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Analysis of the Effectiveness of Using Digital Filters in Electronic Stethoscopes

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ABSTRACT The heart sound produced in some cases of the disease shows a specific pattern. This study aimed to design an electronic stethoscope for cardiac auscultation using a digital filter to improve accuracy. This study's contribution is showing certain patterns that can be diagnosed in the sound signal. So that the pattern can be known when there is a heart disease disorder, an electronic stethoscope will be made for auscultation of the next display, making it easier for users to diagnose heart disease. The heart sound is obtained from the heart's mechanical activity, which is tapped by a condenser mic. The heart sound will be processed in a pre-amp circuit, then the filters used are high pass filters and low pass filters with a bandpass filter of 20-95 Hz. The output of the filter circuit will enter the summing amplifier and power amplifier for the speaker. For the digital signal processing, then the analog signal will be processed by the microcontroller, Arduino Mega 2560. In this study, two types of the filter were evaluated, namely analog filter (Butterworth) and digital filter (infinite impulse response (IIR)). The IIR was embedded in the Arduino program. The comparison between the analog and digital filters showed that the digital filter has higher performance (20.43±1.78 dB). The results of the research that has been done can be implemented using a system that really supports the needs.

INDEX TERMS Stethoscope, Low Pass Filter, High Pass Filter, Speaker.

I. INTRODUCTION

Technological progress is something that we cannot avoid in this life because technological progress will run in accordance with the progress of science. Every innovation is created to provide positive benefits for human life. Provides many conveniences and a new way of doing human activities[1][2]. Especially in the technology field, society has enjoyed many benefits brought by the innovations that have been produced. The technological revolution in the health sector that has been achieved to date is a significant feature of modern life[3]. However, the power of technology must be used carefully and responsibly to ensure that we apply it efficiently and humanely. Appropriate use of health technology involves mastery of science, engineering or machine tools and concepts and knowing economic, ethical, and moral issues [4]. A stethoscope is basically an acoustic medical instrument used to examine sounds in the body. One of them is hearing the heartbeat's sound and detecting abnormalities. The stethoscope was invented in France in 1816 by a man named René-Théophile-Hyacinthe. Earpieces, Tubing or Tube, Diaphragm, and Bell. Auscultation is a technique or method that is most often used by medical personnel in the initial examination of patients[5]. One way is to use a tool called a stethoscope. A stethoscope is a simple acoustic medical instrument that is used to diagnose sounds in the human body. Medical personnel often use this acoustic stethoscope to examine heart sounds. One sound that can be detected is the sound associated with the heart's pumping activity. Voices claim indication of heart rate and heart rhythm. The sound is also useful for providing information about the effectiveness of the pumping activity of the heart and heart valves. Until now, the clinically used instrument for detecting heart sounds is the acoustic stethoscope[6]. The heart is the center of internal blood circulation. The human body has a very vital role. Without a heart, humans will not be able to live, because the organs in the body will lack oxygen and die. A healthy heart is absolutely necessary for a person. Without a healthy heart, a person will lose their quality of life. Knowing the rhythm of the heartbeat is one way to maintain a healthy heart. A heart that works too fast will disrupt the balance of the body and will also have the same result if the heart works too slowly[7]. One way to find out the patient's condition is to listen to sounds from inside the human body, namely through an instrument called a stethoscope. The process of examining the sound of respiration or heartbeat is called auscultation. Problems that occur in cardiac auscultation using a conventional stethoscope are environmental noise, ear sensitivity, low frequency and amplitude, and relatively similar sound patterns. The results of hearing sound are also very subjective so everyone can interpret the results differently[8].

Previous research has been made by Carlos Aguilera-Astudillo et al. to develop a 3D printing stethoscope that is connected to a Smartphone[9]. The study reads data through a smartphone and displays a signal to a smartphone. The weakness of this tool is that there is still a cable connected from the smartphone to the system. Filter, which functions to pass the desired signal frequency and hold unwanted signal frequencies, in the signal extraction process, the filter used can use an analog filter or a digital filter. The analog filter has a weakness; namely, there is still a lot of noise during the process of filtering the respiration rate signal from the ECG signal, while the digital filter produces less noise compared to the analog filter [10][11]. This digital filter is better in using the process of decreasing the respiration rate signal than ECG, and also the level of accuracy and precision of the digital filter is more accurate and precise[12][13]. In 2017, Donald L. Hall et al. made a digital stethoscope that was designed to be reconstructed from a mathematical model accompanied by the physical equipment used. After the systematic exploration of mathematical principles is completed, the working performance of the instrument is shown, followed by the derivation and implementation of the step-size variable least-mean-squares adaptive noise canceling algorithm[14][15].

