Wheelchair for Quadriplegic Patient with Electromyography Signal Control Wireless

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Abstract—Quadriplegia is a paralysis condition in both arms and legs so that the patient is only able to move his neck and head. Manual or electric wheelchairs with joystick or switch control as a tool for people with paralysis certainly cannot be controlled independently by quadriplegic people. This study aimed to help quadriplegic people not to depend on others in carrying out daily activities by developing electric wheelchairs that can be controlled independently. The bioelectric signal which has only been used for diagnostic purposes can be utilized as an electric wheelchair control system for quadriplegic people. In this study, electric wheelchairs were controlled by electromyography (EMG) signals from muscle contractions that can be driven by quadriplegic people, namely the neck and face muscles. The increase in EMG signal amplitude during the muscle contraction is used as a trigger for the electric motor in a wheelchair to move forward, backward, turn right, and turn left. An electronic circuit for signal conditioning was used to amplify the EMG signal leads and filter frequencies that are not needed by the system before being processed by the microcontroller circuit. The use of wireless systems was developed to reduce the use of cables connecting electrodes to patients with electronic devices that will provide comfort to the user. Based on the results of the data collection on the wheelchair system, the detectability and selectivity values were for the 100% and 94% forward commands, 94.33% and 100% reverse commands, 92.31%, and 96% right turn commands and 97.96% and 94.12% left turn commands. The electric wheelchair system with EMG signal control is expected to help the mobility of quadriplegic people.

Keywords—Electromyography, Wheelchair, Quadriplegia, Bioelectric.

1 Introduction

Quadriplegia or often referred to as tetraplegia, is defined as paralysis caused by illness or injury to a human nervous system that results in the partial or total loss of use of all four limbs, namely the hands and feet. The paralysis of the four limbs causes the dependence on others to carry out daily activities to become very dominant, even mobility has done with a wheelchair also needs help from others. Instead of a manual wheelchair, an electric wheelchair with a joystick or switch cannot be used independently by quadriplegic people. For a wheelchair to be used independently it needs a special control system that utilizes internal resources in the form of physiological signals from quadriplegic people. The use of physiological signals is certainly not easy and the amount is limited due to the condition of quadriplegic people who can only move their neck and face muscles.

Research that aims to help people with paralysis by utilizing physiological signals that are converted into signals that can be recognized by machines or computers to help their daily activities has been widely carried out. The system that functions to connect humans and machines or computers is called a human-machine interface (HMI) or human-computer interface (HCI). Some types of physiological signals that can be used on HCI systems include voice commands [1], hand movements [2], [3], head movements [4], electroencephalograph signals (EEG) [5]–[7], electrooculography signals (EOG) [8], [9] and electromyography signals (EMG) [9]–[16].

The HCI system of physiological signals that function to control electric wheelchairs for people with paralysis has also been done in several previous studies [3, 8, 9, 11, 12, 17, 18, 19]. The physiological signal from the mechanical movements of the body for wheelchair control is carried out by Kundu [3] who used hand signals and Prasad [17] who used head movements with an accelerometer sensor. Physiological signals from bioelectric signals are also widely used in previous studies such as Barea [8] which utilized EOG signals and Nikhil [18] EEG signals for wheelchair control. In [8], it is explained that the use of EOG signals for wheelchair control is somewhat difficult because the user eyeballs must always focus moving to the right, left, up and down continuously so that it will cause fatigue in the eye muscles. Likewise [18] which gets into trouble because the EEG signal is a signal that contains a lot of information so the user must always focus on controlling the wheelchair to move as desired. Maeda [11] and Rampriya [12] utilized EMG signals that are tapped from arm muscles as wheelchair controls, but this method cannot be used for quadriplegic people who are only able to move their neck and face muscles. Tien [19] and Ahire [9] combined the use of EMG and EOG signals which alternately control the direction of movement and adjust the speed of a wheelchair.

The use of EMG signals for wheelchair control that is tapped from facial and neck muscles is certainly very useful for quadriplegic people. Taslim [13] used a taping of the trapezius muscle with movements, cervical flexion ie the chin movement is lowered toward the chest for start and stop and cervical rotation, which is turning left and right towards the shoulder for commands to turn right and turn left. Electronic devices such as amplifiers, low pass filters, high pass filters, full-wave rectifiers, and comparators are used as EMG signal processing devices for wheelchair control. Comparator is used to compare the threshold value of 3 V with the amplitude value of the user's muscle contraction. The disadvantage of a fixed threshold value is that the comparator system cannot adjust signal changes when there is fatigue in the user's muscles. Mohammad [20] used EMG signal tapping resulting from the contraction of 3 facial muscle points, namely the frontal and zygomatic muscles. Turn right is done by pulling the corner of the right lip up, turn left by pulling the corner of the left lip up, forward by smiling or pulling the two ends of the lips up, backward by raising the eyebrows and stopping by relaxing the facial muscles. Virtual wheelchair control commands are classified by the Support Vector Machine (SVM) method. Xu[21] used EMG signals from facial muscle tapping. Facial muscles were chosen because there are a lot of muscles in the face that can make various kinds of expressions. Movement of forward, backward, turn right, and left is moved by closing the jawbone once to choose the desired direction of movement, while to stop is by closing the jawbone twice. EMG signal feature extraction in this study used an autoregressive model and the signal classification was updated and trained using the SVM online in real-time to adjust the signal changes if muscle fatigue occurs. Yulianto [16] utilized EMG signals that are tapped from the temporalis muscle to command forward by biting molars, sternocleidomastoid muscles to turn right and left by turning right - left and pectoralis minor to retreat by advancing the right shoulder. Similar to[13], this study also used electronic devices such as amplifiers, low pass filters, high pass filters, buffers, and microcontrollers for signal processing and wheelchair control. Comparator is a comparator of the threshold value and the user's EMG signal was carried out by a microcontroller. If at [13] the threshold value remains at 3 V, then in this study the threshold value is the average maximum amplitude value during the muscle contraction period from 3 times of data collection. The mean value was then multiplied by the constant 0.8. Taking the threshold value from the user was done before the use of a wheelchair.

