Taken a Total of 4 Times in a Si-to-stand Position

FIR respondent STANDING	Mean Orde 2	Mean Orde 4	Mean Orde 6	Mean Orde 8
1	10.1284	9.9568	12.0993	10.5146
2	10.5980	8.8014	8.7287	9.8307
3	9.7276	9.4138	9.0335	10.8279

Accredited by the Director General of Higher Education, Research, and Technology
Decree No: 10/C/C3/DT.05.00/2025, dated March 21, 2025
Journal homepage: http://teknokes.org/

4	10.4902	10.4411	9.0913	10.1395
Mean	10.2360	9.6533	9.7384	10.3282

From the results in Table 1, data collection was carried out using 4 respondents on ECG signals Lead I, II, III aVR, avF, and avL obtained results from the mean value in each order with the best performance seen at order 8 with an average SNR of 10.3282.

Table 2 Average Results of Measurements Using FIR Filters on Patients Taken a Total of 4 Times in a Sitting Position

Respondents FIR SITTING	Mean Orde 2	Mean Orde 4	Mean Orde 6	Mean Orde 8
1	9.9462	11.0838	8.4379	10.1284
2	9.6073	9.6338	9.1686	10.5980
3	10.4931	10.7578	9.4648	9.7276
4	9.8918	9.7717	10.2114	10.4902
Mean	9.9846	10.3117	9.3207	10.2360

From the results in Table 2, data collection was carried out using 4 respondents on ECG signals Lead I, II, III aVR, avF, and avL obtained results from the mean value in each order with the best performance seen at order 4 with an average SNR of 10.3117.

Table 3 Average Results of Measurements Using IIR Filters on Patients Taken a Total of 4 Times in a Si-to-stand Position

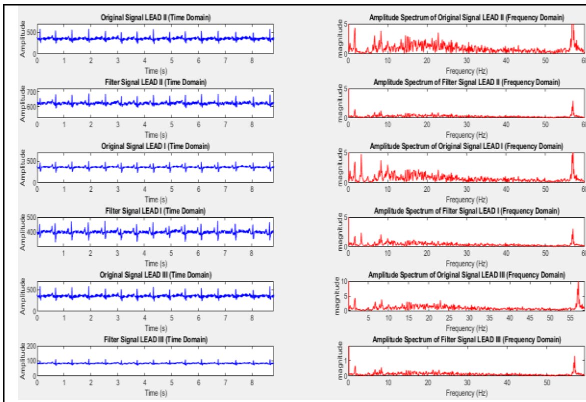
FIR respondent STANDING	Mean Orde 2	Mean Orde 4	Mean Orde 6	Mean Orde 8
1	9.5072	7.9759	7.9001	10.0320
2	9.8345	8.6405	8.3190	10.8525
3	9.6028	7.7010	8.9153	8.5339
4	10.5711	7.6653	8.3780	8.3005
Mean	9.8789	7.9957	8.3781	9.4297

From the results in Table 3, data collection was carried out using 4 respondents on ECG signals Lead I, II, III aVR, avF, and avL obtained results from the mean value in each order with the best performance seen in order 2 with an average SNR of 9.8789.

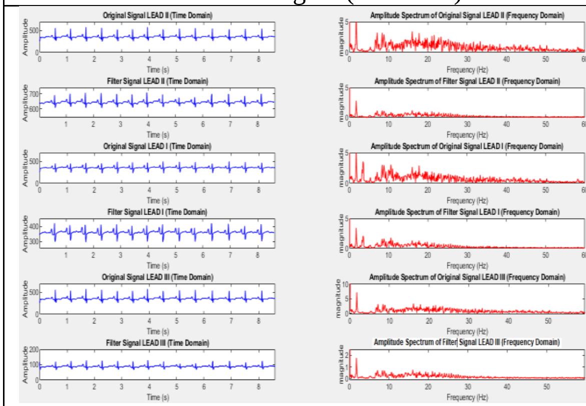
Table 4 Average Results of Measurements Using IIR Filters on Patients Taken a Total of 4 Times in a Sitting Position

Respondents IIR SITTING	Mean Orde 2	Mean Orde 4	Mean Orde 6	Mean Orde 8
1	12.5869	8.7762	8.3306	9.1547
2	11.9605	8.1783	9.0857	10.9180
3	11.8273	8.3745	9.3570	10.4914
4	12.7377	9.2606	8.4589	11.2853
Mean	12.0281	8.6474	8.8080	10.4623

From the results in Table 4, data collection was carried out using 4 respondents on ECG signals Lead I, II, III aVR, avF, and avL obtained results from the mean value in each order with the best performance seen in order 2 with an average SNR of 12.0281.



Pre-filtered signal (Sit-Stand)



Signal after 4th order FIR filter

From the analysis results, the average Signal-to-Noise Ratio (SNR) value produced by the FIR filter at high order (8th order) is 10.3282, while the IIR filter at low order (2nd order) achieves an average SNR of 12.0281. However, no statistical test was conducted to identify significant differences between the two methods. Thus, although an increase in SNR indicates an improvement in signal quality, its impact on clinical diagnosis still needs to be further validated. FIR filters provide better signal stability at high orders, but have greater computational complexity as they require more memory and processing time than IIR filters. On the other hand, IIR filters are more efficient in the use of computational resources, especially at low orders, but produce signals that tend to be unstable at high orders, with potential signal distortion. More detailed analysis is needed to assess the cost-benefit ratio of the two approaches.