In 2017, Jatmiko and Burhanudin made a digital stethoscope with signal-processing wavelet transformation. This research has designed and developed a digital stethoscope with modifications from an ordinary stethoscope that can produce heart sounds through audio and graphics. The results can be stored in computer memory with the identification of heart conditions. The advantages of this research are that the production is very cheap, portable, produces audio and graphic data, and can store data and identify the patient's heart condition 83.3%, mitral stenosis with 75% accuracy and the lowest for a normal heart with 70% accuracy[16]. In (2018) Fardhon Danang Prakoso has made a tool entitled Electronic Stethoscope for Wireless-Based Heart and Lung Auscultation [2][17]. The study reads heart sound signal data using a computer, so that when operating the device, it still requires a computer. The weakness of the tool in using a PC is that when conducting an examination by displaying a heart sound signal, a PC must be available.

In the Year (2019) Muhammad EH Chowdhury et al has made real-time digital stethoscope to monitor the heart disease [18]. The study reads heart sound signal data using a PC, so that when operating the device, it still requires a PC. The weakness of the tool in using a PC is that when examining by displaying a heart sound signal, a PC must be available. In the Year (2019) Gadang Hendra Prabowo. has made a tool entitled Portable Electronic Stethoscope. The study displays the signal and BPM using TFT. The weakness of this tool is that in displaying the signal it still uses TFT[19][20]. Based on some of the references above and there are still shortcomings in the development of the tool, the author will create a device entitled analysis of the effectiveness of using digital filters in electronic stethoscopes. The author wants to develop from the technology side to make

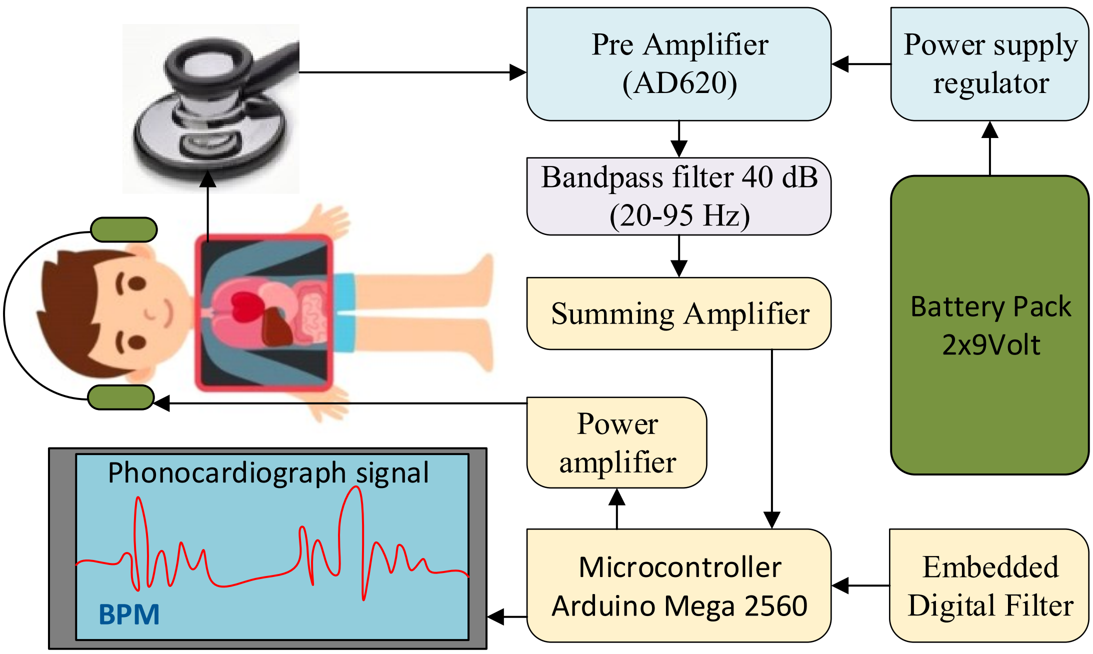

FIGURE 1. Block diagram of sound signal processing from the heart and processing of analog and digital filters to display on the LCD Nextion

it easier for users so that the examination can be monitored in real time by displaying signals and BPM values through the android screen, making diagnosing it easier.

