Comparison of Amplifiers Utilization in Instrumentation to Record Muscle Signals in the Neck for Electrolarynx Applications

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***Abstract*— Electrolarynx is an assistive technology commonly used by speech impaired people to speak. The speech impaired people who have lost their larynx (laryngectomee) or have damaged larynx use an electrolarynx device to be able to speak again. The use of the electrolarynx is generally equipped with a button to turn on and start the generation of sound from the electrolarynx. Several studies have tried to use other control methods by using the muscles in the neck, namely the sternohyoid muscle. Activation of the sternohyoid muscle has an influence on sound formation. The sternohyoid muscle is a small and long muscle so recording EMG (electromyograph) signals from this muscle is quite difficult. If the recording process of this signal can be carried out properly, then the electrolarynx control by empowering this muscle will be another solution in using the electrolarynx. In this study, instrumentation amplifier which is an important stage of recording EMG signals of neck muscle was tested and compared. There are two types of instrumentation amplifier tested. The first instrumentation amplifier uses a single IC from IC AD620 while the other is a combination circuit of IC OP07. The EMG signal in the subject's neck muscles was then recorded using the instrumentation amplifiers. The subject will sit down and pronounce the vowels "a", and "i". From the testing process, it was found that the average gain on IC AD620 (minimum 1.74362 volts and maximum 3.70538 volts) was greater than the gain on IC OP07 (minimum 0.57779 volts and maximum 1.71190 volts). IC AD620 also has an overall use area of 5.61 cm2 with the use of 4 external components. Thus, it can be concluded that the best instrumentation amplifier for recording EMG neck muscle for electrolarynx application is by using IC AD620.**

Keywords—instrumentation amplifier, electrolarynx, electromyograph, analog filter, speech impaired people.

I. INTRODUCTION

The use of electrolarynx for patients who have lost their larynx is one solution to be able to talk again. People with disappeared laryngeal due to removal of the larynx because of laryngeal cancer or other laryngeal diseases are called laryngectomee. Laryngectomee itself consists mostly of people aged 50 years and over. They are experiencing this condition because of cigarette and alcohol consumption [1]. Another solution besides electrolarynx (EL) is the use of esophageal speech (ES) and tracheoesophageal (TE) speech [1]. ES and TE are alternatives that produce a more natural sound and are most commonly used in Indonesia. However, the rehabilitation process using these technologies tends to take a long time until the patient is fully trained and can speak well again. Besides being difficult, the spoken voice often not clear enough to be understood by the other person [2]. Electrolarynx works by generating sound from vibrations given to the neck muscles so that they vibrate the vocal system. EL is the simplest assistive technology for the speech impaired and easy to use.

Several studies have developed methods for controlling the elecrolarynx. The simplest method is to use the on/off button to start the sound generation [3]. In addition, there are methods for analysis of control volume [4] and control by estimating the vibration frequency of the transducer [5] [6]. From these studies, it can be concluded that there is a relationship between neck muscle activity and sound formation. The neck muscle which is quite influential in sound formation is the sternohyoid muscle. This muscle is relatively small and long. The EMG signal generated by the sternohyoid muscle is very small, with values on the order of tens of microvolts [3]. Therefore, the role of instrumentation amplifier as the first stage in the process of recording electromyographic signals is a crucial part. Electromyography (EMG) is a discipline that deals with the detection, analysis, and utilization of electrical signals originating from muscle contractions [7]. The electrical signal data acquisition is carried out using an electromyograph instrument, and the recorded result is called an electromyogram. The characteristics of an EMG signal are random or stochastic signals whose amplitude ranges from 0 to 1.5 mV (root mean square) or 0 to 10 mV (peak-to-peak) with a frequency range of 0 – 500 Hz, with a dominant energy in the range of 50 – 150 Hz [8]. With those amplitude characteristics, the selection of the right amplifier to increase EMG signal is important. This is also reinforced in [9] which states that in an electrodiagnostic system, the amplifier is the

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most critical component. In order to get better EMG signal, it is important to compare some of the amplifiers which are usually used for recording biosignals.

