The Design of the Electromyography Sensor with the Modifying Circuit

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Abstract. The project is about using the Electromyography (EMG) sensor to display the muscle movement and use connecting circuit to modify the signal from the EMG sensor. The modifying circuit connected to the EMG sensor include the amplifier circuit to amplify the signal, the filter to remove the DC offset and the high frequency noise, the rectifier for the positive swing of the signal and the envelope detector to smooth the signal. The circuit is designed according to the signal amplitude and the frequency spectrum and is simulated on the Multisim and have the output. The actual circuit is built as in the simulation and the signal is from the electrode. The output is in audiovisual and performance of the EMG sensor circuit is demonstrated by experiment. The design of the EMG in the project uses the simple component in electronic circuit with the desired output. The display of the EMG sensor in the project is audiovisual which provides the user with output format both in visual and in audio that allows hearing disability and visual disability users to use the EMG sensor.

1. Introduction
The Electromyograph (EMG) sensor with the audiovisual output of the project is the device that is controlled by the sensor of the muscle activity [1]. The EMG sensor sense the current flowing from the muscle to test the muscle movement and the muscle strength. The original signal the muscle generated could not be easily interpreted and the signal and the information is provided in analysing human biomechanics and the movement of the animal by using the EMG sensor [2]. The aim of the project is using EMG sensor to measure and to show muscle activity movement and muscle activity strength display using different display of audio, visual and/or motion. The aim of the project is achieved using the circuit connected to the EMG sensor that the original signal the muscle generated is amplified with the amplifier circuit, modify the amplified signal with the modifying circuit and the output of the circuit is displayed in audio and visual by connecting the output of the circuit to the microcontroller. The basic component of the EMG sensor has the instrumentation amplifier, the filter, the rectifier, the envelop detector and the microcontroller which in the project used is the Arduino to display the output. The work research the property of the EMG sensor circuit, modify the design of the circuit, investigate the characteristic of different component and experiment the performance of the circuit.
2. Theory

2.1. EMG
The technique Electromyography (EMG) measure and record the muscle activity signal and the muscle activity is recorded using the electrodes which is inserted on the muscle and detect the potential of the action of the individual muscle units [3]. The signal of the EMG is transmitted and detected by the electrode inserted on the muscle [4]. The range of the amplitude of the EMG signal is from sub-mV to the few mV and the range of the frequency of the signal is from 0 to 500Hz and the range of the dominant signal is of 50 to 150Hz [2]. The EMG signal power density spectrum range for most muscle is from 0 to 400Hz and above the power density spectrum range the EMG signal is not distinguished from the detected noise and the from the recording system [2].

2.2. Instrumentation Amplifier
The EMG signal amplitude is detected however the EMG signal amplitude is not large enough for the signal measurement. The instrumentation amplifier is used to amplify the EMG signal with large gain and the instrumentation amplifier is used with large noise [5]. The different input, the large input impedance, the defined gain and the reject common mode signal is the benefits of the instrumentation amplifier [1].

2.3. Filter
The instrumentation amplifier amplify the few millivolts offset voltage generated in the interface of the electrode-skin. The high-pass filter is filter the DC offset and the low-pass filter is filter the noise in the signal. The benefit of the high-order filter is that the large rate of the roll-off gain after the bandwidth compare with the low-order filter [6]. The second-order high-pass filter is used to attenuate the DC offset and the second-order low-pass filter is used to attenuate the noise generated in the signal [1].

2.4. Rectifier
The signal of the EMG sensor is rectified to calculate the average value of the EMG sensor amplitude. The signal flow direction is the same in the rectifier which uses the diode as the rectifier [7]. The EMG signal which is rectified only has the positive swing or the negative swing. The super diode circuit has the small conduction threshold which is close to 0V and the super diode circuit has the characteristic of the diode [1].

2.5. Envelope detector
The signal is modulated by the envelope detector [8]. The output signal of the rectifier is smooth by the envelope detector for the more DC signal and connect the envelope detector to the microcontroller.

3. Method

3.1. The EMG Sensor with the Audiovisual Output Design and the Simulation on the Multisim
The component in the EMG sensor is the EMG sensor electrode, the instrumentation amplifier, the filter, the rectifier, the envelop detector, the microcontroller and the display. The modifying circuit connected to the EMG sensor is simulated on the Multisim to measure the circuit performance. The circuit design of the simulation on the Multisim is shown in Figure 1.
Figure 1. The circuit design of the simulation on the Multisim
The amplifier LMC660CN/NOPB is used for the amplifier in the circuit because of the feature of the large voltage gain and the low input offset voltage as shown on the LMC660CN/NOPB datasheet [9]. The sine wave input signal has the frequency of 100Hz, the amplitude of 500μVpp and the 0 offset voltage.

