International Research Journal of Advanced Engineering and Science
ISSN (Online): 2455-9024

Development of Low-Cost Multi-channel Portable sEMG for Arm Muscle Strength Scale

Aulia El Hakim, Sulfan Bagus Setyawan, Dyah Anggun Sartika, Hanum Arrosida, Rendi Pambudi Wicaksono, R. Gaguk Pratama Yudha, Muhsin Toriq, Nadia Adinda Fauziah Putri
Computer Control Engineering, Madiun State of Polytechnic, Indonesia

***Abstract*— *Muscle weakness is when one part of the body's muscles experiences weakness, so that body part is challenging to move. In patients with muscle weakness, periodic therapy and examination of the condition of the muscles using an Electromyograph (EMG) are required with a reasonably high cost for one analysis. Several studies have been completed: detecting movement using a muscle sensor module that displays a muscle strength scale with an LED indicator and research on detecting biceps muscle movement using a surface electrode. Then the signal, type of movement, and MPF value are displayed on the raspberry pi LCD. Therefore, This research was conducted to assist users in knowing the condition of muscle strength by self. Muscle signals can be read with three channel surface electrodes and enter the Differential Amplifier circuit, LPF, HPF, and Notch Filter circuits to reduce noise. Adder circuits so that the ADC can read EMG signals, and then the ADC is connected to the raspberry pi and the cloud database. The overall Multichannel sEMG testing result shows that this tool can read and display signals on the raspberry pi and determine muscle strength scale using the Fast Fourier Transform and mean power frequency methods based on the user's arm movements. This tool has an accuracy rate of about 80% in determining the muscle strength scale based on the direction of the user's arm.*

***Keywords*— *Muscle Weakness, Multichannel sEMG, Surface Electrodes, Filter Circuit, Fast Fourier Transform, mean power frequency, muscle strength scale.*

I. INTRODUCTION

The disability that occurs in the human arm is a severe problem for some people due to the weakening of the function of the movement system in humans. One of the causes of disability can occur due to damage or stimulation of nerves to muscles, either caused by damage to the central or peripheral nerves [1]. As a result, the affected area of the brain cannot work typically and causes the sufferer to be unable to move some limbs or carry out bodily activities that humans do every day; because of this condition, humans are unable to carry out these activities like normal humans. In patients after stroke, a rehabilitation process is needed to restore body functions to return to normal with an exercise program and treatment according to the patient's muscle condition so that the rehabilitation process can be maximized and improve muscle condition. In the rehabilitation of post-stroke patients, an examination is needed to determine the patient's muscle strength and development state. Still, such treatment is quite expensive for the middle to lower class.

Biomedical signals are signals from within the human body that can be analyzed to obtain a picture and structure of tissues or organs associated with the biomedical signal. There are several types of biomedical signals in the form of the human body, one of which is Electromyograph or EMG signals [2]. Electromyograph signal has an amplitude of around 0 – 10mV peak to peak and a frequency range of 20Hz – 500Hz [3]. From the characteristics of the electromyograph signal, an instrumentation circuit is needed to capture shallow EMG signals from the skin surface and amplify and filter them so that signal characteristics can be produced that can be processed by a computer [4]. Electromyograph (EMG) is a technique for analyzing and recording signals in human muscles. Electromyograph works by detecting the electrical potential generated when the muscle contracts and when the muscle relaxes [5]. In the medical world, EMG is used to examine and analyze the condition and health of human muscles.

Fast Fourier transform is a method used to represent signals in discrete time domains into signals in frequency domains [6]. In analyzing EMG signals, the Fast Fourier Transform method is used to determine the frequency value of the muscle signal in each movement from the frequency of each activity so that the condition of the patient's muscles can be analyzed. In the biceps muscle, the flexion movement has an average frequency value of less than 180Hz, and the extension movement has an average frequency value of more than 180Hz [7].

A study is used to detect muscle strength scales using surface EMG with multiple channel methods using myoware sensors [8]. The output of the myoware sensor is an analog signal between 0 – 5v. The work of this tool is 6 LED indicators and a muscle strength scale. However, in this study, the signal results are only displayed on the oscilloscope; of course, not everyone has one, so it is less efficient and less portable.