Based on the description of the library study, this research aims to help the quadriplegic people to be more independent in conducting daily activities by making the design of electric wheelchairs controlled by EMG signals through contraction and relaxation of muscles. EMG signals are selected and tapped from the muscles that are still able to be contracted by the quadriplegia, the neck and face muscles. Contraction and relaxation of muscles will result in changes in the amplitude of the EMG signal that acts as the user's command to the electric motor so that the wheelchair can move forward, backward, turn right and turn left. Delivery of orders from muscle contraction to electric motors is sent wirelessly to reduce the use of cables that can interfere with the comfort of wheelchair users.

The organization of the paper is as follows, Section II will explain the materials and methods used in this study, Section III will show the results and discussion of research findings and chapter IV concludes and provide advice for future research.

2 Materials and Methods

2.1 Participants

This study used 5 male participants aged 18-20 years in a healthy volunteer with bodyweight between 60-70 kg. Before entering the testing phase, participants were allowed to do a wheelchair trial to understand how to operate a wheelchair. EMG signal tapping electrodes were placed on 4 muscle points, namely the temporalis muscle for forwarding command by biting molars, sternocleidomastoid for left and right turn commands by turning left and right, pectoralis major muscle for backward order by advancing the right shoulder and relaxing condition for a stop command. This research has obtained ethical approval from the Health Research Ethics Committee Poltekkes Kemenkes Surabaya with number: No. EA/056/KEPK-Poltekkes_Sby/V/2019.

2.2 Materials and equipment

The wheelchair for quadriplegic people utilized 4 EMG signal channels for forward, reverse, right turn, and left turn commands. The wheelchair frame used is a modified manual wheelchair with the addition of 2 48 Volt/350 Watt/16-18 Ampere/Torque 18 - 25 Nm Brushless Direct Current (BLDC) motors installed on both rights and left wheels. The wheelchair electronic device consists of 4 Myoware Muscle Sensor modules as EMG signal tapping devices, and Analog Signal Processing (ASP) circuit consisting of a summing amplifier, low pass filter with 589 Hz cut-off frequency, high pass filter with cut-off frequency of 48 Hz, buffer and envelope detectors, ATmega8 microcontrollers, decoders, transmitters/receivers as wireless system devices and motor driver circuits.

2.3 System design

This wheelchair used a wireless system to reduce the use of connecting cables between EMG signal tapping devices attached to the neck and face muscles and transmitter circuits placed in the pocket of the receiver and motor drivers under the wheelchair as shown in Figure.1. Block diagram electronic system consisting of input, process until the output of the electric wheelchair with EMG signal control is shown in Figure.2.

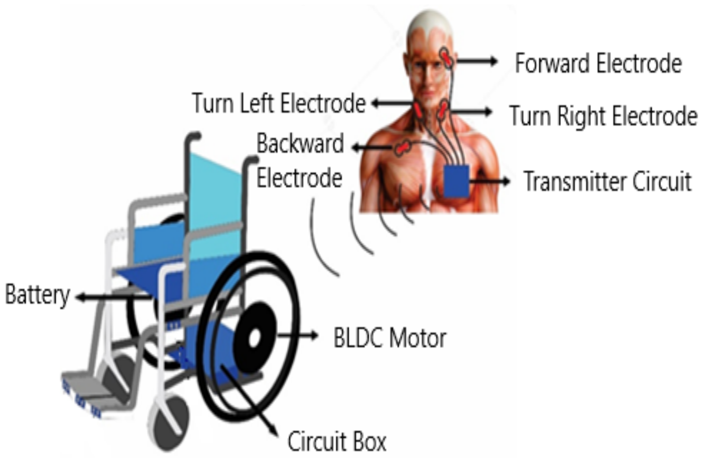

Fig. 1. Mechanical

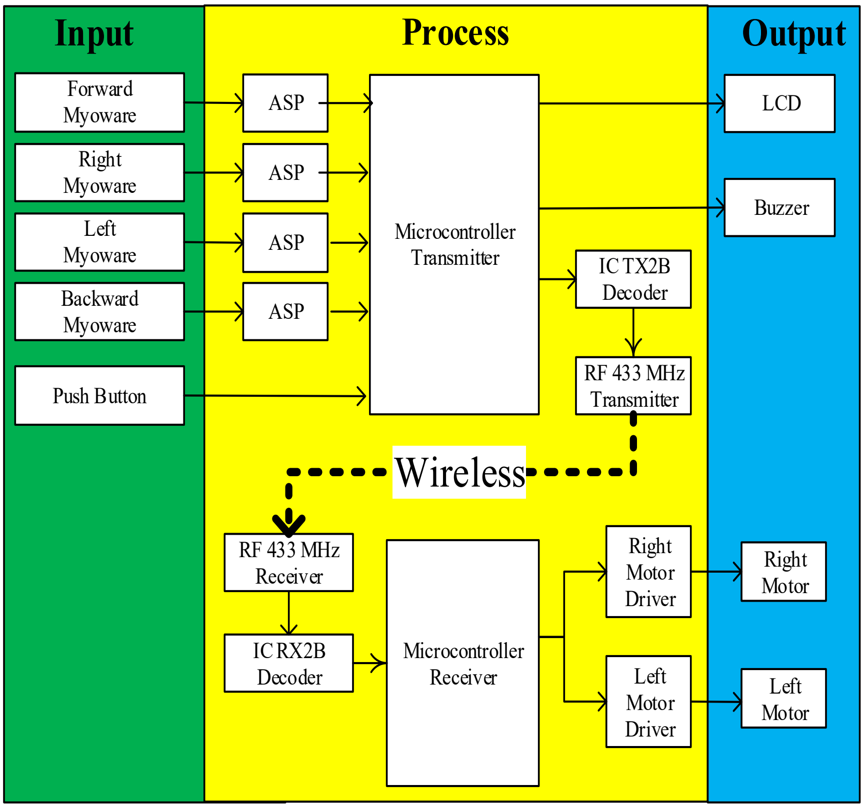

Fig. 2. Block Diagram of Electronic Systems

EMG signals obtained from the four pairs of electrodes placed on the muscle temporalis for forward command, the sternocleidomastoid muscle for the right-left turn command and the pectoralis major muscle to retreat command through the Myoware Muscle Sensor module which is an EMG signal tapping device. The analog signal from Myoware was then be processed by ASP to condition the signal that still contains a lot of noise and very small amplitude values through the stages of summing, filters, buffers, amplifiers, rectifiers, and envelopes. The envelope circuit output from ASP becomes the input for the ATmega8 transmitter microcontroller which includes an Analog to Digital Converter (ADC), a comparator system between the threshold value and the user's EMG signal, a logic wheel motor motion command and displays the ADC data on an 8x2 character LCD. Motion logic commands sent by the microcontroller transmitter was changed by the TX-2B decoder into data bits sent via the 433 Mhz RF transmitter via wireless.