This article has the following structure, in Section 1 (Introduction) which contains the background of the research. Then Section II (Materials and Method) explains the materials used in the research, data collection, and procedures used. In Section III (Result) contains the results and data analysis of the research that has been done. Section IV (Discussion) contains sections that need to be discussed regarding the findings in the research conducted. For Section V (Conclusion) contains the conclusions of the research that has been done and suggestions for further research.

II. MATERIALS AND METHODS

This research was conducted as experimental research. The author intends to conduct further research on the effectiveness of the use of digital filters to be used in electronic stethoscopes. Materials and methods will be explained in the following sections. In the experimental setting, this study used 8 normal people as respondents. Each respondent will be tapped heart sounds with several different frequencies. After going through the tapping process, the signal will be processed with a digital filter and displayed to the PC display and the signal that has been converted into a heart sound will be transmitted to a Bluetooth headset. This study uses a condenser microphone to capture heart sounds. For voice signal processing digital filters are used. This study also uses Bluetooth headset that functions to receive heart signals that have been processed in the form of sound. For this reason, this research also uses a Bluetooth module. In this study, after the device was completed, the researchers carried out the process of tapping heart sounds. Tests carried out at 8 respondents who have gone through the sound recording process. In the testing process, each respondent will be wired 2 times.

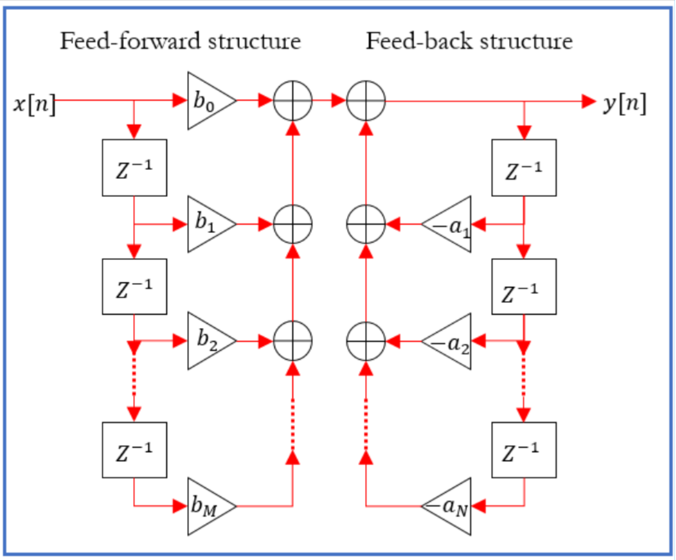

FIGURE 2. Infinite Impulse Response (IIR) structure

In this research, the digital filter used is the infinite impulse response (IIR) type with the order used is order 4. The selection of IIR as a digital filter in voice signal processing, this is because IIR is able to reduce unwanted signals with a minimal number of orders. The IIR filter is composed of two structures, namely feed forward and feed back. The signal to be processed x[n] enters the feed-forward structure through the process of b0, b1, b2, bM and delay (Z-1). All signal multiplication outputs against the coefficient bx are accumulated in one summing point which is then forwarded to the feed-back structure y[n]. The IIR type digital filter equation can be written according to Eq. (1).

$$y[n] = b_0 x[n] + b_1 x[n-1] + b_2 x[n-2] + b_3 x[n-3] + b_4 x[n-4] \\ - a_1 y[n-1] - a_2 y[n-2] - a_3 y[n-3] - a_4 y[n-4] \tag{1}$$

Where x[n] is the digital signal from analog to digital converter, b0, b1, b2, b3, b4 are the feed forward coefficient. y[n] is the processed signal in the feed-back structure. The a1, a2, a3, a4 are the feed back structure coefficient.

The proposed method performance was measured using signal power as shown ini Eq. (2).

$$P = \frac{1}{N} \sum_{i=1}^{N} | x_i |^2 \tag{2}$$

where the N indicated number of discrete data, and xi indicate the signal. Moreover, the effectiveness of the digital and analog performance was measured using Eq. (3), the signal to noise ratio SNR(dB):

$$SNR(dB) = 10 \log_{10} \frac{P_s}{P_n} \tag{2}$$

where Ps shows the signal power and Pn indicate the noise power.

The heart sound signal measured using a condenser mic is recorded using an analog to digital converter on the microcontroller to obtain digital data. The sound signal is buffered in the microcontroller memory and then processed for digital filter purposes using the IIR algorithm as shown in FIGURE 3.