In this study, a comparison was made with the use of two types of instrumentation to record EMG signals of the neck muscles. The standard instrumentation for EMG as described in [9] has a stipulation that EMG instrumentation must consist of amplifiers and filters in the hardware part. Modular EMG instrumentation was also used in study [10] to record EMG signals and analyze fatigue levels. However, there are many simple instrumentation amplifiers that can be used to record EMG signals. Starting from a single IC to the use of multiple ICs. This study compares the use of IC AD 620 and IC OP 07. Both ICs are quite widely used either as ordinary amplifiers or other electronic circuits. Because of that, this study wants to compare ICs which is commonly used, especially in Surabaya, Indonesia. OP07 is good Operational Amplifier, it is not too cheap nor too expensive with good performance. OP07 often used as comparator, simple amplifier, or complementary operational amplifier. It often used as instrumentation amplifier by combining several OP07's. Compared to the AD620 which also famous for instrumentation amplifier, AD620 is difficult to get in present day. So, by comparing the two ICs, it would be known which version of instrumentation amplifier that can record EMG signals better. Especially in applications to record EMG signals of the neck muscles.

II. Methods

Instrumentation to acquire EMG signals in neck muscles was designed in this study. EMG signals in the neck muscles can be used to control the use of the electrolarynx. The electrolarynx is used to produce replacement sounds. Sound is produced when an object (source) vibrates and causes the surrounding air to move. The production of human voice in the vocal tract basically starts from the nervous system commands in muscle control and manipulation of a series of sound-producing organs [11]. Respiration activity initiates the air production process by utilizing the air flow in the sound system. Inspiratory air is expelled from the lungs through the trachea and larynx to exert pressure. The vocal cords in the larynx vibrate as a result of this pressure. The vibrations of the vocal cords then resonate and the resulting sound is articulated by the articulator components, such as the tongue, teeth, and lips.

In this study, the instrumentation which is designed consists of several blocks. There are blocks that are made same and act as control variables such as analog filters, adders, and microcontrollers used. The variable which discussed in this study is the instrumentation amplifier circuit block. The amplifier circuit that will be the focus of this research is the use of two different types of ICs with different configurations.

A. *Experiment System Design*

In general, the experiment system used in this study has a purpose to compare two types of instrumentation amplifiers in recording EMG signals of the neck muscles when speaking. Fig. 1 shows how the block diagram of the circuit will be made. In the amplifier instrumentation block, there are 2 types of circuits made, namely a circuit using the AD620 IC and a circuit with a combination of IC OP07. The amplified signal is then processed in the next circuit block. In this study, the circuit blocks after instrumentation amplifier are made the same. Those are analog filters: band pass filter with gain, notch filter, low pass filter, and high pass filter. At the end of analog circuit, there is an adder amplifier which have functions to increase the voltage amplitude so that it can be converted to digital signal by the microcontroller.

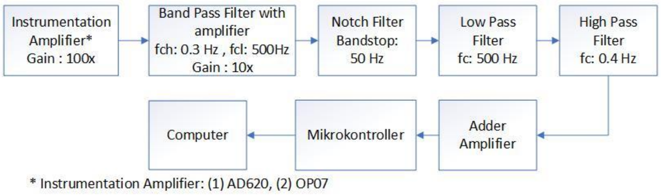


Fig. 1. Diagram of EMG Instrumentation Circuit.