The comparator system on the microcontroller transmitter functions to compare the user's EMG signal with the threshold value. Each forward, backward, turn right and turn left commands has a threshold value that has been stored in the memory of the transmitter microcontroller before the user controls the wheelchair. When the amplitude value in one of the muscles is greater than the threshold value, it will provide a logic low on the IC TX-2B input, PORTD.0 - PORTD.3. PORTD.0 for forwarding commands, PORTD.1 for the right turn, PORTD.2 for left turn, and PORTD.3 for backward. PORTD.5 has low logic when muscle relaxation occurs. IC TX-2B is a decoder to form the information signal to be sent based on the logic at the input. The signal is forwarded to RF 433 Mhz which will be sent via wireless. The flow diagram of the comparator system is shown in Figure 3.

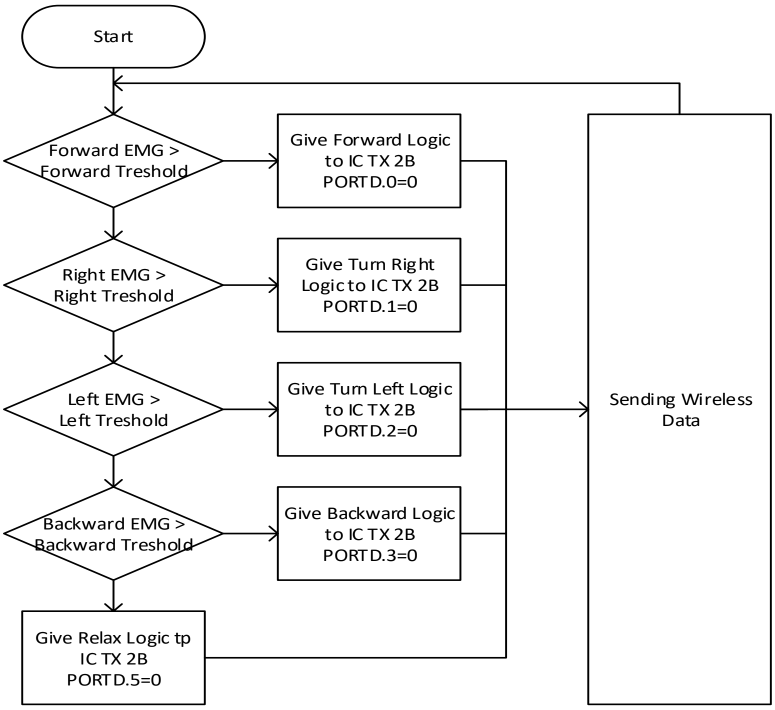

Fig. 3. Diagram Comparator System Flow

In this study, the threshold value in the comparator system was determined from the average amplitude of the EMG signal output from the envelope circuit when the muscle contraction period was carried out for 5 seconds. The mean results were then multiplied by a constant 0.4 to be stored in the memory of the transmitter microcontroller. The determination of threshold values can also be done by entering a certain constant value manually via the pushbutton as shown in the flow diagram of Figure 4. The determination of threshold value determination threshold value that can be easily changed according to the force of muscle contraction was so that the system can adjust the signal change caused by muscle fatigue or changes in the strength of muscle contraction due to physical therapy undertaken by the user.

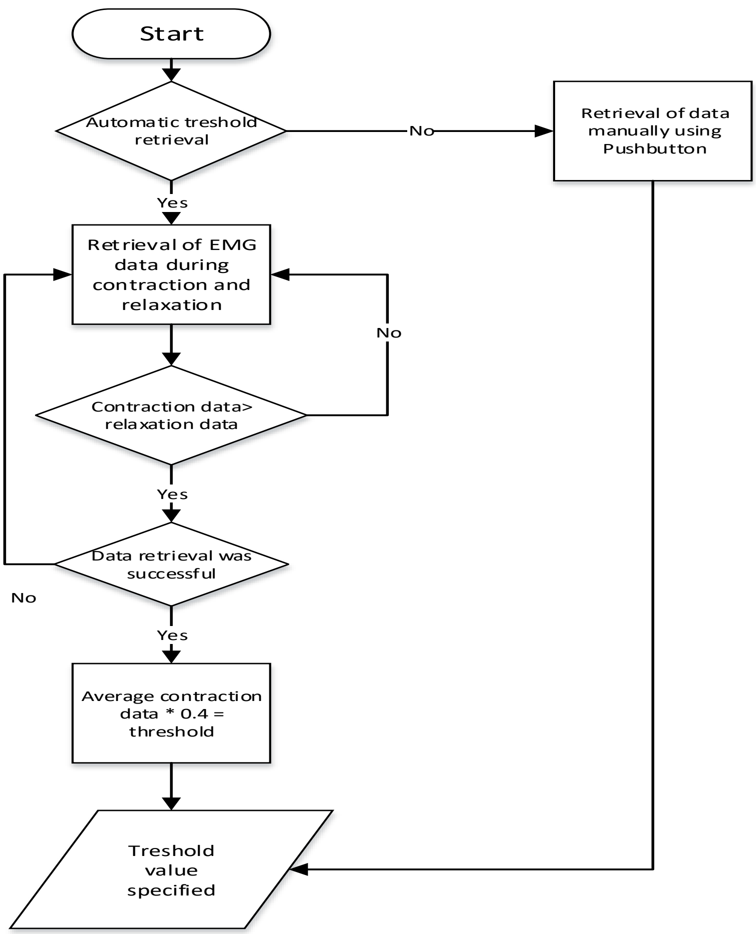

Fig. 4. Flow Chart Determination of Threshold Value

Data sent via wireless was captured by an RF 433 Mhz receiver which was forwarded to the RX-2B encoder to be converted into logic at the RX-2B IC output. The logic command was connected to the receiver microcontroller pins that were tasked with reading the RX-2B logic. The motion command of IC RX-2B was in the form of logic HIGH on PIND.0 for forward, PIND.1 for right, PIND.2 for left, PIND.3 for backward. If there is a command to relax, the receiver microcontroller will instruct the motor to stop.