The following research is entitled Design of portable surface electromyography in 2020. The study aims to tap muscle signal activity in the biceps; muscle signals are detected using a patch electrode sensor, then the electrode signal that has been filtered and amplified will be processed with a Raspberry pi. The processed EMG signal will be displayed on the LCD [7]. However, the muscle signal tapping method still uses the single-channel method so that it can only tap one part of the arm muscle and produces a limited scale of muscle strength; it is necessary to increase the number of channels in detecting muscle signals so that muscle signal detection can be carried out in several parts of the muscle at once and increase the level of muscle signaling—accuracy of the detected muscle signal strength scale.

Based on this, in this study, sEMG was made using a three-channel electrode sensor placed on the Forearm Flexor Carpi radialis muscle to detect wrist muscle signals, Bicep Brachi to detect muscle signals in the upper arm, Extensor Digitorum to see the signals on the fingers [9]. And making signal conditioning instrumentation, this tool is expected to produce an output in the form of an EMG signal from the arm muscles, which can be processed to determine the condition of the 0-5 muscle strength scale in the arm based on the EMG signal in post-stroke patients in the rehabilitation process or for rehabilitation of muscle injury recovery arm and knowing the treatment actions to the patient according to the condition of muscle strength. Using inexpensive components that are easy to find on the market at affordable prices in the manufacture of EMG signal conditioning instrumentation and Raspberry pi can reduce delays in reading EMG signals. This tool is designed to be portable, low cost, and easy to use so that it can be a solution for the lower middle-class community to check the development of the condition of arm muscle strength in post-stroke patients.

II. Methodology

The research was conducted using a prototype development approach, with a descriptive method to collect data and information needed in the design and manufacture of muscle strength detection devices. A quantitative way to obtain primary data. The data required is the average muscle frequency and arm muscle movement. Data processing was performed by looking at the relationship between the average value of muscle frequency based on muscle movement, then used to create a system design and prototype development to determine the level of muscle strength based on arm movements.

A. Tool Specification

The specifications of the tools used in the manufacture are as follows:

1. Raspberry Pi 3B+ as a data processor.
2. IC MCP3008 as ADC Raspberry Pi.
3. Patch electrodes as muscle sensors.
4. IC INA106KP as a differential amplifier
5. IC TL072 as an amplifier in the active circuit.
6. TFT LCD as Interface.

B. System Planning

The system planning can be divided into three parts, planning for the Multichannel Instrumentation Circuit, preparing for the data processing system on the Raspberry Pi, and the Display Interface on the TFT LCD. The working procedure of this tool is as follows: 3 electrode channels will be placed on the arm muscles, the first channel is placed on the Forearm Flexor Carpi radialis muscle to detect muscle signals when there is flexion of the wrist, then the second channel will be placed on the Bicep Brachi muscle to detect muscle signals when there is flexion. On the upper arm, a third channel will be placed on the Extensor Digitorum muscle to detect muscle signals when there is flexion of the fingers. The differential Amplifier circuit will amplify the positive and negative signals detected from the electrode because the amplitude of the muscle signal captured by the electrode is only around 0-10mV. The Low Pass Filter circuit will process the wave signal generated by the Differential Amplifier circuit by filtering and blocking waves with values below the muscle signal frequency. The High Pass Filter circuit will filter the signal movement as bethe Low Pass Filter circuit has filtered and blocked waves with values above the muscle signal frequency. A notch Filter circuit has been used to secure the frequency nets' noise. The Adder circuit is used to shift the overall muscle signal results to a positive value so that the ADC can read it. The ADC will convert the received analog signal wave into a digital signal. Raspberry pi will process the digital signal from the three channels to be displayed on the TFT LCD and sent to Firebase with an internet connection. LCD is used as an Interface to display MPF value, Muscle signal, and muscle strength scale

C. Device Design

In this study, the Raspberry Pi 3B+ is used to process muscle signal data captured by the electrodes and enter the electromyograph instrumentation circuit. Then the results of muscle signal processing will be displayed on the TFT LCD. The following is a picture of the design of the instrumentation circuit on the electromyograph device.