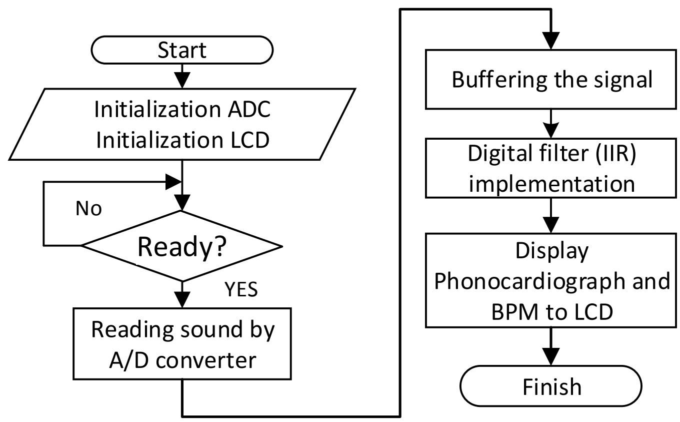

FIGURE 3. Flowchart process measurement sound detection until processing data

A. DATA COLLECTION

In this study, researchers used a stethoscope with a condenser mic as the unit tested for measurements on a digital filter. This research utilizes heart sound signals as research materials, Arduino components as microcontrollers. The results are displayed in the form of a graph on the Nextion TFT LCD. The heart sounds or phonocardiography will be captured by a stethoscope through a condenser mic. The condenser mic (on the stethoscope) converts sound into an electrical signal which will be amplified through a pre-amplfier circuit with an adjusted gain value. The output of the pre-amplifier goes into the band pass filter circuit so that it can filter out the sound frequency needed then the signal enters the microcontroller to be processed. The signal are then displayed through Nextion in the form of analog and digital filters.

III. RESULT

In this study, an electric stethoscope was tested to determine the results of the signal emitted. The following, FIGURE 3 shows the proposed design of the heart sound detection based on digital filter. Design of electronic stethoscope device module for digital stethoscope with Nextion display. This tool has undergone the process of taking data from the circuit using an oscilloscope as a measuring instrument. The results showed that the analyzer module of the stethoscope device worked well and could display graphics on the TFT LCD screen, the condenser mic used was able to capture heart sound signals clearly.

FIGURE 4. Analog filter Circuit for sound detection and processing circuit for processing data

A. PERFORMANCE MEASUREMENT AND TESTING RESULTS

This Electronic Stethoscope module is equipped with LPF and HPF filters to be able to capture human heart signals, so that the resulting data can not only be seen through the TFT LCD. The following are the measurement results on HPF and LPF filter measurements. FIGURE 4 explains the measurement results on a digital oscilloscope on the signal output from the condenser mic, the amplitude obtained is 7.29 Vpp output from the Initial Amplifier (Pre-Amp) when detecting auscultation of heart sounds which has the first amplification of 20 times.

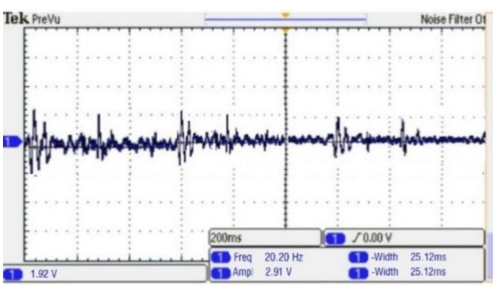

FIGURE 5. Measurement of heart sound signal output from analog filter

FIGURE 5 explaining the results of the amplifier output from the Pre-Amp circuit, the amplitude obtained is 1.92 Vpp the output signal after passing through the high pass filter circuit is to pass high frequencies above the cut off frequency according to the calculation (54.908 Hz) and suppress frequencies below the cut off. The heart sound which is processed using analog filter was shown in FIGURE 6. FIGURE 6(a) is the analog high pass filter respons. The analog filter was tested by using signal generator from 0 to 200 Hz. Moreover, the analog low pass filter was tested using the same range. The low pass filter respons was shown in the FIGURE 6(b).

