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Course: Physics 111

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Grading Rubrics

	Maximum Points	Points Received
Introduction	20	
Diagrams	20	
Descriptions	40	
Level of Functioning	40	
Design Creativity	40	
Measurements	10	
Conclusions	10	
References	5	
Total	185	

Lab 12 Final Project

Abstract

In our final project EMG (electromyography) mouse cursor controller, we use 9 EMG/EEG electrodes (Ambu/Neuroline Cup Electrodes), 1.8kΩ, 2.2kΩ, two 4.7kΩ resistors, 4 BNC Cables, +12V and -12V DC power supply, 6 instrumentation amplifiers (AD62AN), and wires. We quantitatively measure and analyze the RMS voltage of our analog signals from moving left, right, up, down our hands and find out the gain of each instrumentation amplifier. Also, we have developed many techniques in EMG signal processing and noising cancelling.

Introduction

As we know, human's muscle can generate approximately 2 to 5mV signals when we flex bicep. We are not only able detect these signals but also use it to create something fun and useful. Our group is interested in EMG (electromyography) technology and applying our muscle signals to control mouse cursor. Our goal is to reduce the pain of traditional mouse users and create a new way to control mouse cursor.

Our final project consists of hardware and software components. For its hardware part, we search which type of amplifier we should use and obtain the signal. Since we plan to model a real mouse, we should have left, right, upward, downward functions. Therefore, we decide to use 9 electrodes, two for each function, and 4 instrumentation amplifiers to process the raw EMG signal. Our first step is to attach electrodes on our right hands and connect the other end to the positive and negative input V_+ and V_- of the instrumentation amplifier. Theoretically, we understand that we should use differential amplifier. However, after doing research, we know that a simple differential amplifier does not work well in obtaining EMG signals because of the large common mode from the noise. Therefore, we use instrumentation amplifier to reject the common mode signal and amplify the differential mode. We then send the signals in the DAQ to acquire analog signal.

After acquiring the EMG signals, we need to use it to control the mouse cursor. Thus, for the software component, we write a LabVIEW routine that filters noise signals and controls the mouse cursor as precisely as in pixel in accordance with the input signal. We use a 60Hz notch filter and a 50Hz to 200Hz band pass filter to filter the noise and obtain the muscle signal. The RMS voltages of the input signals determine the direction, distance, and speed the mouse cursor moves. Our program can move the mouse in four directions. We will explain the ideas, structures, block diagram, and functionality of our program in details in the next section.

We also plan to test, debug, and improve our circuit. We understand that our project greatly depends on the environment. In other word, it may work on one day, but may not work on the next day because factors like the level of noise the environment, the position of our electrodes on our hands, and the conditions our body may change. We try our best to improve our circuit to minimize these factors.

Finally, with our modification and calibration of our mouse cursor program, we should be able to build a “real” mouse controlled by our EMG signals. We aim at designing our EMG mouse cursor controller to have more advantages and powerful functions than traditional mouse.

In the Lab

i. Block Diagram of All Our Major Operations

We followed this process to build our final project EMG mouse cursor controller. Here is our block diagram:

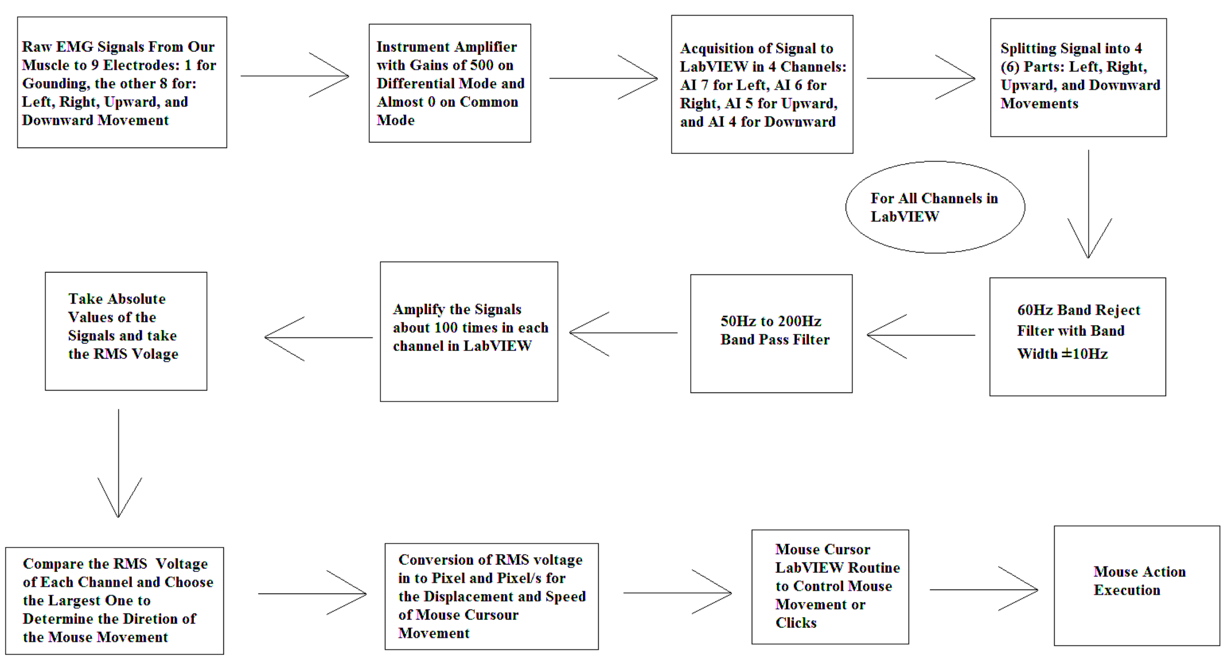


Figure 1. Block diagram of the procedure for our final project EMG mouse cursor controller

ii. Circuit Diagrams for Hardware Component and Block Diagram for Software Component

This is our finalized circuit diagrams for hardware component and block diagrams for LabVIEW programs after building, test, debugging, and improving our final project EMG mouse cursor controller:

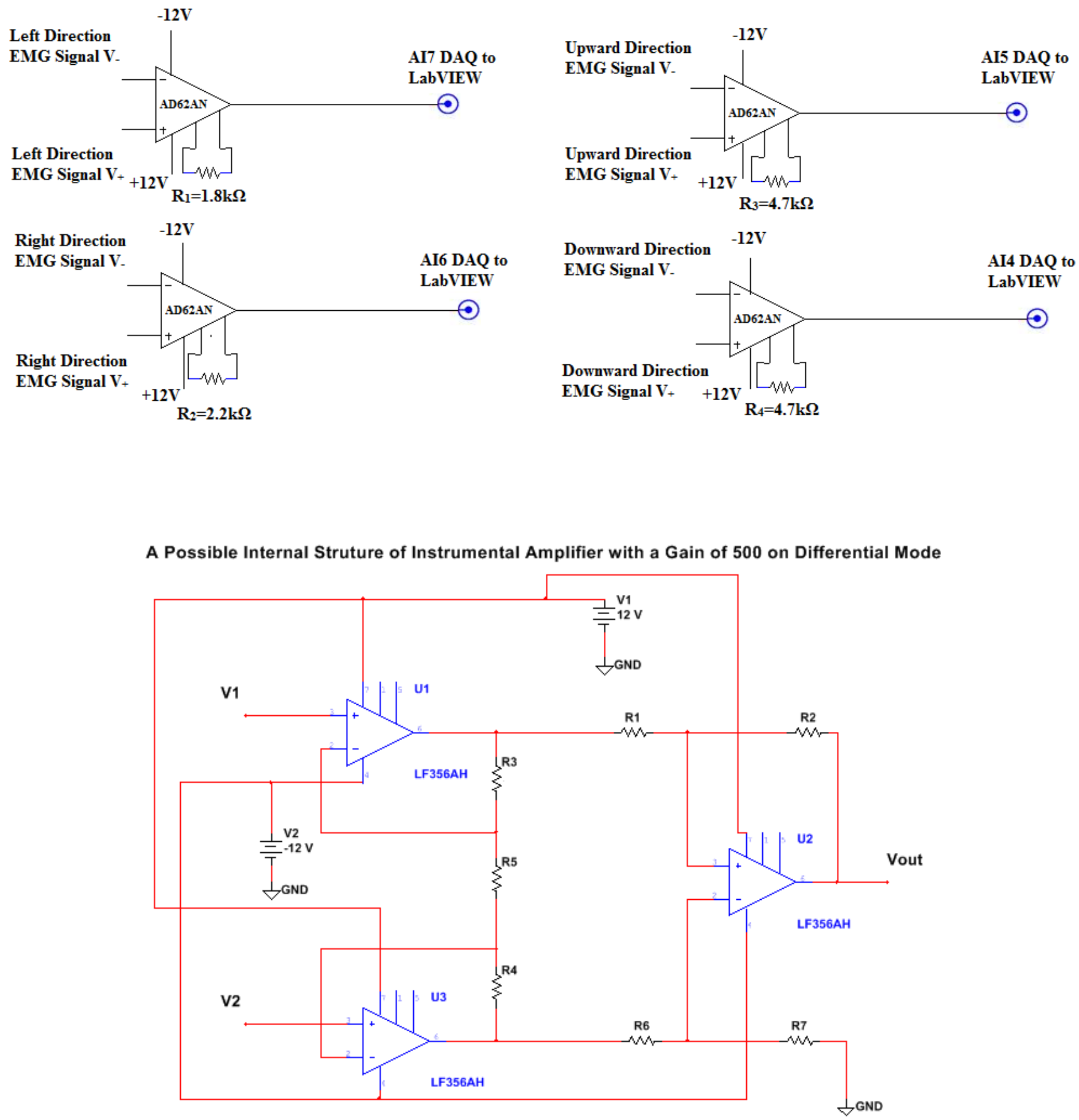


Figure 2. The circuit diagram of the hardware components of EMG mouse cursor controller and the possible internal structure of the instrumentation amplifier [1]