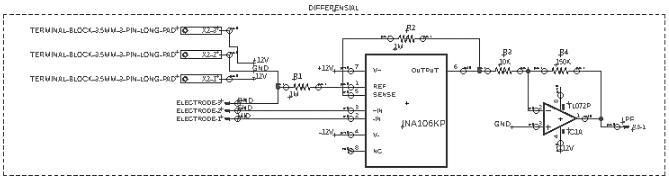

Fig. 1. Differential Amplifier circuit

Figure 1 is the differential amplifier circuit functions as an Amplitude amplifier of the EMG signal from the electrode; the amplification value must be made so that the output does not exceed 5V so that the ADC does not cut off the signal. The following is the equation of the differential amplifier circuit gain.

$$Vout = -V1(R3/R1) + V2(R4/(R2+R4))((R1+R3)/R1) \quad (1)$$

Figure 2 is the LPF circuit functions as a filter to pass the wave frequency below the cut-off frequency value and hold the wave frequency above the cut-off frequency value. In this circuit, the cut-off frequency used is 500 Hz.

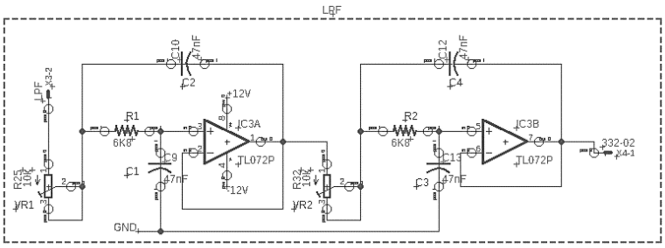

Fig. 2. Low Pass Filter circuit

Figure 3 is the HPF circuit functions as a filter to pass wave frequencies above the cut-off frequency value. The frequency above the cut-off value will be suppressed to eliminate low-frequency signal noise. In this High Pass filter circuit, the cut-off frequency used is 20H.

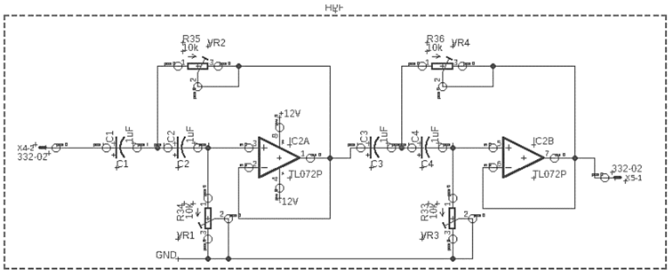

Fig. 3. The high Pass Filter circuit

Figure 4 shows the Notch Filter circuit that removes noise from the 50Hz frequency grid on the supply voltage and instrumentation support. In this Notch filter circuit, the cut-off frequency used is 50Hzz

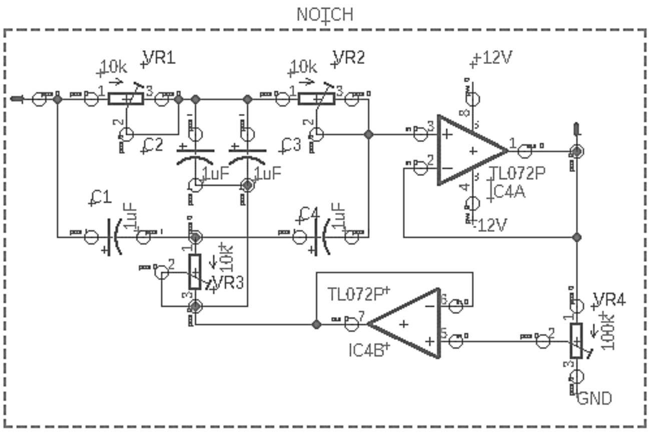

Fig. 4 . Notch Filter circuit

Figure 5 is the Adder circuit is used to shift the value of the sEMG signal voltage so that the overall signal is positive.