B. *Protection Circuit*

The protection circuit is the first circuit in testing this instrumentation. In the protection circuit, the voltage is limited between ±Vm, where the magnitude of Vm is obtained by adjusting the potentiometers R_5 and R_6 in Fig. 2 (for Instrumentation with IC AD620) and Fig. 3 (for Instrumentation with IC OP07). So the magnitude of Vm is:

$$+V_m \text{ max} = +V \text{ supply}$$

$$-V_m \text{ max} = -V \text{ supply}$$

In addition, there is a passive low pass filter in the protection circuit. (1) is calculated to get cut off frequency (f_c). By selecting R_1=R_3=27k and C_1=C_2=10n, so

$$f_c = 1 / (2 \pi R C) = 1 / (2\pi \, 27k \, 10n) \quad (1)$$

$$f_c = 589{,}46 \text{ Hz}$$

The choice of this cut off frequency is because the EMG signal in the range of 0 – 500 Hz. After this circuit block, there will be other filtering processes to remove unwanted signals.

C. *Instrumentation Amplifier with IC AD620*

The Instrumentation Amplifier with IC AD620 is a special type of IC with a wide range of uses. This circuit is the first amplifier circuit to be tested. Design of the circuit is shown in Fig. 2. The selection of the gain of the circuit is adjusted to obtain graded gain. Based on the datasheet, the selected value of R_{17} is 500 Ω to obtain gain around 100x.

D. *Instrumentation Amplifier with IC OP07*

The instrumentation amplifier with OP07 is a basic type of instrumentation amplifier consisting of three op amps. The first and second op amps are used to amplify the input signal of those two op amps. The gain configuration of the two op amps is non-inverting, the output of these two op amps becomes the input for the third op amp which functions as a differential amplifier. This instrumentation amplifier circuit is the second circuit that will be compared in this study. This design is equipped with one op amp that functions as a signal reference channel. The overall circuit design is shown in Fig. 3.

In the gain section, the gain of the instrumentation amplifier design is set by selecting the following components:

$R_7 = R_8 = 10k$
$R_9 = 2k2$
$R_{10} = R_{11} = 1k$
$R_{12} = R_{19} = 10k$. (2) calculate the gain, so

$$Gain = (10k / 1k)\ (1 + (2 * 10k) / 2k2) \quad (2)$$
$$= (10)\ (1 + 9.09) = 100.09\ x$$

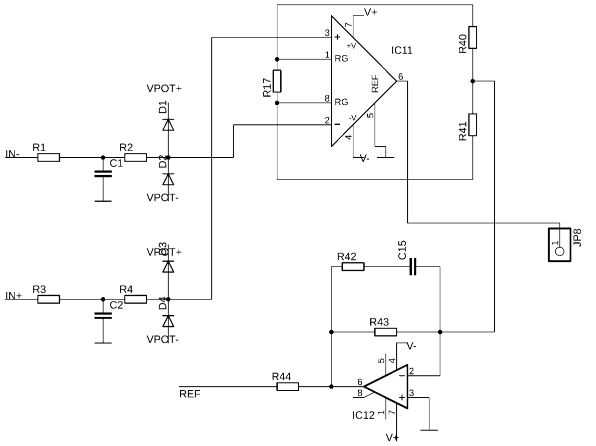


Fig. 2. Instrumentation amplifier circuit with IC AD620

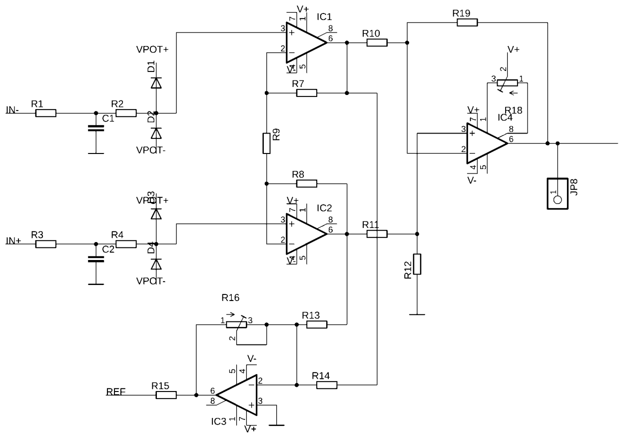


Fig. 3. Instrumentation amplifier circuit with IC OP07

In the last amplification section, there is a multitune R_{18} which functions to adjust the offset of the signal. The Op Amp (IC3) functions as a reference channel where the configuration is an inverting amplifier with inputs from IC1 and IC2. The magnitude of the gain of this amplifier is

$$Gain\ max = - R_{16} / R_{13} = - 100k / 10k = -100\ x$$
$$Gain\ min = - R_{16} / R_{13} = - 0 / 10k = 0\ x$$

The negative gain here functions as a phase inverter from the existing input signal, so that the noise signal can be removed with 180^0 different phase.