The coin is chosen as the electrode because of the conductivity of the material and the accessibility of the material. The compound metal is chosen as the electrode because of the conductivity of the material [10]. The 1p coin is minted in steel and electroplated in copper and the 2p coin is made of the material of copper-plated steel as researched [12]. By using the electrode that the surface area is large, the signal of the electrode is large. It is researched that the 2p coin is not easy to connect tightly with the surface the skin when the muscle activity is produced. As the measurement of the different coins shown the electrode use the 1p coin. To build the electrode, the conductive tape is used to provide conductivity and the circuit wire is used to connect the electrode to the circuit.

The input signal from the electrode to the circuit is amplified by the instrumentation amplifier. The instrumentation amplifier circuit design is shown in Figure 2.

![Figure 2. The instrumentation amplifier circuit design](image-url)

The electrode 1 and the electrode 2 and the reference electrode is connected to the instrumentation amplifier and the instrumentation amplifier amplify the difference of the input signal. The instrumentation amplifier should not amplify the signal when the inputs are the same [13]. The large resistor value of 220Ω to 10kΩ is used in the circuit to reduce the current and to stabilize the signal. The instrumentation amplifier gain is

\[ A = \frac{V_o}{V_i} = \frac{V_o}{(V_2 - V_2)} = \frac{R_6}{R_5} \left( 1 + \frac{2R_2}{R_1} \right) = 275 \]

The simulation of the circuit on the Multisim shows that the input signal amplitude is 386.114μV and the output signal amplitude is -98.027mV. The gain of the simulation on the Multisim is similar to the gain calculated on the equation which is -253.88 however it is the negative gain of the simulation on the Multisim.

The second-order filter is used to filter the DC offset and to filter the noise with the large rate. The high-pass filter and the low-pass filter circuit design is shown in Figure 3.
The capacitor value of 1μF and the 100pF is used in the circuit and the resistor value from 15kΩ to 33kΩ is used in the circuit to filter the DC offset and to filter the noise. The operational amplifier has the DC offset \[14\]. The filter cut off frequency is \[ f_H = \frac{1}{2\pi R_1 C_1 C_2} = 6\text{Hz} \] and \[ f_L = \frac{1}{2\pi R_3 R_4 C_3 C_4} = 106k\text{Hz} \]

The input signal amplitude of the simulation on the Multisim is 100.621mV and the output signal amplitude of the simulation on the Multisim is 110.440mV. The corner frequency of the filter measured on the Bode plot is 50Hz and 40kHz and the calculated corner frequency on equation is larger than the corner frequency in the Bode plot.

The full-wave bridge rectifier circuit has the advantage that achieve larger output power \[15\]. The bridge amplifier is widely available \[16\]. The full-wave rectifier circuit design is shown in Figure 4.

![Figure 4. The full-wave rectifier circuit design](image)

It can be shown in Figure 4 that the resistor value from 2.2kΩ to 10kΩ is used in the rectifier to reduce the current and to stabilize the circuit. The input signal to the rectifier is rectified in full wave with the positive swing as shown in the simulation on the Multisim. The input signal amplitude of the
simulation on the Multisim is 100.713mV and the output signal amplitude of the simulation on the Multisim is 83.092V. The output signal amplitude of the rectifier is reduced compared with the input signal amplitude of the rectifier.

The additional amplifier is connected to the rectifier to amplify the signal because the energy loss of the signal is rectifier. The additional amplifier circuit design is shown in Figure 5.

![Figure 5. The additional amplifier circuit design](image)

The resistor value from 100Ω to 2.2kΩ is used in the additional amplifier circuit. The input signal amplitude of the simulation on the Multisim is 14.746mV and the output signal amplitude of the simulation on the Multisim is 415.837mV. The gain of the amplifier calculated is 28.

The envelope detector is connected to the additional amplifier to smooth the additional amplifier output signal. The envelope detector could respond to the magnitude of the resultant carrier [17]. The envelope detector circuit design is shown in Figure 6.

![Figure 6. The envelope detector circuit design](image)
The microcontroller is Arduino used in the EMG sensor circuit. The microcontroller process the output signal of the envelope detector.

The EMG sensor output is the audio display and the visual display. The LED bar contains several individual LEDs and the large number of LEDs in the LED bar light up the large amplitude is. The large speaker voice is the large amplitude is.