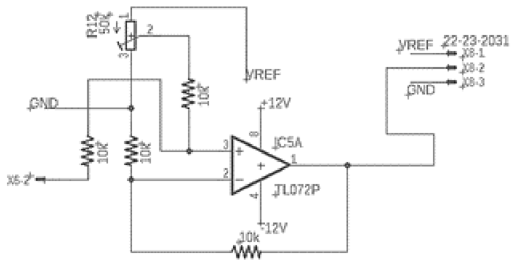

Fig. 5. The Adder circuit

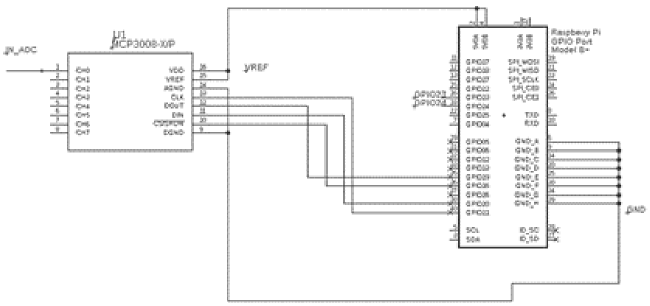

Fig. 6. ADC circuit

Figure 6 shows that the ADC circuit converts analog signals into digital signals so that the Raspberry Pi can read the signal data captured by the electrodes.

III. Results and Analysis

This chapter will explain testing the Low-Cost Multichannel Surface Electromyograph system. To determine whether the instrumentation series and the overall data processing system can work as expected.

A. Instrumentation Circuit Testing

Instrumentation circuit testing aims to determine whether the circuit that has been made can amplify the voltage difference at the electrodes, filter muscle signals from noise, and shift the overall muscle signal value to a positive value. In testing the Differential Amplifier circuit, the output signal is obtained, as shown in Figure 7. Differential Amplifier Output

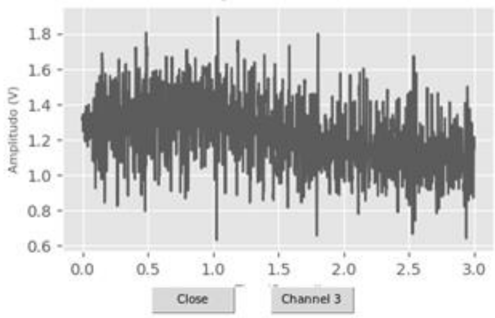

Fig. 7. Differential Amplifier Output

Based on the picture above, the EMG signal, which has a minimal amplitude characteristic of 0-10mV peak to peak, can be amplified by the value of the voltage difference and obtained a Differential Amplifier circuit output with a value range of 0.6V - 1.8V according to arm muscle movement with a gain of approximately 1620 time. From the test, it can be concluded that the differential amplifier circuit works according to its function. In testing the filter circuit, namely LPF, HPF, and Notch Filter, the following results were obtained; figure 8 shows the frequency response of the LPF.

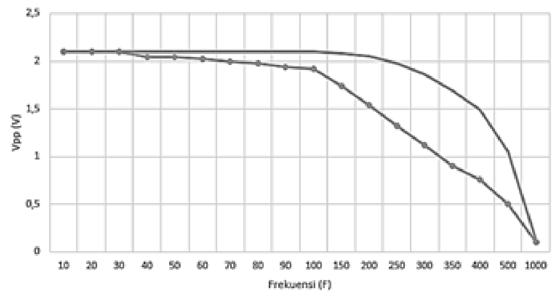

Fig 8. the frequency response of the LPF

The following is a table of Tests on the Low Pass Filter circuit.

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TABLE 1. LPF circuit test results

Fin	Vin (V)	Vpp Test (V)	Vpp theory (V)	Error (V)	Error %
10	2.1	2.10	2.100	0.00	0.0%
20	2.1	2.10	2.100	0.00	0.0%
30	2.1	2.10	2.100	0.00	0.0%
40	2.1	2.04	2.100	0.060	2.9%
50	2.1	2.04	2.100	0.060	2.8%
60	2.1	2.02	2.100	0.080	3.8%
70	2.1	2.00	2.099	0.099	4.7%
80	2.1	1.98	2.099	0.119	5.7%
90	2.1	1.94	2.098	0.158	7.5%
100	2.1	1.92	2.097	0.177	8.4%
150	2.1	1.74	2.083	0.343	16.5%
200	2.1	1.54	2.048	0.508	24.8%
250	2.1	1.32	1.976	0.656	33.2%
300	2.1	1.12	1.859	0.739	39.8%
350	2.1	0.90	1.693	0.793	46.9%
400	2.1	0.76	1.490	0.730	49.0%
500	2.1	0.50	1.050	0.550	52.4%
1000	2.1	0.10	0.124	0.024	19.0%
Mean of Error				0.283	17.6%
Standard Deviation				0.294	

The following is the frequency response in the High Pass Filter circuit.