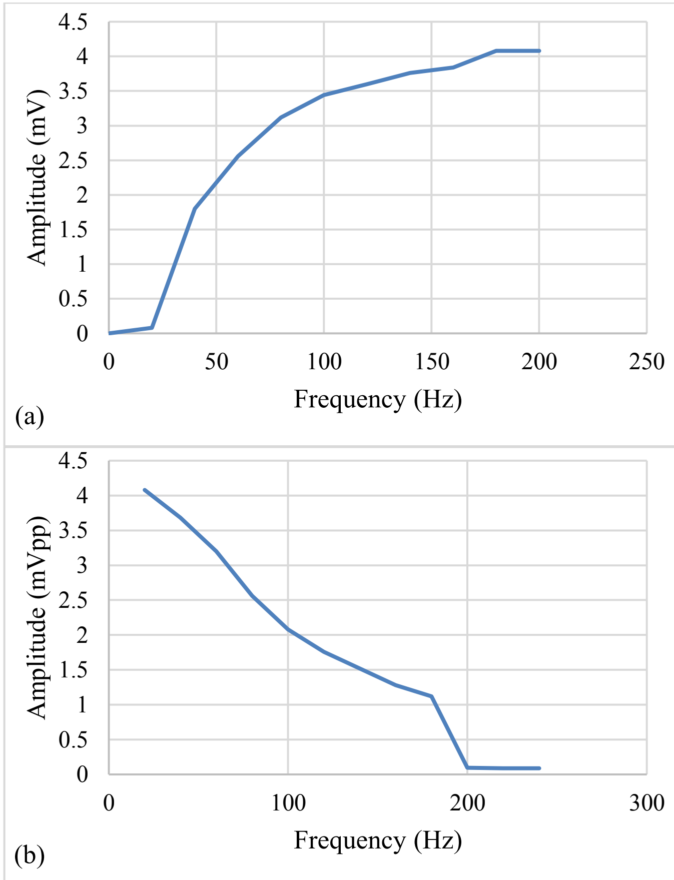

FIGURE 6. The analog filter performance (a) high pass filter, (b) low pass filter.

TABLE 1
SNR in dB comparison between the analog and digital filter (infinite impulse response). The result was obtained for 10 times repeat measurement.

Orde	SNR (dB)	
	Analog filter	Digital Filter (IIR)
2	10.2±1.3	15.78±0.98
4	12.5±2.5	20.43±1.78

The TABLE 1 shows the performance (SNR in dB) comparison between the analog and digital filter for two difference filter orde. TABLE 1 indicates that the digital filter (IIR) outperformed compared to the analog filter. The SNR of analog filter and digital filter was 10.2±1.3 and 15.78±0.98, respectively for filter orde 2. Moreover, when the filter orde was increased the performance of both filter (analog and digital) was also increased.

FIGURE 6 explaining the results of measurements on a digital oscilloscope on the output signal of the HPF filter circuit, the amplitude obtained is 1.92 Vpp. The output signal after passing through the high pass filter circuit is to pass high frequencies above the cut off frequency according to the calculation, namely (54.908 Hz) and suppress the frequency at below the cut-off.

B. MEASUREMENT RESULTS ON RESPONDENT

The FIGURE 7 explain the output on the analog filter before being inputted into the Arduino program to perform digital filter signal processing. The output in patient 1 male gets a frequency of 10.42KHz with an amplitude of 2.92Vpp. In the Data FFT output digital filter, the author gets the results from the stethoscope output where data is retrieved through the Ministry of Environment software then processed into FFT which serves to find the dominant frequency of the PCG pre-amp circuit.

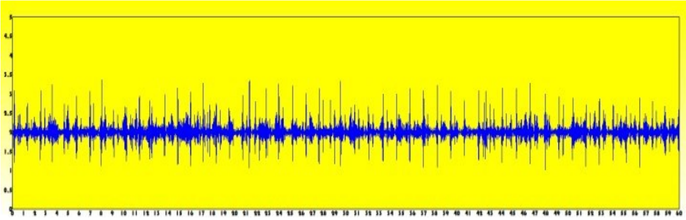

FIGURE 7. Output measurement of digital filter.

IV. DISCUSSION

For the electric stethoscope concept, a condenser mic that has been integrated with the stethoscope will intercept heart sounds. Later the heart sounds that have been tapped will be processed with a digital filter. After that, the processed signal will be displayed on the PC screen. In addition, users can also choose the signal to be sent. After that the signal will be converted into heart sounds and sent to the Bluetooth headset. PC displays and Bluetooth headsets will be monitored directly by the user or the doctor conducting the examination.