E. Band Pass Filter with Gain

After the first gain of the instrumentation amplifier, the EMG signal enters the band pass filter circuit block. This filter is designed to pass signals in the frequency range between 0.3 Hz and 500 Hz. The high cut off frequency (f_{ch}) 0.3 Hz serves to dampen the DC signal while the low cut off frequency (f_{cl}) serves to dampen the signal above 500 Hz. This is because the maximum EMG bandwidth is 500 Hz. The design of the amplified band pass filter is shown in Fig. 4. With the selection of f_{cl} and f_{ch}, the components used in the circuit of bandpass filter with gain are:

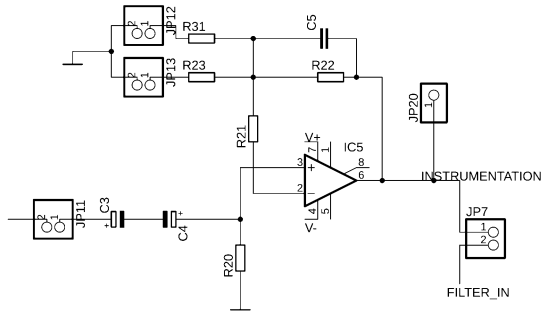


Fig. 4. Circuit design of band pass filter with gain

(3) calculate the high cut off frequency (f_{ch}). With f_{ch} = 0.3 Hz and R_{20} = 100k, so

$$f_{ch} = ½\ \pi\ ((C_3\ x\ C_4) / (C_3+C_4))\ R_{20} = 1 / (\pi\ C\ 100k) \quad (3)$$
$$C = 1 / (\pi\ f_{ch}\ 100k) = 1 / (\pi\ 0.3\ 100k)$$
$$C = C_4 = C_3 = 10{,}61\ \mu F \approx 10\ \mu F$$

(4) calculate the low cut off frequency (f_{cl}). With f_{cl} = 500 Hz and R_{22} = 100k, so

$$f_{cl} = 1 / (2\pi\ C_5\ x\ R_{22}) = 1 / (2\pi\ C_5\ 100k) \quad (4)$$
$$C_5 = 1 / (2\pi\ f_{cl}\ 100k) = 1 / (2\pi\ 500\ 100k)$$
$$C_5 = 3{,}183\ nF \approx 3{,}3nF$$

Basically, this band pass filter functions more as an amplifier than as a filter. The designed amplification is quite large, by utilizing R_{23} or R_{31}, different amplification will be obtained.

(5) is amplification using R_{23}:

$$Gain = (R_{22} + R_{23}) / R_{23} = (100k + 1k) / 1k = 101\ x \quad (5)$$

(6) is amplification using R_{31}:

$$Gain = (R_{22}+R_{31}) / R_{31} = (100k + 10k) / 10k = 11\ x \quad (6)$$

The multilevel filtering process is commonly use in an instrumentation, especially in biomedical instrumentation. After the band pass filter with gain circuit, the next step is filtering. Multilevel filtering is also used in [12]. With multilevel filtering, unwanted noise will be suppressed.

F. Notch Filter

The notch filter on this instrumentation is used to dampen the signal from the electric grid. So, the frequency to be rejected is 50 Hz. Fig. 5 is a design of a notch filter circuit with a Twin T configuration.