2.4 Muscle sensor module

In the myoware muscle sensor module that functions as an EMG signal tapping device, there are 2 output pins, the GIS pin which produces the signal from the processing of the Myoware system and the RAW pin that produces raw EMG signal data.

This research utilized raw data from the RAW pin output. The Myoware module is shown in Figure 5.

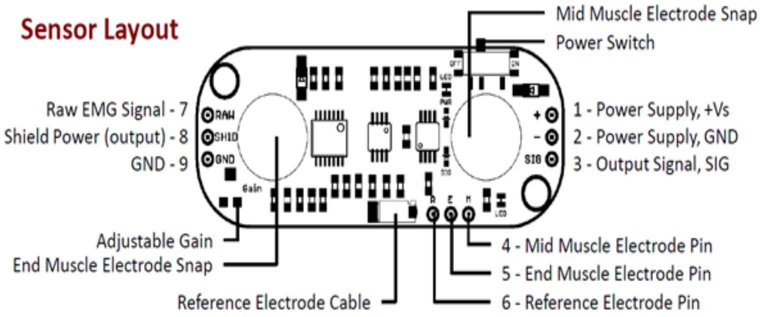

Fig. 5. Myoware Muscle Sensor Modul [22]

The output of the RAW pin of the myoware muscle sensor module becomes an input for the ASP.

2.5 Analog signal processing

The ASP circuit consists of a series of summing amplifiers, low pass filters, high pass filters, buffers, amplifiers, rectifiers, and envelopes.

Summing amplifier: This circuit serves to reduce the signal baseline value and also increase the value of the signal amplitude so that the output can begin to distinguish the difference between the amplitude of contraction and relaxation of muscles. The summing amplifier circuit is shown in Figure 6.

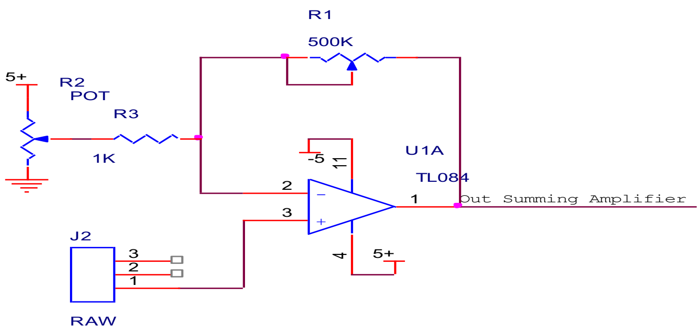

Fig. 6. Summing Amplifier Circuits

Signal gain on summing amplifier circuit is shown in the following equation,

$$Vout = (R1/R3)(VRaw + Vadjust) \tag{1}$$

Low pass filter: The low pass filter circuit with a 589 Hz cut-off frequency in addition to functioning to reduce the signal that has a frequency above the cut-off value also increased the signal amplitude value by 2 times the gain. The low pass filter circuit is shown in Figure 7.

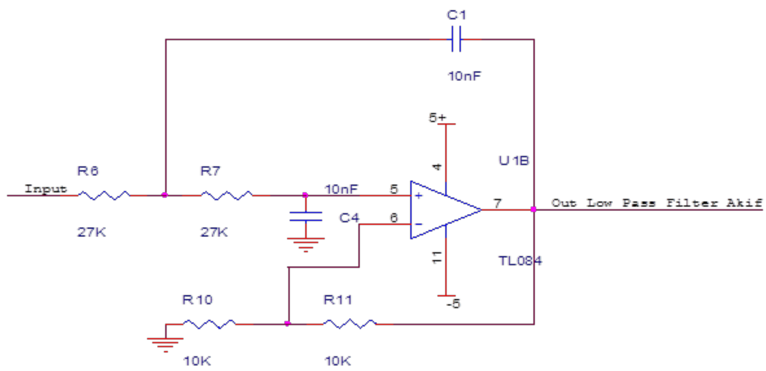

Fig. 7. Low Pass Filter Circuit

The cut-off frequency of low pass filter and signal gain is shown in the following equation,

$$Fc = 1/(2\pi\sqrt{(R6.R7.C1.C4)}) \tag{2}$$

$$Vout = \left(1 + (\mathrm{R11}/\mathrm{R10})\right).Vin \tag{3}$$

High pass filter circuit: This circuit function dampens the signal with a frequency below the cut-off frequency of 48 Hz so that the baseline signal is more evenly as shown in Figure 8.

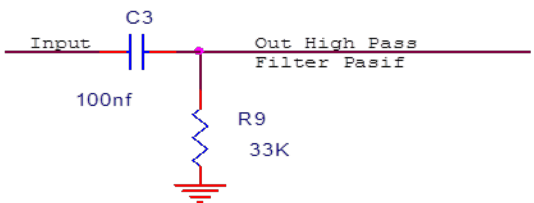

Fig. 8. High Pass Filter Circuit

The cut-off frequency of high pass filter is shown in the following equation,

$$Fc = 1/(2\pi.R9.C3) \tag{4}$$

Buffer circuit: Large input impedance in the buffer will make the buffer input signal will be the same as the output signal. The buffer circuit is shown in Figure 9.

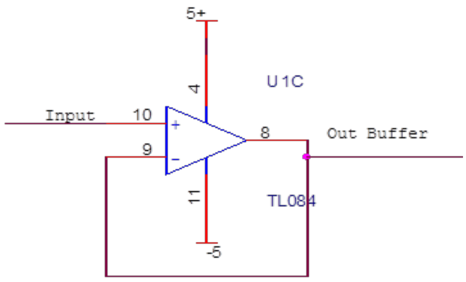

Fig. 9. Buffer Circuit

Amplifier circuit: After passing through the filtering process, the amplifier circuit functions to amplify the EMG signal amplitude so that the amplitude difference when contracting and relaxing muscles is visible. Amplifier circuit is shown in Figure 10.