Based on TABLE 1 it can be seen that researchers took data with several frequencies. The input used is 4.4 volts. It can be concluded that the data collection on the High Pass Filter circuit with a cutoff frequency of 20 Hz, the higher the frequency, the greater the resulting output. Likewise with table 2 of the low pass filter with a cutoff frequency of 100 Hz, it can be seen that the lower the frequency, the greater the output. This is because the High Pass Filter passes signals with frequencies above the cutoff frequency. while the Low Pass Filter passes signals with frequencies below the cutoff frequency. The advantage of this tool is that researchers use condenser mics. The audio signal produced by a condenser microphone is stronger than that of a dynamic microphone. Since they tend to be more sensitive and responsive than dynamic microphones, condenser microphones are better suited for capturing small details in sound. Meanwhile, the drawback of this tool is that researchers use a Bluetooth module to transmit heart sounds to a headset. The use of Bluetooth has a weakness, namely the data transfer speed is not fixed and tends to be low. The initial amplifier circuit module (Pre-Amp) uses the TL084 Op-Amp, where the IC has 4 Op-Amps in it. For the input voltage on this Op-Amp using +5 and -5 VDC, it is expected that the Op-Amp can work properly. Reinforcement occurs 20 times. Comparison of the resistor values above to determine the desired multiplier gain. The -40dB active filter circuit module requires a passive HPF filter circuit with 54 Hz Cut Off and an LPF active filter circuit with 95 Hz Cut off. And we get the first filter circuit in the form of a -40dB HPF filter and the second filter in the form of a -40dB LPF filter circuit. The Adder circuit is used to set the reference signal that is processed by the minimum system. Uses a variable resistor to adjust the voltage divider[21][21] to the sound signal that appears on the Nextion screen.

V. CONCLUSION

Overall, this research can be concluded that the addition of a condenser mic on this tool is very helpful for doctors in analyzing the patient's condition. When compared to conventional stethoscopes, stethoscopes. This electric can catch the sound more clearly. That matter because the author uses a digital filter with a range of the cut-off frequency is between 20 – 106.15 Hz[13]. Can be seen also on High Pass Filter data table that the frequency is below the cutoff has a small output as well as table data Low Pass Filter that the frequency above the cutoff has an output that is small[22][23][24]. In this study, the researcher used an input of 4.4 volts[25], Cardiac signals that are captured and processed by the device This electric stethoscope is successfully displayed on the PC display and sending signals to the Bluetooth headset and the user can select the signal to be transmitted to the Bluetooth headset[27]. The advantage of this tool is that the heart sound is clearly captured with the help of a condenser mic so that doctors can more easily analyze the patient's health condition and make it easier to use this tool. In this study[28], the tool can produce sound that can analyze the patient's health condition[29]. Thus this tool can be used to analyze the condition of the patient's heart health[30][31].

From the system performance in this circuit[32], when tapping the condenser mic sensor there is an output signal in the form of S1 and S2 signals from the heartbeat sound signal with an indication of lub and dub sounds on the speakers used, the performance of the circuit is both the Pre-Amp circuit, HPF Filter and The LPF filter that has been made, the output in the circuit gets the form of S1 and S2 signals, there is noise caused by sounds from the surrounding environment[33]. The system performance on the Nextion display will help monitor the patient's heart rate signal so that the Nextion display will work optimally by using the input power supply that has been set at 5 V and the Baud Rate usage on the Nextion of 9600[1].

REFERENCE

[1] N. Katyal, M. Mathrani, and M. Kumar Hota, "Preparation of a Digital Stethoscope," *2018 IEEE Int. Conf. Syst. Comput. Autom. Networking, ICSCA 2018*, 2018, doi: 10.1109/ICSCAN.2018.8541261.

[2] Y. Nanda Khurniawan, T. Hamzah, and D. Titisari, "Stetoskop Elektronik Sederhana untuk Auskultasi Jantung dan Paru," *Semin. Tugas Akhir Juni*, 2017.

[3] K. Patil, "Design of Wireless Electronic Stethoscope Based on Zigbee," *Int. J. Distrib. Parallel Syst.*, vol. 3, no. 1, pp. 351–359, 2012, doi: 10.5121/ijdps.2012.3130.

[4] L. P. W. Frank and M. Q. H. Meng, “A low cost bluetooth powered wearable digital stethoscope for cardiac murmur,” *2016 IEEE Int. Conf. Inf. Autom. IEEE ICIA 2016*, no. August, pp. 1179–1182, 2017, doi: 10.1109/ICInfA.2016.7831998.