(7) calculate the reject frequency (f_{reject}). Component selection start with $R_{36} = R_{37} = 33k$, so

$$f_{reject} = 1 / (2 \pi R C) = 1 / (2\pi\ 33k\ C) \quad (7)$$

$$C = 1 / (2\pi\ 33k\ f_{reject}) = 1 / (2 \pi\ 33k\ 50)$$
$$C = 1 / (2\pi\ 33k\ f_{reject)} = 1 / (2 \pi\ 33k\ 50)$$
$$C_{10} = C_{11} = C_{12} = C_{13} = 90.6\ nF \approx 100\ nF$$

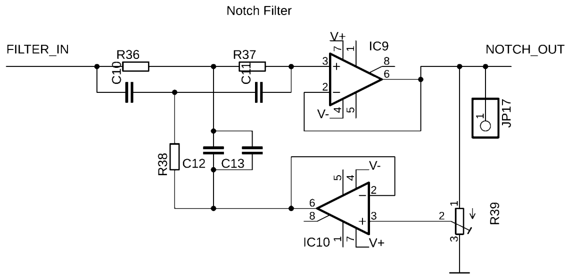


Fig. 5. Circuit design of notch filter

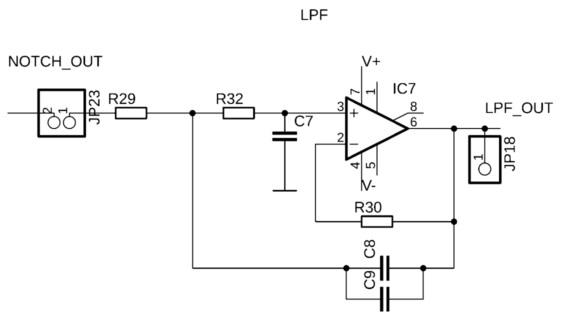


Fig. 6. Circuit design of low pass filter

G. Low Pass Filter

The circuit design used in Fig. 6 for the low pass filter is a butterworth order 2 with a cut off frequency of 500 Hz. The frequency selection at 500 Hz is also used in [13]. (8) calculate this cut off frequency. By calculation, the result if $R_{29} = R_{32} = R = 10k$ are

$$f_c = 1 / (2 * 1.414\ \pi\ R\ C) = 1 / (2 * 1.414\ \pi\ 10k\ C) \quad (8)$$
$$C = 1 / (2 * 1.414\ \pi\ 10k\ f_c) = 1 / (2 * 1.414\ 10k\ \pi\ 500)$$
$$C = 22.5\ nF \approx 22\ nF$$

So $C_7 = C_8 = C_9 = 22$ nF.

H. High Pass Filter

The circuit design used in Fig. 7 for the high pass filter is a butterworth order 2 with a cut off frequency of 0.4 Hz. The selection of the cut off frequency aims to eliminate the DC signal (0 Hz). (9) calculate this cut off frequency. By calculation, the result if $C_6 = C_{14} = 1\ \mu F$ are

$$f_c = 1.414 / (2\pi\ R\ C) = 1.414 / (2\pi\ R\ 1\mu) \quad (9)$$
$$R = 1.414 / (2\pi\ f_c\ 1\mu) = 1.414 / (2\pi\ 0.4\ 1\mu)$$

$$R = 562{,}7k \approx 560k$$

So $R_{33} = R_{35} = 560k$.

The output of the high pass filter is then forwarded to the adder amplifier. Because the signal from the EMG has a negative component, the adder amplifier serves to increase the signal's magnitude so that the overall signal will be positive. The signal that has gone through the process is then acquired by the microcontroller with a sampling frequency of 1.6 kHz. According to the Nyquist theorem,

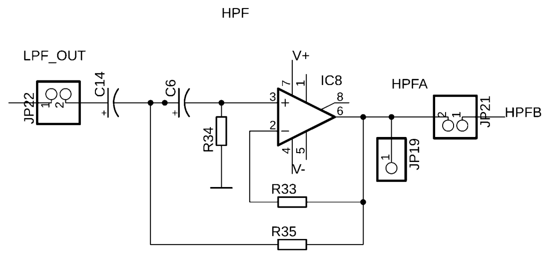


Fig. 7. Circuit design of high pass filter

the maximum frequency that can be recorded with this sampling frequency is 800 Hz.