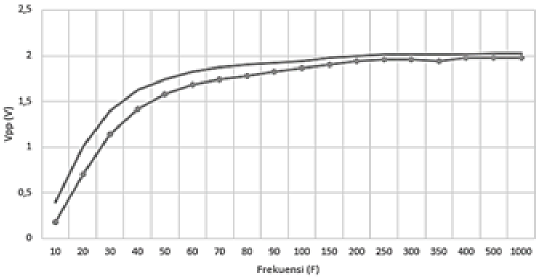

Fig. 9. HPF circuit frequency response

The following is a table of test results on the High pass Filter circuit.

TABLE 2. HPF circuit test results

Fin	Vin (V)	Vpp Test (V)	Vpp theory (V)	Error (V)	Error %
10	2.02	0.18	0.40	0.22	55.4%
20	2.02	0.70	1.01	0.31	30.7%
30	2.02	1.14	1.40	0.26	18.5%
40	2.02	1.42	1.62	0.20	12.1%
50	2.02	1.58	1.74	0.16	9.3%
60	2.02	1.68	1.82	0.14	7.6%
70	2.02	1.74	1.87	0.13	6.8%
80	2.02	1.78	1.90	0.12	6.4%
90	2.02	1.82	1.92	0.10	5.5%
100	2.02	1.86	1.94	0.08	4.2%
150	2.02	1.90	1.98	0.08	4.3%
200	2.02	1.94	2.00	0.06	3.0%
250	2.02	1.96	2.01	0.05	2.3%
300	2.02	1.96	2.01	0.05	2.5%
350	2.02	1.94	2.01	0.07	3.6%
400	2.02	1.98	2.01	0.03	1.7%
500	2.02	1.98	2.02	0.04	1.8%
1000	2.02	1.98	2.02	0.04	1.9%
Mean of Error				0.120	9.9%
Standard Deviation				0.082	

The following is the frequency response in the Notch Filter circuit.

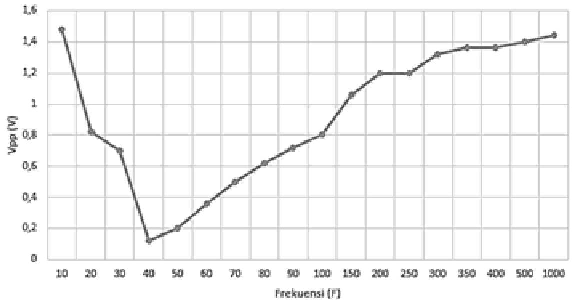

Fig. 10. Notch circuit frequency response

TABLE 3. HPF circuit test results

Fin(Hz)	Vin(Hz)	Vpp Test (V)
10	2.00	1.48
20	2.00	0.82
30	2.00	0.70
40	2.00	0.12
50	2.00	0.20
60	2.00	0.36
70	2.00	0.50
80	2.00	0.62
90	2.00	0.72
100	2.00	0.80
150	2.00	1.06
200	2.00	1.20
250	2.00	1.20
300	2.00	1.32
350	2.00	1.36
400	2.00	1.36
500	2.00	1.40
1000	2.00	1.44

Based on the data obtained from the test, such as the cut-off frequency response and the test results table, it can be concluded that the Low pass filter circuit, in principle, can function by passing frequencies below the Cut-off value and holding frequencies that are more than the Cut-off value, The High pass filter circuit has the characteristic that in principle it can function by passing frequencies above the Cut-off value and holding frequencies that are less than the Cut-off, the Notch filter circuit can already work according to the principle of reducing the frequency around the Cut-off value of 50 Hz. The resulting frequency response is not precisely at 50Hz, but around 40Hz. This error occurs because the components used are not so precise that, in practice, the resulting Cut-off frequency is not precisely 50Hz. In principle, the Notch filter circuit has worked well, reducing the frequency between the Highpass and Lowpass frequencies. In the test table for the three filters, it can be seen that there is a difference in the value or difference between the theoretical Vpp value and the one measured in the test. This difference in weight can be caused by the value of the capacitor and resistor being used, which is less precise and still has error tolerance, thus making the Cut-off value in practice not follow theoretical calculations.