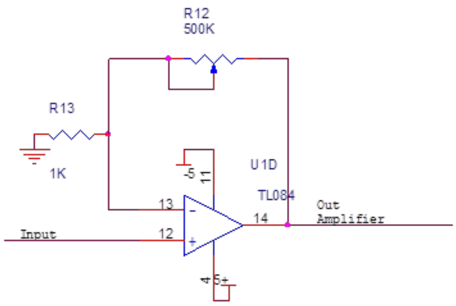

Fig. 10. Amplifier Circuits

$$Vout = (1 + (\mathrm{R12/R13})).\ \mathrm{Vin} \tag{5}$$

Rectifier and envelope circuits: In the final stages of this ASP circuit two processing occurs, the signal is rectifying performed by the diode component and the envelope process carried out by the capacitor component. Rectifying is the process of blocking a signal with a negative phase so that only signals in the positive phase are raised. The envelope is a process for detecting analog signals based on the detection of signal amplitudes, ie EMG signals. The circuit of this stage are shown in Figure 11. The output of the envelope sequence is the input for the transmitter microcontroller circuit.

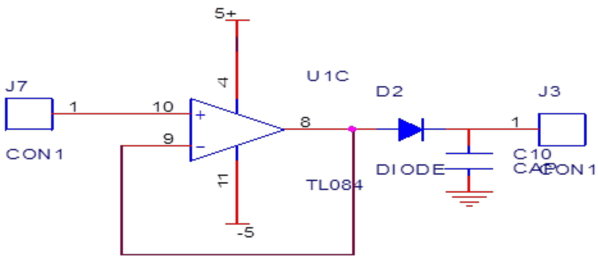

Fig. 11. Rectifier and Envelope Circuits

2.6 Comparator system and minimum system transmitter

The comparator system functions to compare the amplitude of the EMG signal read by the tapping device with the previously stored threshold value. When one of the amplitude values of the contractions of one muscle is greater than the threshold it will provide a logic low on the IC TX-2B input and when PORTD.5 muscle relaxation has a low logic as a relaxation command. The logic of the wheelchair command is shown in Table 1.

Table 1. Logic Table Command Movement

	Threshold Forward	Threshold Right	Threshold Left	Threshold Backward
Forward	FE > TF	Ignore	Ignore	Ignore
Turn Right	FE < TF	RE > TR	Ignore	Ignore
Turn Left	FE < TF	RE < TR	LE > TL	Ignore
Backward	FE < TF	RE < TR	LE < TL	BE > TB

In Table 1, the tapping position of electrodes is abbreviated as FE (Forward Electrode), RE (Right Electrode), LE (Left Electrode), BE (Backward Electrode) and for threshold abbreviated as TF (Threshold Forward), TR (Threshold Right), TL (Threshold Left), TB (Threshold Backward). FE is a tapping EMG signal from the temporalis muscle, RE from the left sternocleidomastoid muscle, LE from the right sternocleidomastoid muscle and BE from the pectoralis major muscle. To move forward, the value of FE> TF and other values are ignored so that PORTD.0 has logic 0 and others have logic 1. Turn right, RE value> TR, FE value <TF and other values are ignored so that PORTD.1 has logic 0 and others have logic 1 Turn left, LE value> TL, FE value <TF and RE <TR, BE values are ignored so that PORTD.2 has logic 0 and others have logic 1. To reverse, BE values> TB, and other EMG values must be smaller than the threshold value each so that PORTD.3 has logic 0 and the other has logic 1. Figure 12 is the Minimum System of the transmitter device.

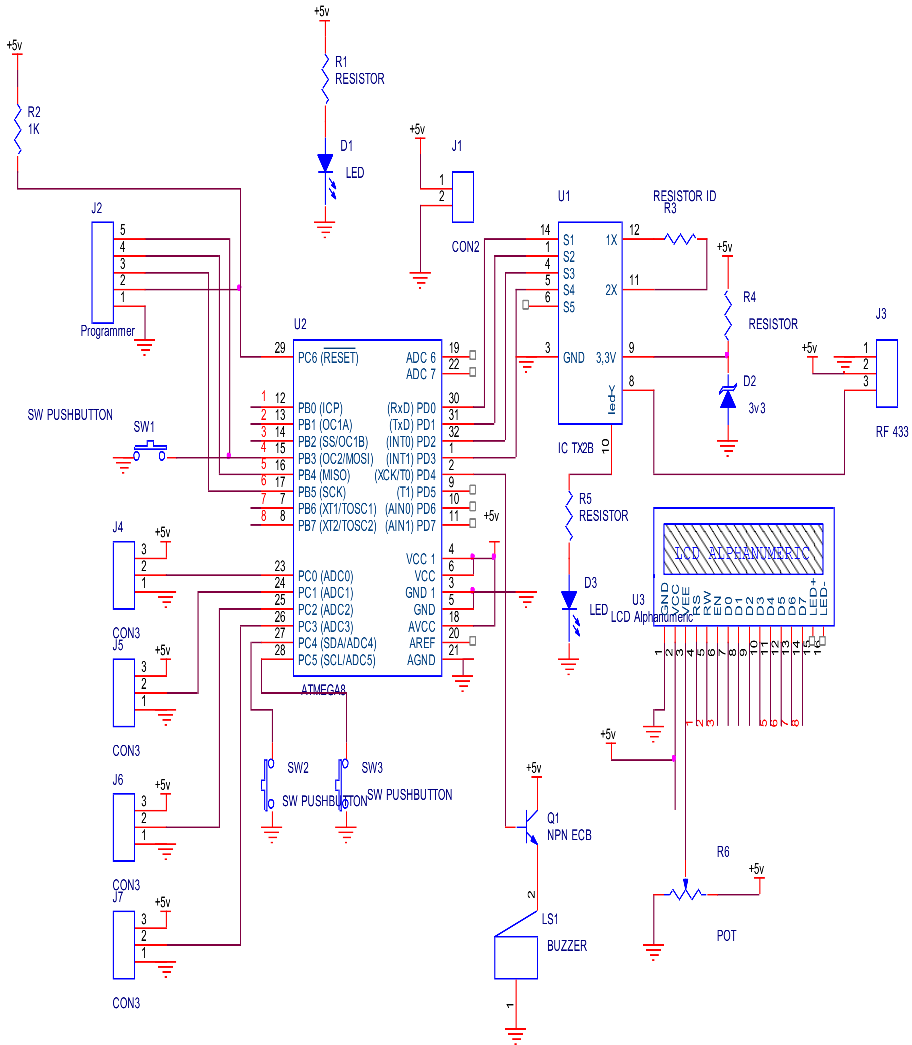

Fig. 12. Minimum System Transmitter

2.7 Minimum system receiver and motor driver

The minimum system receiver was tasked with reading the motion commands from IC RX-2B in the form of HIGH logic on PIND.0 for forward, PIND.1 for right, PIND.2 for left, PIND.3 for backward and PINB.7 for stop Figure 13 is the minimum receiver system circuit.