The signal graphs before and after the filtration process show significant artifact reduction in the time domain. However, additional analysis with the frequency spectrum using Fast Fourier Transform (FFT) shows that FIR filters are able to reduce noise at high frequencies more effectively, while IIR filters provide the best results for noise at low frequencies. This difference makes it important to select a filter based on the specific needs of the application. Compared to the work

Accredited by the Director General of Higher Education, Research, and Technology
Decree No: 10/C/C3/DT.05.00/2025, dated March 21, 2025
Journal homepage: http://teknokes.org/

of Vital Reddy et al. who concluded the superiority of FIR filter for ECG signals, the results of this study are in line with the performance of FIR at high order which is more stable than IIR. However, the analysis shows that IIR at low orders provides competitive and more resource-efficient results, supporting the findings of Thion Ming Chieng et al. who stated that IIR filters are effective in preserving ECG signal morphology. The measurement results showed significant signal variations during the filtration process, especially in the case of motion (sitting-standing) data collection. Anomalies in the form of unexpected noise at certain frequencies (outliers) were detected, but not specifically analyzed in this study. The addition of data validation steps or outlier handling methods, such as signal interpolation or smoothing, is recommended to improve the accuracy of the results.

V. DISCUSSION

This research shows that FIR filters excel in providing signal stability at high orders, while IIR filters are more computationally efficient at low orders. The FIR filter is more stable at high orders (6 and 8) compared to the IIR filter, with a fairly good average SNR for ECG signals. In particular, at order 8, the FIR filter gives the best results with an average SNR of about 10.3282 in the sitting or standing position. The IIR filter, on the other hand, is better at low orders such as order 2, with an average SNR of 12.0281, but starts to show instability and distortion when used at higher orders. This is due to its limitation to resist high frequency noises, which causes the signal to become unstable in certain places. The IIR filter is effective at low orders, reducing noise without significantly altering the original signal, while the FIR filter provides more uniform and stable average SNR results at orders 4-8. While the IIR filter is more prone to distortion, especially at high orders, which impacts the reliability of the resulting signal, when the patient is standing, the FIR filter can still maintain stability at high orders. Holter leads are original data that contain many noises, such as electrical interference, movement noises, and bioelectric artifacts. To obtain data that can be interpreted correctly, special processing is required. The results of FIR and IIR filters are helpful for Holter signals; FIR is better for applications that require clear signals without distortion, and IIR is better for applications that require fast response at low orders, but may cause distortion at high orders. However, the limitations of each filter, such as high computational intensity in FIR and low frequency distortion in IIR, need to be evaluated more critically. Although the results show an improvement in ECG signal quality with noise reduction through FFT analysis, integration of the results with existing literature, such as the findings by Thion Ming Chieng and Sancho Harmalita Liu, may strengthen the argument and clinical relevance. In addition, the implications of SNR improvement on clinical diagnosis accuracy have not been thoroughly explored. This study has not provided recommendations for filter performance optimization, such as the application of hybrid filters or real-time adaptation, which could expand its scope of application. The scalability of the findings also needs to be reviewed, especially in the development of wearable devices or remote monitoring in various clinical and non-clinical environments. This is important to ensure that the research results can be widely and effectively implemented in the real world. such as applications in telemedicine to support remote diagnosis, implementation of AI and machine learning.

V. CONCLUSION

The use of FIR and IIR digital filters to reduce motion artifacts in ECG signals recorded by Holter Monitor. This study shows that high order FIR filters (6 and 8) provide more stable and clean ECG signals without distortion, with an average SNR of 10.3282 at order 8. In contrast, the IIR filter is optimal at low orders (2 and 4) with an average SNR of 12.0281 at order 2, but suffers from distortion at high orders. The implementation of a TFT LCD display supports real-time monitoring, while data storage on an SD Card enables advanced analysis. These results prove that FIR filters are more suitable for applications requiring high signal stability, while a combination of FIR and IIR filters could potentially be a solution for more efficient motion artifact reduction. The use of higher order filters (above 6) is recommended to optimize motion artifact reduction, especially in the case of FIR filters. In addition, a combination of FIR and IIR filters could be a potential solution to maintain a balance between signal stability and processing time efficiency. Further research is needed to address technical challenges, such as delay in higher-order filters, to support the development of more reliable portable cardiac monitoring technology.

REFERENCES

[1] M. Hutasuhut and A. H. Nasyuha, "Analisis Aritmia (Gangguan Irama Jantung) Menerapkan Metode Certainty Factor," *J. MEDIA Inform. BUDIDARMA*, vol. 5, pp. 1386–1393, 2021, doi: 10.30865/mib.v5i4.3289.