From the test results, it can be concluded that the three Adder circuits can work linearly, as evidenced by the more voltage V2, the greater the Vout voltage, approaching Vpp. The adder circuit can add up the two voltage inputs to produce a larger Vout so that it can be used to shift the overall EMG signal value to a positive value. In testing, the Adder, circut obtained the following result.

Aulia El Hakim, Sulfan Bagus Setyawan, Dyah Anggun Sartika, Hanum Arrosida, Rendi Pambudi Wicaksono, R. Gaguk Pratama Yudha, Muhsin Toriq, and Nadia Adinda Fauziah Putri, "Development of Low-Cost Multi-channel Portable sEMG for Arm Muscle Strength Scale," *International Research Journal of Advanced Engineering and Science*, Volume 7, Issue 4, pp. 12-17, 2022.

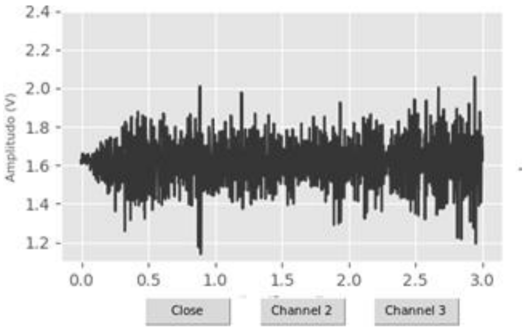

Fig. 11. Adder circuit output

The following is a table of test results on the Adder series

Table 4. Adder circuit test results

V1 (V)	V2 (V)	Vout Test (V)	Vout Theory (V)	Error (V)	% Error
1.00	0.00	0.98	1.00	0.018	1.75%
1.00	1.00	2.00	2.00	0.000	0.00%
1.00	2.00	3.10	3.00	0.103	3.44%
1.00	3.00	3.85	4.00	0.151	3.77%
1.00	4.00	4.93	5.00	0.074	1.48%
Mean of Error				0.069	2.09%

B. EMG Signal Data Processing System Testing

Testing of the EMG signal data processing system aims to determine whether the program used to process the signal can produce the appropriate output or not. The following is a table of the results of the FFT program testing and the value of MPF.

TABLE 5. FFT and MPF program test results

Frequency	MPF
10	14.35 Hz
70	98.27 Hz
150	175.6 Hz
350	353.51 Hz
500	497.58Hz

The test results show that the FFT and MPF programs produce outputs that detect the average value of the frequency compiler. From the test results, it can be concluded that the hand muscles tested for MPF values have different MPF value characteristics in each movement; the MPF value during flexion movements will be less than 170 Hz, and the MPF value in the relaxation movement will be more than 170 Hz. The following is a table of the results of the FFT program testing and the MPF value with the input signal from the instrumentation circuit.

TABLE 6. Program and MPF test results with EMG signal input

No	Motion	*Sampling Rate/S*	MPF
1	Flexion	1032 Hz	150.24 Hz
2	Extension	1031 Hz	173.58 Hz
3	Flexion	998 Hz	168.15 Hz
4	Extension	1039 Hz	186.42 Hz
5	Flexion	962 Hz	149.27 Hz
6	Extension	1031 Hz	179.81 Hz
7	Flexion	992 Hz	141.77 Hz
8	Extension	1022 Hz	207.02 Hz
9	Flexion	1014 Hz	144.72 Hz
10	Extension	1024 Hz	186.87 Hz
Average MPF on Flexion motion			150.83 Hz
Average MPF on Extension motion			186.74 Hz

C. Overall Test

The overall test of the tool is carried out to know how the EMG signal results when it has passed through a series of instrumentation and is processed by a raspberry pi, so that it can be seen whether the Multichannel Surface electromyograph can distinguish between flexion and relaxation movements based on the MPF value in each muscle movement and perform a strength scale. muscles based on the movement conditions of the three channels placed on the user's hand muscles. The following is a table of the results of testing the determination of the muscle strength scale.