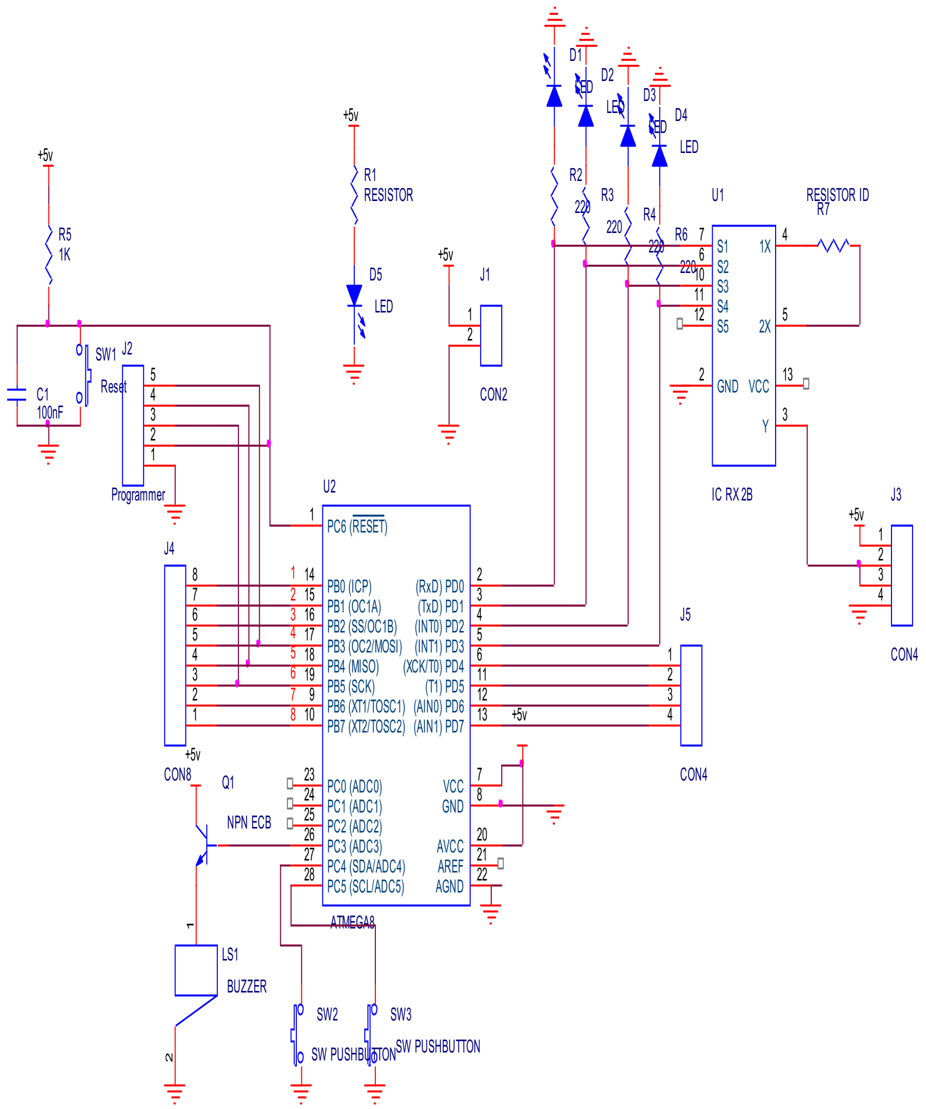

Fig. 13. Minimum System Receiver

A wheelchair motor consisting of right and left motors each has 4 input pins namely Brake (BK), Forward (FD), Backward, and Speed (SP). For the BK, FD and SP pins of the two motors get the same input from the microcontroller, namely PORTB.6, PORTD.6, and PORTD.4 while for the Right (BR) and left (BL) Backward motors get different inputs namely PORTD.5 and PORTD.7. The logic commands given by the receiver microcontroller to the motor driver are shown in Table 2 below.

Table 2. Logic Commands for Motor Drivers Wheel

Command	**Command Logic**					**Motor**	
	BR	***FD***	***BR***	***BL***	***SP***	***Right Motor***	***Left Motor***
Forwad	0	1	0	0	0	Forward	Forwad
Turn Right	0	1	1	0	1	Forward	Backward
Turn Left	0	1	0	1	1	Bakcward	Forward
Backward	0	1	1	1	0	Backward	Backward
Brake	1	0	0	0	0	Brake	Brake

On the SP pin if the logic is 0 then the motor rotates slowly, however if the logic 1 then the motor rotates faster. It is intended that when turning the motor, speeds become faster.

3 Result and Discussions

3.1 Mechanicals wheelchairs

The results of manual wheelchair modification by adding 2 BLDC motors on the right and left wheels as movers can be seen in Figure 14. The electronic system and wheelchair battery were placed at the bottom of the seat. There were also safety iron on the right and left wheels to avoid damage to the motor in the event of a collision.

Fig. 14. Wheelchair Mechanical Systems

Furthermore, testing on electronic circuits was carried out by tapping EMG signals from participants when performing muscle contraction and relaxation commands measured using a digital oscilloscope at each circuit output.