[2] D. Trisuciyani, T. Hamzah, and E. D. S, "Implementasi Filter Digital Untuk Mengurangi Motion Artefak Pada Alat Holter," pp. 1–7, 2020.

[3] A. Kalra and A. Lowe, "Wireless Holter monitoring system with a dual-core processor Wireless Holter monitoring system with a dual-core processor," *IOP Conf. Ser. Mater. Sci. Eng.*, 2020, doi: 10.1088/1757-899X/919/2/022040.

[4] V. V. Reddy, M. Neelaveni, M. Sandeep, S. K. Ahmad, and P. V. Krishna, "COMPARISON OF FIR AND IIR FILTERS USING ECG SIGNAL WITH DIFFERENT SAMPLING FREQUENCIES," no. 04, pp. 2576–2581, 2023, doi: https://www.doi.org/10.56726/IRJMETS35977.

[5] X. An and G. K. Stylios, "Comparison of Motion Artefact Reduction Methods and the Implementation of Adaptive Motion Artefact Reduction in Wearable Electrocardiogram Monitoring," 2020.

[6] S. H. Liu and N. H. Shabrina, "Comparison of FIR and IIR Filters for Audio Signal Noise Reduction," vol. 15, no. 1, 2023.

[7] C. Saxena, A. Sharma, R. Srivastav, and H. K. Gupta, "Denoising of Ecg Signals Using Fir & Iir Filter : a Performance Analysis," vol. 7, pp. 1–5, 2018.

Accredited by the Director General of Higher Education, Research, and Technology
Decree No: 10/C/C3/DT.05.00/2025, dated March 21, 2025
Journal homepage: http://teknokes.org/

[8] T. M. Chieng, Y. W. Hau, and Z. Omar, “The Study and Comparison between Various Digital Filters for ECG De-noising,” *2018 IEEE-EMBS Conf. Biomed. Eng. Sci.*, pp. 226–232, 2018.

[9] D. Sanders, L. E. O. Ungar, M. A. Eskander, and A. H. Seto, “Ambulatory ECG monitoring in the age of smartphones,” pp. 483–493, doi: 10.3949/ccjm.86a.18123.

[10] G. Aditya, M. Oka, A. Pudji, M. Ridha, and E. Yulianto, “Design of Vital Sign Monitor with ECG , BPM , and Respiration Rate Parameters,” *ndonesian J. Electron. Electromed. Med. Informatics*, vol. 3, no. 1, pp. 34–38, 2021, doi: 10.35882/ijeeemi.v3i1.6.

[11] H. Kim, S. Member, R. F. Yazicioglu, and P. Merken, “ECG Signal Compression and Classification Algorithm With Quad Level Vector for ECG Holter System,” *IEEE Trans. Inf. Technol. Biomed.*, vol. 4, no. January, 2010, doi: 10.1109/TITB.2009.2031638.

[12] I. Fahruzi, “Mengurangi Pengaruh Noise Baseline Wander pada Sinyal Electrocardiogram (ECG),” *J. Integr. Batam State Polytech.*, vol. 5, no. Engineering, pp. 1–5, 2013.

[13] D. S. Warner and M. A. Warner, “Equipment-related Electrocardiographic Artifacts,” no. 1, pp. 138–148, 2008.

[14] A. R. Pérez-riera, R. Barbosa-barros, R. D. Luiz, and C. De Abreu, “Main artifacts in electrocardiography,” no. July, pp. 2–9, 2017, doi: 10.1111/anec.12494.

[15] S. P. D. Sriyanto, “Pengaruh Penggunaan Filter Butterworth pada Penentuan Waktu Tiba Gelombang P,” *JST (Jurnal Sains dan Teknol.*, vol. 7, no. 2, pp. 168–177, 2018, doi: 10.23887/jstundiksha.v7i2.13013.

[16] T. S. Sollu, Alamsyah, and M. Bachtiar, “Sistem Pemantauan Sinyal Detak Jantung Pasien Menggunakan Protokol Zigbee Dan Arduino,” no. September 2017, 2020, doi: 10.33633/tc.v16i4.1528.

[17] M. Majid, “Implementasi arduino mega 2560 untuk kontrol miniatur elevator barang otomatis,” 2016.

[18] F. A. Perdana, “Baterai lithium,” *J. Pendidik. IPA*, vol. 9, no. 2, pp. 103–109, 2020, doi: 10.20961/inkuiri.v9i2.50082.

[19] M. Hilman, “IMAGE VIEWER BERBASIS ARDUINO,” *J. MOSFET*, vol. 1, no. 2, pp. 5–8, 2021.

[20] B. Cahyono, “PENGGUNAAN SOFTWARE MATRIX LABORATORY (MATLAB) DALAM PEMBELAJARAN ALJABAR LINIER,” *PHENOMENON*, vol. 1, pp. 45–62, 2013.

[21] Atina, “Aplikasi Matlab pada Teknologi Pencitraan Medis,” *J. Penelit. Fis. dan Ter.*, vol. 1, no. 1, pp. 28–34, 2019, doi: 10.31851/jupiter.v1i1.3123.