I. Experiment Scenario

Data collection to compare the performance of the instrumentation amplifier using IC AD620 and IC OP07 was carried out by recording the EMG signal directly to the subject when speaking. Proper electrode placement is important in analyzing the electrical signals of muscle activity that are related to sound formation. Study [14] studied the proper placement of electrodes in recording muscle signals in the neck. The neck strap muscle has been a commonly studied muscle in previous EMG-EL studies, particularly the sternohyoid muscle [15]. Utilization of muscle signals in the neck is also widely used as a control signal. One of them is in [16] as a form of human computer interaction on the subject of tetraplegia patients.

In this study, the subject was asked to sit in a chair with his head turned to the right. The positive electrode is then placed in the middle of the sternohyoid muscle. The negative electrode is placed on the edge of the sternohyoid muscle while the reference electrode is on the mastoid. After the electrodes were placed, the subjects were then asked to pronounce the letter "a" and the letter "i". This pronunciation is done 5 times for each letter and each instrumentation amplifier used. So the data obtained are 5 vowel data "a" and 5 vowel data "i" for IC AD620. The same amount is also obtained using IC OP07. From these data, gain analysis and analysis on the frequency spectrum were then carried out. This analysis will determine the instrumentation amplifier that has the best performance.

III. Results and Discussion

The analysis process starts with digital signal processing after the data is acquired by the microcontroller. The microcontroller does sampling on the signal every 0.625 ms or equivalent with 1.6 kHz. To validate the sampling frequency, tests are carried out so that it can generate impulses every 0.625ms. Fig. 8 shows the test results of the sampling frequency. It can be seen that the impulse repeats with a frequency of 1.6 kHz. Thus, all EMG signals in the 0-

800 Hz range can be recorded according to the Nyquist theorem.

The EMG signal has a small amplitude with the smallest order in the tens of microvolts. To compare the performance of the two types of instrumentation amplifiers, several analyzes were carried out. The recorded signal is then analyzed from the output signal data obtained. The main analysis is the result of signal amplification, whether the signal is large enough with the same amplification design.

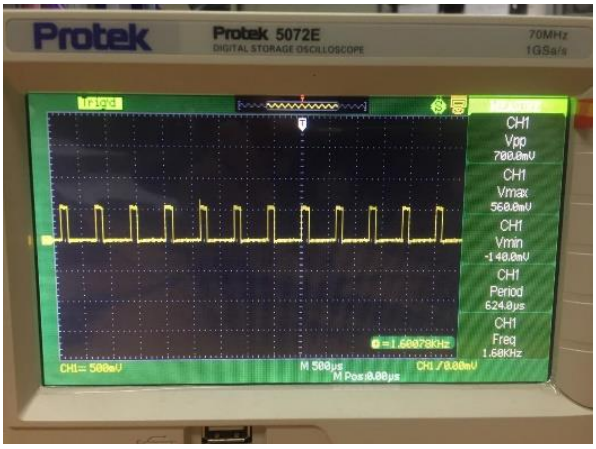
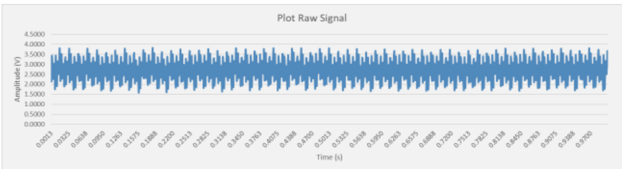
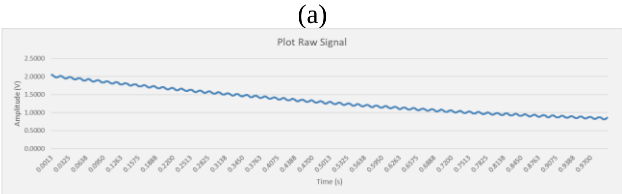


Fig. 8. Validating the sampling frequency of 1.6 kHz.