3.2 Output of muscle sensor and analog signal processing circuit

Output Myoware EMG signal output on the RAW pin has a baseline value + Vs/2 of 2.5 V and an amplitude of 0.8 Vpp. The difference in amplitude during contractions and relaxation has not been seen due to the amount of noise that has not been filtered and the amplitude of the contraction that is too small as shown in Figure 15

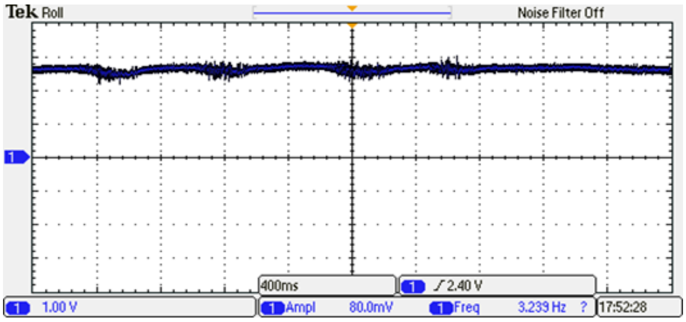

Fig. 15. The Output of Myoware Muscle Sensor

The output of summing amplifier circuit manages to reduce the initial signal baseline value at 2.5 V to 0 V and increase the signal amplitude value so that it can be distinguished between contraction amplitude and muscle relaxation as shown in Figure 16

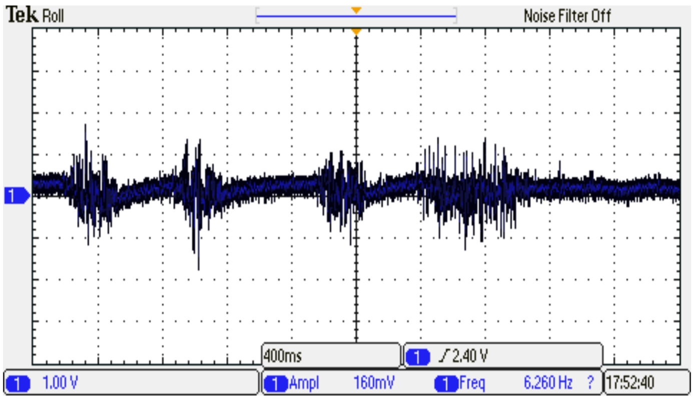

Fig. 16. The Output of Summing Amplifier Circuits

The low pass filter circuit has reduced the noise signal with frequencies above 589 Hz and increased the signal amplitude value by 2 times the gain as shown in Figure 17.

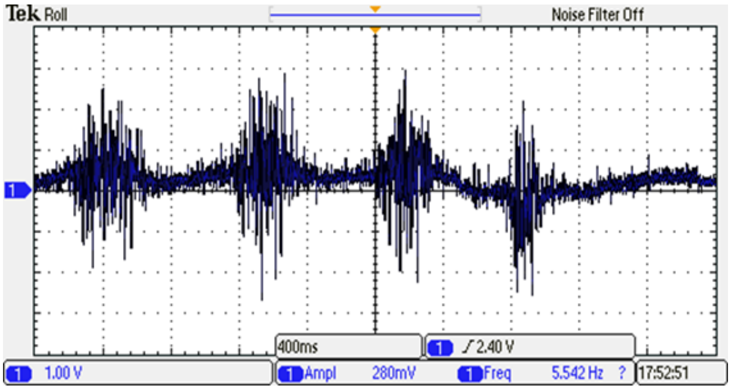

Fig. 17. The Output of Low Pass Filter Circuit

Noise caused by low frequencies can be seen from a baseline value that is not located precisely at a value of 0 V. Noise at low frequencies will cause a wavy base line signal. The high pass filter circuit successfully dampens the noise signal with frequencies below 48 Hz so that the baseline signal is not wavy as shown in Figure 18.

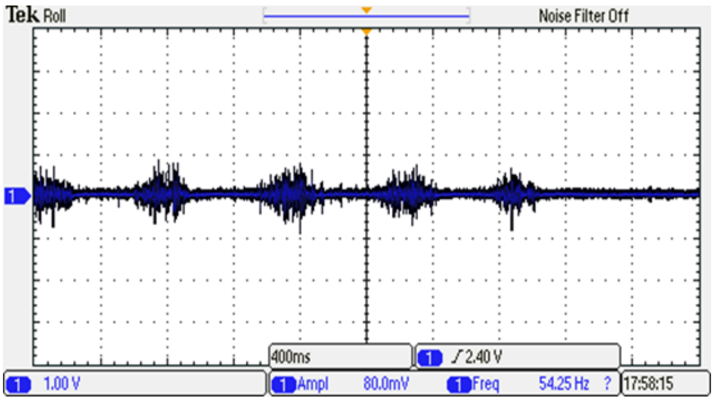

Fig. 18. The Output of High Pass Filter Circuit

Output of the buffer circuit is an EMG signal with a current gain without any amplitude reinforcement as shown in Figure 19.

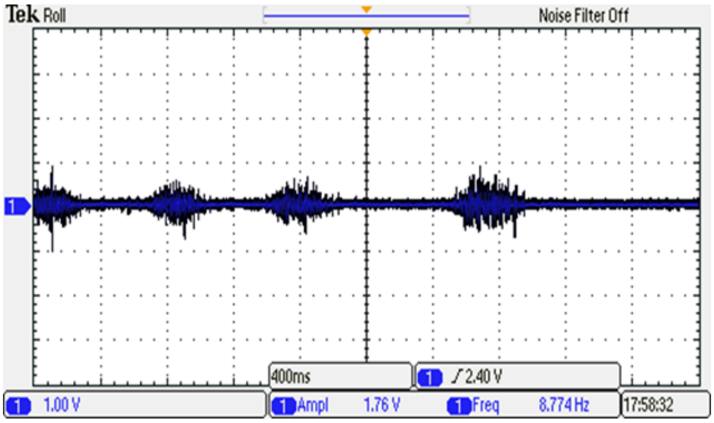

Fig. 19. Buffer and Output Circuit

The output of amplifier circuit makes the amplitude of EMG signal when contraction and relaxation of muscles is very clearly visible as shown in Figure 20.

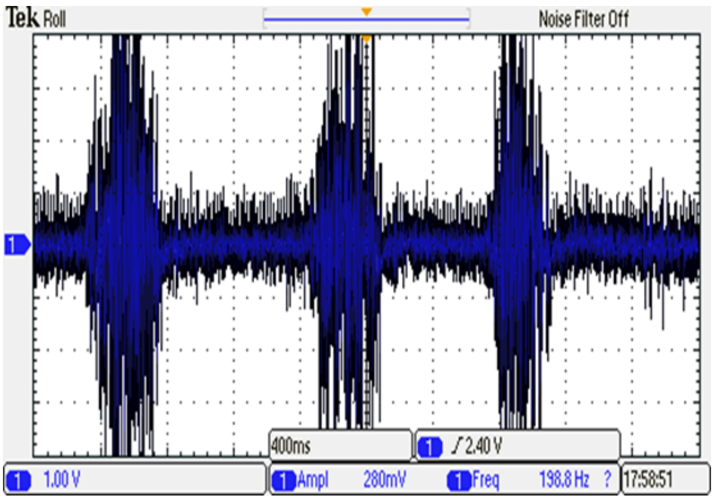

Fig. 20. Output of Amplifier Circuits

The output of the rectifier circuit has eliminated the signal-negative phase and the envelope circuit minimizes the EMG signal ripple due to the instability of the muscle contraction strength when controlling the wheelchair. The ripple signal will make the wheelchair not run smoothly as the signal fluctuates above and below the threshold value. The output of this stage is shown in Figure 21.