[5] M. N. Türker *et al.*, “Smart Stethoscope,” *TIPTEKNO 2020 - Tip Teknol. Kongresi - 2020 Med. Technol. Congr. TIPTEKNO 2020*, 2020, doi: 10.1109/TIPTEKNO50054.2020.9299229.

[6] S. Swarup and A. N. Makaryus, “Digital stethoscope: Technology update,” *Med. Devices Evid. Res.*, vol. 11, pp. 29–36, 2018, doi: 10.2147/MDER.S135882.

[7] H. Wang, J. Chen, Y. Hu, Z. Jiang, and C. Samjin, “Heart sound measurement and analysis system with digital stethoscope,” *Proc. 2009 2nd Int. Conf. Biomed. Eng. Informatics, BMEI 2009*, no. 09209025, 2009, doi: 10.1109/BMEI.2009.5305287.

[8] A. Ramanathan *et al.*, “Assessment of breath sounds at birth using digital stethoscope technology,” *Eur. J. Pediatr.*, vol. 179, no. 5, pp. 781–789, 2020, doi: 10.1007/s00431-019-03565-8.

[9] C. Aguilera-Astudillo, M. Chavez-Campos, A. Gonzalez-Suarez, and J. L. Garcia-Cordero, “A low-cost 3-D printed stethoscope connected to a smartphone,” *Proc. Annu. Int. Conf. IEEE Eng. Med. Biol. Soc. EMBS*, vol. 2016-Octob, pp. 4365–4368, 2016, doi: 10.1109/EMBC.2016.7591694.

[10] S. Basu and S. Mamud, “Comparative Study on the Effect of Order and Cut off Frequency of Butterworth Low Pass Filter for Removal of Noise in ECG Signal,” *2020 IEEE Int. Conf. Converg. Eng. ICCE 2020 - Proc.*, no. October, pp. 156–160, 2020, doi: 10.1109/ICCE50343.2020.9290646.

[11] C. Leonard and N. H. Shabrina, “Analisis Keefektifan Penggunaan Filter FIR dan IIR pada Sinyal Pernapasan EMGdi dengan Simulasi MATLAB,” *Ultim. Comput. J. Sist. Komput.*, vol. 12, no. 1, pp. 29–34, 2020, doi: 10.31937/sk.v12i1.1618.

[12] E. Khan, F. Al Hossain, S. Z. Uddin, S. K. Alam, and M. K. Hasan, “A Robust Heart Rate Monitoring Scheme Using Photoplethysmographic Signals Corrupted by Intense Motion Artifacts,” *IEEE Trans. Biomed. Eng.*, vol. 63, no. 3, pp. 550–562, 2016, doi: 10.1109/TBME.2015.2466075.

[13] P. Oktivasari, R. Riandini, R. A. Fitri, and S. I. Malaon, “Active Filter Analysis on Designing Electronic Stethoscope,” *J. Elektron. dan Telekomun.*, vol. 19, no. 2, p. 51, 2019, doi: 10.14203/jet.v19.51-56.

[14] D. L. Hall, M. I. McTaggart, and W. K. Jenkins, “Use of adaptive filtering for improved performance in digital stethoscopes,” *Conf. Rec. 51st Asilomar Conf. Signals, Syst. Comput. ACSSC 2017*, vol. 2017-Octob, pp. 108–112, 2018, doi: 10.1109/ACSSC.2017.8335147.

[15] and M. E. Valerie Rennoll, Ian McLane, Dimitra Emmanouilidou, James West, “Electronic Stethoscope Filtering Mimics the Perceived Sound Characteristics of Acoustic Stethoscope,” *IEEE J Biomed Heal. Inform.*, vol. May; 25(5), 2021.

[16] J. E. Suseno and M. Burhanudin, “The signal processing of heart sound from digital stethoscope for identification of heart condition using wavelet transform and neural network,” *Proc. - 2017 1st Int. Conf. Informatics Comput. Sci. ICICoS 2017*, vol. 2018-Janua, pp. 153–157, 2017, doi: 10.1109/ICICOS.2017.8276354.

[17] Dessy Irmawati1 & Ridho Prasakti, “MODIFIKASI ALAT MEDIS STETOSKOP UNTUK MONITORING SUARA JANTUNG MENGGUNAKAN TAMPILAN GUI MATLAB,” *ELINVO(Electronics, Informatics, Vocat. Educ. May 2018,3(1), 106-112*, 2018.

[18] M. E. H. Chowdhury *et al.*, “Real-time smart-digital stethoscope system for heart diseases monitoring,” *Sensors (Switzerland)*, vol. 19, no. 12, 2019, doi: 10.3390/s19122781.