(a)



(b)

Fig. 9. Recording result of output EMG signal on (a) IC AD620 (letter a-4), and (b) IC OP07 (letter a-2)

This analysis process can be carried out in the time domain or in the frequency domain.

Fig. 9 is the result of the circuit from all the stages (instrumentation amplifier, bandpass filter with gain, notch filter, low pass filter, high pass filter, adder amplifier). Because the circuit after instrumentation amplifier is same, then Fig. 9 actually show the difference between two instrumentation amplifiers. Fig. 9a shows that the result of IC AD620 has a larger waveform than IC OP07. While IC OP07 has a fairly large DC drift. The EMG signal in Fig. 9b decreased after recording started. The signal range of Fig. 9b is also not as large as that of Fig. 9a. Through the time domain analysis, it is known that the gain of IC AD620 is better than IC OP07. Statistically in Table I and Table II, the average gain on IC AD620 (minimum 1.74362 volts and maximum 3.70538 volts) is larger than using IC OP07 (minimum 0.57779 volts and maximum 1.71190 volts).

The results of good amplification are also shown in the frequency analysis, it was found that the frequency component of the signal amplified by AD620 is better than the amplification of IC OP07. Fig. 10 shows the frequency spectrum analysis of the recorded signal. Details of the frequency analysis for each pronounced letter are presented statistically in Table III and Table IV. In Table IV it is also known that there are several pronunciations of letters that have a high DC component. This appears a lot in the use of IC OP07. In the time domain, we can inspect visually DC drift of the EMG signal. The DC drift is very prominent.

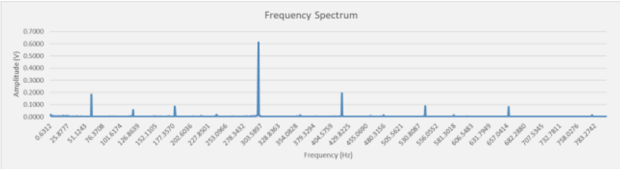
TABLE I. RESULT OF SIGNAL AMPLIFYING FOR EVERY LETTER USING IC AD620

No.	Letter	Minimum (v)	Maximum (v)	Range (v)
1	a1	1.56648	3.80152	2.23504
2	a2	1.69336	3.74296	2.04960
3	a3	1.77632	3.67464	1.89832
4	a4	1.59088	3.82592	2.23504
5	a5	1.77144	3.74296	1.97152
6	i1	1.84952	3.64536	1.79584
7	i2	1.81048	3.66000	1.84952
8	i3	1.77144	3.67952	1.90808
9	i4	1.80560	3.63560	1.83000
10	i5	1.80072	3.64536	1.84464
Average		1.74362	3.70538	1.96176

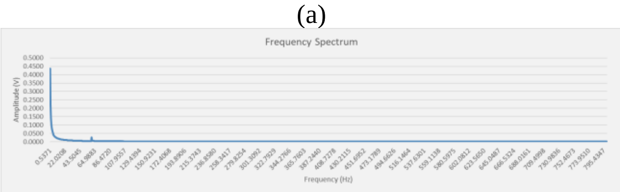
TABLE II. RESULT OF SIGNAL AMPLIFYING FOR EVERY LETTER USING IC OP07

No.	Letter	Minimum (v)	Maximum (v)	Range (v)
1	a1	0.00000	1.52256	1.52256
2	a2	0.65392	2.04960	1.39568
3	a3	0.65392	2.01544	1.36152
4	a4	0.65392	1.65432	1.00040
5	a5	0.63928	1.65920	1.01992
6	i1	0.63928	1.63968	1.00040
7	i2	0.63928	1.65432	1.01504
8	i3	0.63440	1.63480	1.00040
9	i4	0.63440	1.64456	1.01016
10	i5	0.62952	1.64456	1.01504
Average		0.57779	1.71190	1.13411

Different things are shown on the IC AD620. The IC AD620 has no significant DC drift.