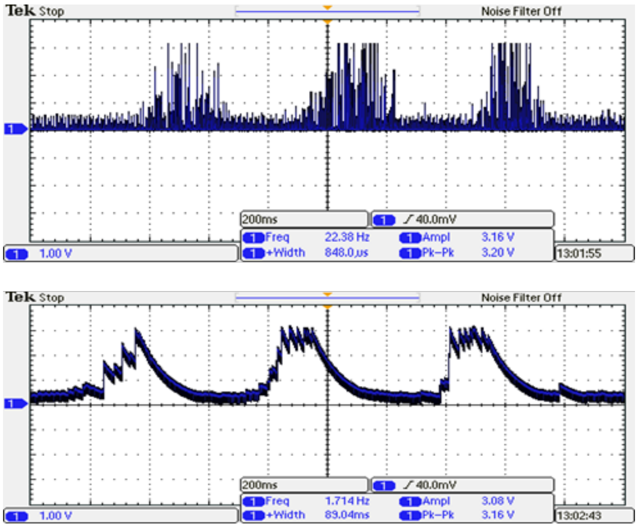

Fig. 21. Output of Rectifier and Envelope Circuits

3.3 Wheelchair testing

The testing technique in this study was carried out by comparing the direction of the movement of the wheelchair with the commands from the EMG signal. The placement of the EMG signal tapping electrodes in the participant is shown in Figure 22.

Fig. 22. Position of the EMG Signal Tapping Electrodes

Each participant performed 10 times each of the EMG signal control commands on a wheelchair which are forward, backward, turn right, turn left and stop as shown in Table. 3.

Table 3. Wheelchair Test Results

		Direction					
		Stop	***Forward***	***Backward***	***Turn Right***	***Turn Left***	***False Negatif (FN)***
Command	Stop	50	0	0	0	0	0
	Forward	0	47	1	2	0	3
	Backward	0	0	50	0	0	0
	Turn Right	0	0	1	48	1	2
	Turn Left	0	0	1	2	47	3
False Positif (FP)		0	0	3	4	1	

True Positive is a condition when the direction of a wheelchair is following the user's command, Positive False is a condition when the direction of the wheelchair is correct even though the user's command false and False Negative is a condition when the direction of a wheelchair is not following the user's command. Furthermore, the test results presented in Table 3 were calculated through Detectability value = TP / (TP + FP) and Selectivity = TP / (TP + FN) wheelchair system as shown in Table 4.

Table 4. Detectability and Selectivity

		Testing				
		True Positif (TP)	***False Positif (FP)***	***False Negatif (FN)***	***Detactibility (%)***	***Selectivity (%)***
Command	Stop	50	0	0	100	100
	Forward	47	0	3	100	94
	Backward	50	3	0	94.33	100
	Turn Right	48	4	2	92.31	96
	Turn Left	47	1	3	97.92	94

Detectability and Selectivity for all motion commands of a wheelchair system with special EMG signal control for quadriplegic people had values above 90%. Then, the Detectability and Selectivity values was compared to the use of the first threshold value (T1) from Yulianto [16], which is the average maximum amplitude of 3 times the data collection multiplied by 0.8 with the second threshold (T2), which is the average amplitude of the contraction period for 5 seconds multiplied by 0.4 shown in Table 5.

Table 5. Detectability Value and Selectivity

	Stop		**Forward**		**Backward**		**Turn Right**		**Turn Left**	
	Det	***Sel***	***Det***	***Sel***	***Det***	***Sel***	***Det***	***Sel***	***Det***	***Sel***
T1	92.59	100	71.43	100	100	96	94.23	98	96.15	50
T2	100	100	100	94	94.34	100	92.31	96	97.92	94

In general, the value of Detectability and Selectivity from T2 is better than T1. At T1, there are still Detectability and Selectivity values below 90%, which are the forward and left turn commands. This study has limitations. We do not use the participants from quadriplegic people because they are related to the safety issues of wheelchair systems that are still in the development phase. The failure of the control system can cause a wheelchair to suffer a fatal impact on the quadriplegic people. However, the results of this research can be applied to the quadriplegic people by regulating the value of the threshold on the comparators.

The results of this study compared with the results of other studies that also utilize physiological signals for the control of electric wheelchairs. Table 6 shows the comparative value of this research's average accuracy with other studies.

Table 6. Accuracy comparison of several studies

Studies	Accuracy (%)
T1, Yulianto [16]	88,8
T2	96,8
Kundu [3]	90,5
Kaiser [10]	97
Mahendran [12]	90,2
Prasad [17]	87,5

A comparison with some wheelchair control studies with physiological signals showed that the study had a high accuracy value even though it was slightly lower when compared to the Kaiser [10].

4 Conclusion

The purpose of this research is to help quadriplegic people to be more independent in their activities through electric wheelchair designs that utilize the amplitude of contraction and relaxation of EMG signals from the tapping of the neck and face muscles as a means of control. The trigger of electric wheelchair motor work in this study uses a comparator system that compares the value of the user's contraction amplitude and muscle relaxation with the threshold value that has been stored in the microcontroller memory. In this study the determination of the threshold value of the mean EMG signal amplitude when the contraction period is 5 seconds multiplied by the constant 0.4 produces an average accuracy of wheelchair movements of 96.8%. The advantage of the method of determining the threshold value in this study is that the threshold value can be changed according to the strength of the user's muscle contraction in order to be able to adjust changes in the value of the contraction amplitude and relaxation caused by muscle fatigue or changes in the strength of the muscle contraction due to physical therapy undertaken by the user. Detectability and selectivity for all forward, backward, turn right and left turn commands all have values above 90%. Future studies are determining the position of electrodes in the face and neck muscles that produce the most significant contraction amplitude values as a wheelchair control device for quadraplegic people. Also, the use of precision rectifier also known as super diode for better signal processing performance.

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