3.2. Experimental procedure
Step 1: Build the circuit of the circuit design in the Figure 1 on the breadboard.
Step 2: Power the amplifier using the DC voltage of the +9V and the DC voltage of -9V and set the sine wave with amplitude of 1mVpp and with the frequency of 100Hz for the input signal. The amplifier LMC660CN/NOPB in the instrumentation amplifier gets hot and smells like burnt.
Step 3: Test the instrumentation amplifier, the filter, the rectifier and the envelope detector part of the circuit separately. The instrumentation amplifier output signal is not amplified compared with the instrumentation amplifier output signal. However, according to the output of the part of the circuit slightly changes is made of the value of the resistor and the value of the capacitor.
Step 4: Each amplifier is tested separately in the instrumentation amplifier and it shows that one of the amplifiers does not work in the instrumentation amplifier. When changing the circuit design of the simulation in the Multisim the amplifier output signal is connected to the amplifier positive input. After the design of the circuit is changed the amplifier works well for the input signal of the amplifier,
Step 5: Then solder the coin centre and connect the EMG electrode to the EMG circuit. When contracting the muscle on the LED bar more LEDs light up and the speaker voice is larger.

3.3. Results
The input signal of the component in the circuit is shown in channel 1 of the oscilloscope and the output signal of the component in the circuit is shown in channel 2 of the oscilloscope.

The instrumentation amplifier input signal and the instrumentation amplifier output signal is shown in Figure 7.

![Figure 7. The instrumentation amplifier input signal and the instrumentation amplifier output signal](image-url)
The input signal amplitude on the oscilloscope is 2.4122mV and the output signal amplitude on the oscilloscope is 120.35mV.

The filter input signal and the filter output signal is shown in Figure 8.

Figure 8. The filter input signal and the filter output signal

The noise in the input signal of the filter on the oscilloscope of the filter and the noise is filtered in the output signal of the filter on the oscilloscope of the filter.

The rectifier input signal and the rectifier output signal is shown in Figure 9.

Figure 9. The rectifier input signal and the rectifier output signal
The rectifier output signal on the oscilloscope is rectified by the rectifier with the positive swing of the signal. However, in the rectifier output signal the voltage loss is in the negative swing rectified of the output signal.

The additional amplifier input signal and the additional amplifier output signal is shown in Figure 10.

![Figure 10. The additional amplifier input signal and the additional amplifier output signal](image)

The additional amplifier input signal amplitude on the oscilloscope is 2.4419mV and the additional amplifier output signal amplitude on the oscilloscope is 3.414V. The additional amplifier gain is 1398.

The envelope detector input signal and the envelope detector output signal is shown in Figure 11.

![Figure 11. The envelope detector input signal and the envelope detector output signal](image)
The envelope detector smooth the envelope detector output signal compared with the envelope detector input signal.

In general, the large number of the LEDs in the LED bar light up the large speaker voice frequency and the large muscle strength. However, change the microcontroller code to make the output respond based on the muscle activity frequency.

3.4. Discussion and problems
However, according to the experiment the EMG sensor output signal is not stable and the EMG sensor output signal not always respond to the EMG circuit. Any circuit wire movement and wire intercontact affects the output of the EMG sensor. The two close unconnected terminals of the circuit acts as the antenna and the noise presented in the output signal of the circuit is generated by the circuit. The large permeability and permittivity ratio of the wire has effect on the antenna as which the unconnected wire perform [18]. The use of the ‘auto set’ function of the oscilloscope for testing the output signal of the oscilloscope cause the signal on the oscilloscope not the same as the output signal and reset the oscilloscope. The muscle activity signal is measured by the EMG electrode and the muscle activity signal is affected by the point the EMG placed whether it is the obvious activity of the muscle.

4. Conclusion
The aim of the project which is show the muscle activity movement and muscle activity strength using the EMG sensor with the display of audio, visual and/or motion is achieved. The EMG electrode design use the 1p coin and the design of the instrumentation amplifier has the 200 gain to amplify the signal. The filter design has the corner frequency of 6Hz to 106kHz filter the DC offset and filter the noise. The filter output signal is rectified with the positive swing of the signal to calculate the mean value of the amplitude of the signal. However, the additional amplifier is used because the voltage loss in the output signal of the rectifier to amplify the rectifier output signal amplitude. The envelope detector connected to the rectifier is used to process the signal smooth the rectifier output signal to the more DC signal of the rectifier output signal. The envelope detector output signal is connected to the LED bar and is connected to the speaker which shows the muscle activity movement and the muscle activity strength and providing the display of visual and/or audio so that the visual problem people and the hearing problem people could read the muscle activity movement and the muscle activity strength.

For future work, using the conductive gel to connect the EMG electrode on the electrode-skin surface provide stable signal of the muscle activity for building the EMG electrode. The circuit designer is benefited by the connection of the component in the EMG sensor and the reduce of the circuit wire of the circuit in problem shooting and reduce overlapping wires of the circuit reduce the noise in the EMG circuit. The noise generated in the circuit is reduced by using the stripboard to provide the stable EMG sensor signal.

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