(a)



(b)

Fig. 10. Result of frequency spectrum's signal on (a) IC AD620 (letter a-4), and (b) IC OP07 (letter a-2)

TABLE III. FREQUENCY ANALYSIS ON IC AD620

No.	Letter	Minimum		Maximum	
		Mag_DFT (v)	Freq(Hz)	Mag_DFT (v)	Freq(Hz)
1	a1	0.000107208	234.77	0.52001188	299.81
2	a2	3.23815E-05	295.02	0.262622534	0.57
3	a3	0.04257026	59.97	0.36518574	299.86
4	a4	0.000187821	542.80	0.609932484	299.80
5	a5	0.00012402	157.04	0.399425302	299.57
6	i1	0.000105683	176.64	0.367276989	300.28
7	i2	0.000154937	162.37	0.412724467	299.89
8	i3	0.00010532	19.44	0.476586945	299.85
9	i4	0.000230903	531.17	0.421997538	299.56
10	i5	9.21225E-05	123.55	0.346135165	299.65
Average		0.004371066	230.28	0.418189904	269.88

TABLE IV. FREQUENCY ANALYSIS ON IC OP07

No.	Letter	Minimum		Maximum	
		Mag_DFT (v)	Freq(Hz)	Mag_DFT (v)	Freq(Hz)
1	a1	3.23815E-05	295.02	0.262622534	0.57
2	a2	0.000808522	602.62	0.436234469	0.54
3	a3	0.000778653	419.80	0.417567953	0.54
4	a4	0.000380073	799.71	0.28941417	0.57
5	a5	0.000382307	58.62	0.29078676	0.56
6	i1	0.000295353	61.38	0.293458734	0.57
7	i2	0.000435777	800.00	0.300504645	0.58
8	i3	0.000383879	800.00	0.293866232	0.57
9	i4	0.000406954	800.00	0.295548927	0.57
10	i5	0.000380815	799.71	0.295159525	0.58
Average		0.000428472	543.69	0.317516395	0.56

TABLE V. COMPARISON OF AREA AND COMPONENT USED IN IC OP07 AND IC AD620

Comparison	IA with IC OP07	IA with IC AD620
Over All Area (cm2)	10.64	5.61
Component used	10	4

AD620 is a single IC so it is normal if the area required to use this IC as an instrumentation amplifier is smaller than when using IC OP07. Table V shows the area in the instrumentation amplifier circuit using AD620 and OP07. The AD620 also uses fewer external components than the OP07, so it can be concluded that the use of the AD620 as an instrumentation amplifier is more effective and efficient when using the circuit area. In the application of electrolarynx, this will be good feature because usually wearable part (neck strap of EMG sensors) become smaller and comfortable. With better gain and smaller area, the AD620 will be superior and can control the activation of electrolarynx.

In the experiment, it was also known that there was a difference between the magnitude of the EMG signal produced when pronouncing a letter. The letter "a" produces a larger EMG signal than the letter "i". This is because the movement of the mouth when pronouncing the letter "a" causes more muscle contractions. Thus, if we want to use the pronunciation of certain letters as a control in the electrolarynx, then the letter "a" is better to use than the letter "i".

IV. CONCLUSION

The sternohyoid muscle gives off a unique electromyograph signal when speaking. These signals are on the order of mV and can be recorded with the instrumentation amplifier. From the recording results, it was found that the instrumentation amplifier using the AD620 IC was better at recording EMG signals. The average gain on the AD620 IC is greater than the gain on the IC OP07. IC AD620 also has an overall use area of 5.61 cm2 with the use of 4 external components.

The placement of electrodes when recording to get an EMG signal in the neck muscles also needs to be considered. Especially when the subject is the laryngectomee. In order to use EMG signals in the neck muscles as an electrolarynx control, it is also necessary to pay attention to the correct pronunciation of the letters to use. In this study, the pronunciation of the letter "a" has a greater EMG signal than the pronunciation of the letter "i"

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