[19] G. H. Prabowo, M. R. Mak’ruf, S. Sumber, L. Soetjiatie, and B. Utomo, “Perancangan Stetoskop Elektronik Portable,” *J. Teknokes*, vol. 12, no. 1, pp. 39–44, 2019, doi: 10.35882/teknokes.v12i1.7.

[20] Wawan Sutrisna, *Desain Prototipe Front End Stetoskop Digital*. 2021.

[21] M. N. Eka, “Perancangan Filter Suara pada Stetoskop Digital,” 2021.

[22] Y. J. Lin, C. W. Chuang, C. Y. Yen, S. H. Huang, J. Y. Chen, and S. Y. Lee, “Live demonstration: An intelligent stethoscope with ECG and heart sound synchronous display,” *Proc. - IEEE Int. Symp. Circuits Syst.*, vol. 2019-May, pp. 19–22, 2019, doi: 10.1109/ISCAS.2019.8702244.

[23] V. Rennoll, I. McLane, D. Emmanouilidou, J. West, and M. Elhilali, “Electronic Stethoscope Filtering Mimics the Perceived Sound Characteristics of Acoustic Stethoscope,” *IEEE J. Biomed. Heal. Informatics*, vol. 25, no. 5, pp. 1542–1549, 2021, doi: 10.1109/JBHI.2020.3020494.

[24] S. Leng1, K. T. C. C. , Ru San Tan1, 2, Chao Wang3, D. Ghista4, and 2 and Liang Zhong1, “The electronic stethoscope,” *Leng al. BioMed Eng OnLine*, vol. 14;66, 2015.

[25] W. Y. Shi, J. Mays, and J. C. Chiao, “Wireless stethoscope for recording heart and lung sound,” *BioWireleSS 2016 - Proceedings, 2016 IEEE Top. Conf. Biomed. Wirel. Technol. Networks, Sens. Syst.*, pp. 1–4, 2016, doi: 10.1109/BIOWIRELESS.2016.7445545.

[26] C. K. Pawar and U. M. Chaskar, “FM based eletronic digital stethoscope using DSP,” *2014 Int. Conf. Control. Instrumentation, Commun. Comput. Technol. ICCICCT 2014*, pp. 538–542, 2014, doi: 10.1109/ICCICCT.2014.6993020.

[27] S. Szot, A. Levin, A. Ragazzi, and T. Ning, “A Wireless Digital Stethoscope Design,” *Int. Conf. Signal Process. Proceedings, ICSP*, vol. 2018-Augus, pp. 74–78, 2019, doi: 10.1109/ICSP.2018.8652475.

[28] B. Silverman and M. Balk, “Digital Stethoscope—Improved Auscultation at the Bedside,” *Am. J. Cardiol.*, vol. 123, no. 6, pp. 984–985, 2019, doi: 10.1016/j.amjcard.2018.12.022.

[29] Y. Ma *et al.*, “Lungbrn: A smart digital stethoscope for detecting respiratory disease using bi-resnet deep learning algorithm,” *BioCAS 2019 - Biomed. Circuits Syst. Conf. Proc.*, pp. 1–4, 2019, doi: 10.1109/BIOCAS.2019.8919021.

[30] A. Lakhe, I. Sodhi, J. Warrier, and V. Sinha, “Development of digital stethoscope for telemedicine,” *J. Med. Eng. Technol.*, vol. 40, no. 1, pp. 20–24, 2016, doi: 10.3109/03091902.2015.1116633.

[31] F. L. Rifalda, “PURWARUPA STETOSKOP DIGITAL TERINTEGRASI REKAM MEDIS,” 2021, [Online]. Available: http://eprints.unram.ac.id/id/eprint/25971.

[32] S. Leng, R. S. Tan, K. T. C. Chai, C. Wang, D. Ghista, and L. Zhong, “The electronic stethoscope,” *Biomed. Eng. Online*, vol. 14, no. 1, pp. 1–37, 2015, doi: 10.1186/s12938-015-0056-y.

[33] B. Malik, N. Eya, H. Migdadi, M. J. Ngala, R. A. Abd-Alhameed, and J. M. Noras, “Design and development of an electronic stethoscope,” *2017 Internet Technol. Appl. ITA 2017 - Proc. 7th Int. Conf.*, pp. 324–328, 2017, doi: 10.1109/ITECHA.2017.8101963.