TABLE 7. Program Test Results and MPF with EMG Input

No	Motion	MPF	Scale
1	Relaxation of all hand muscles.	Ch1 : 174.50 Hz Ch2 : 177.78 Hz Ch3 : 185.60 Hz	0
2	Flexion of the fingers	Ch1 : 162.46 Hz Ch2 : 154.83 Hz Ch3 : 212.01 Hz	1
3	Flexion of the wrist.	Ch1 : 194.83 Hz Ch2 : 158.68 Hz Ch3 : 188.85 Hz	2
4	flexion of the fingers and wrist.	Ch1 : 165.70 Hz Ch2 : 146.35 Hz Ch3 : 191.86 Hz	3
5	flexion of the wrist and biceps with light resistance in the form of a book.	Ch1 : 172.97 Hz Ch2 : 157.20 Hz Ch3 : 170.56 Hz	4
6	Full strength flexion of the hand muscles with a barbell resistance load of 6Kg.	Ch1 : 146.04 Hz Ch2 : 151.81 Hz Ch3 : 170.12 Hz	5

Testing of all these tools can work according to the principles that have been planned, as evidenced by the functioning of the instrumentation circuit to produce a filtered EMG signal to reduce noise and can be read by the ADC. This tool can determine a muscle strength scale from 0 to 5 based on the MPF value of muscle movement detected from the three channels of the EMG instrumentation series.

IV. CONCLUSION

Based on the results of the experiments carried out in this study, conclusions can be drawn, among others: Multichannel surface electromyograph instrumentation can detect, amplify, and filter signals with an average error of 17.6% on the LPF, 9.9% on HPF, and the notch filter with an error of 19.5 %, then shifts the EMG signal to a positive value in the Adder circuit with an average error of 2.09% so that it can be read by the ADC MCP3008 and processed by the Raspberry Pi. This sEMG Multichannel Tool can display EMG Signals from all three channels on the TFT LCD and the level of muscle strength according to conditions of the user's arm muscles with an accuracy of about 80%. This tool can send test results to the cloud database using firebase Library in the Python program to upload user check result data to Firebase Database.

ACKNOWLEDGMENT

This research was made possible thanks to the assistance of several parties. The author would like to thank those who have provided advice, input, and facilities, especially the Madiun

State of Polytechnic and the laboratory of computer control engineering, so that this research can be carried out well.

References

[1] Hakim, A. E., Setyawan, S. B., & Santika, D. A., "*Smart detection of arm muscle strength for post-strokee patient therapy," JEECAE. Vol.6, No.*

[2] Maulana, R., & Putri, R. R., "Pengkondisian Sinyal Electromyography Sebagai Identifikasi Jenis Gerakan Lengan Manusia," JTIIK. Vol. 5, No. 3, pp. 297-304, Agustus 2018.

[3] Pratiwi, I., Purnomo, Dharmastitti, R., & Setyowati, L., "Letak Elektroda Elektromiografi pada Upper Extrimity Muscle," Prosidin Seminar Nasional TEKNOIN. ISBN 978-602-14272-1-7, 2014.

[4] Sitanaya, J. G., Tasripan, & Arifin, A., "Pengolahan Sinyal EMG sebagai Perintah Kontrol untuk Kursi Roda Elektrik," JTEK ITS. Vol. 7, No. 2, 2018.

[5] Sipasulta, R. Y., Lumentra, A., Sompie, S., "Simulasi Sistem Pengacak Sinyal Dengan Metode FFT (*Fast Fourier Transform),"* JTEK UNSRAT. ISSN 2301-8402, 2014.

[6] Chandrasekhar, V., Vazhayil, V., & Rao, M., "*Design Of A Real Timer Portable Low-Cost Multi-Channel Surface Electromyography System To Aid Neuromuscular Disorder And Post Stroke Rehabilitation Patients,"* IEEE. Vol. 20, 2020.

[7] Hakim, A. E., Kusbandono, H., Jihaadi, F. I H., Widyaningsih, R., "Rancang Bangun Elektromiografi Permukaan Portabel," JETT. Vol. 8, No. 1, pp. 997-1005, Juli 2021.

[8] Hakim, A. E., Setyawan, S. B., & Santika, D. A., "*Detection of Muscle Strength Scale with Surface electromyography using Multiple Channels Point Measurement Method,"* ICVIAS. Jilid 1, 2019.

[9] Criswell, E., Cram's Introduction To Surface Electromyography, Second Edition. Sudbury: Jones And Bartlett Publishers, 2010.