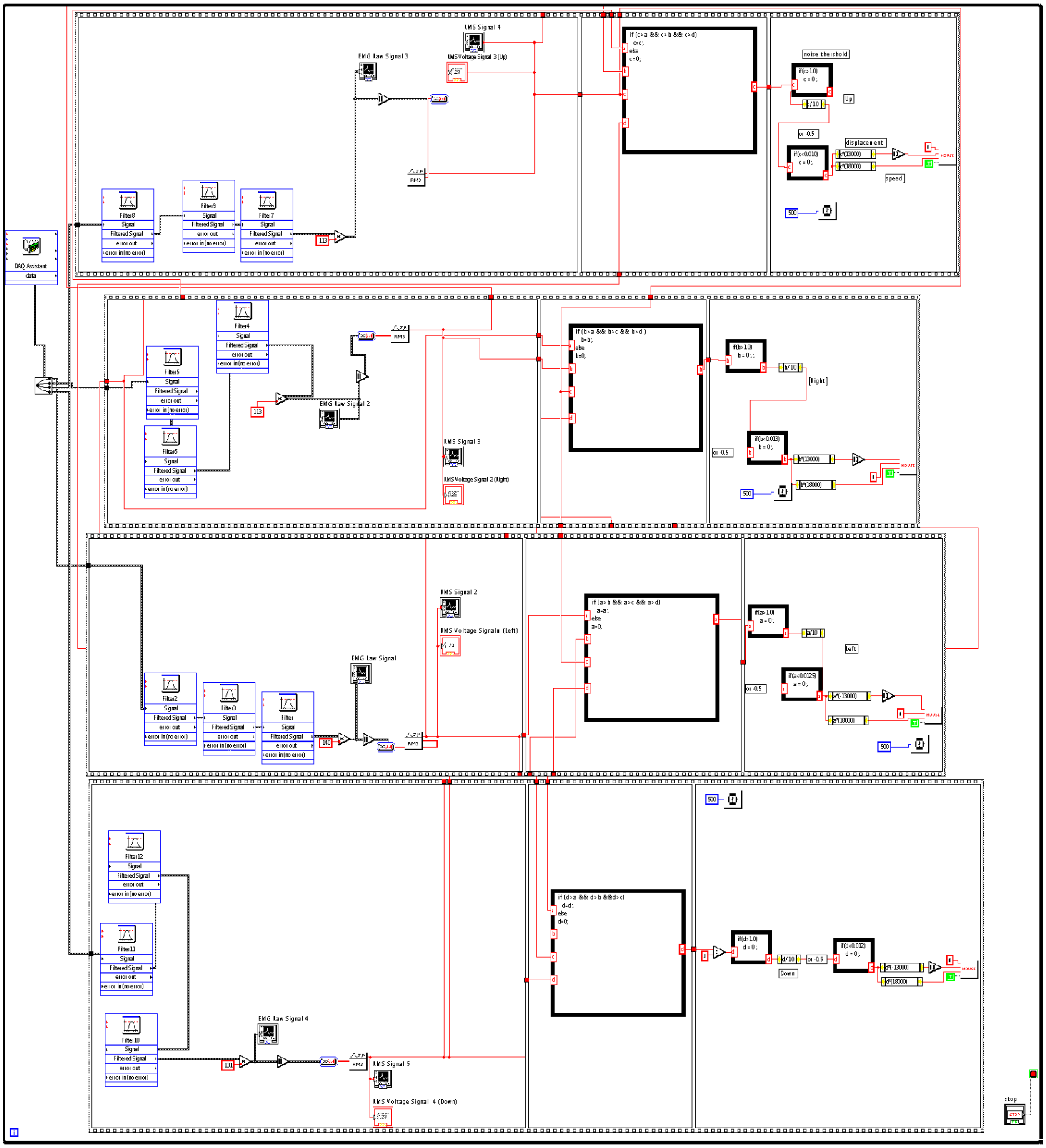


Figure 3. The block diagram of the EMG signal processing program that processes the raw EMG signals and calibrate them from volts to pixels

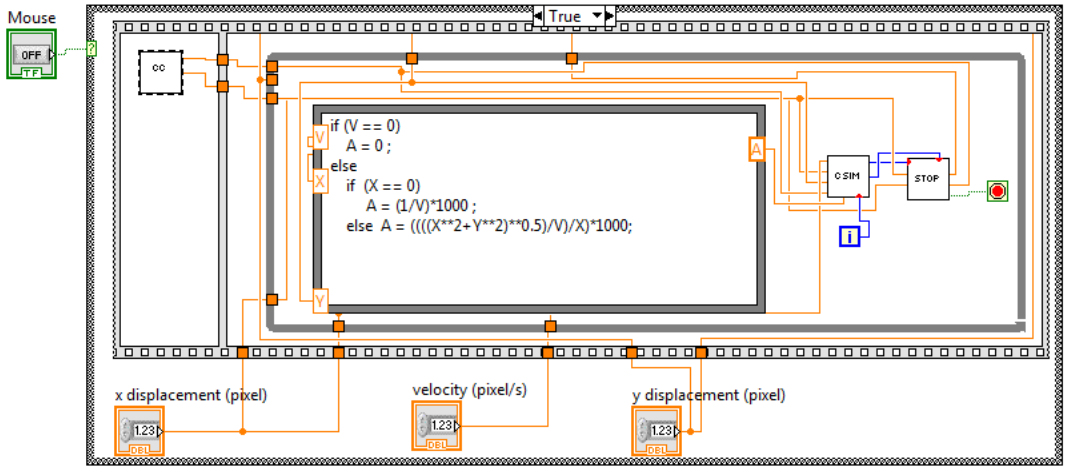


Figure 4. The block diagram of the mouse cursor controlling program that controls the direction, displacement, and speed of the mouse cursor according to the processed EMG signals

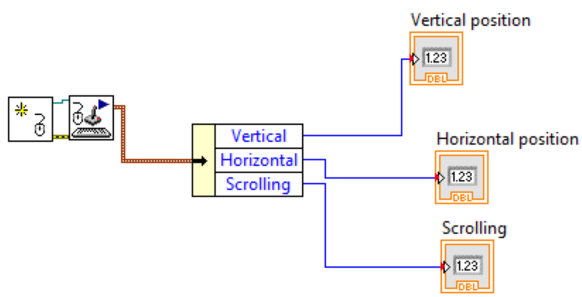


Figure 5. The block diagram of the mouse cursor position program (SubVI for the mouse cursor controlling program) that records the current mouse cursor position

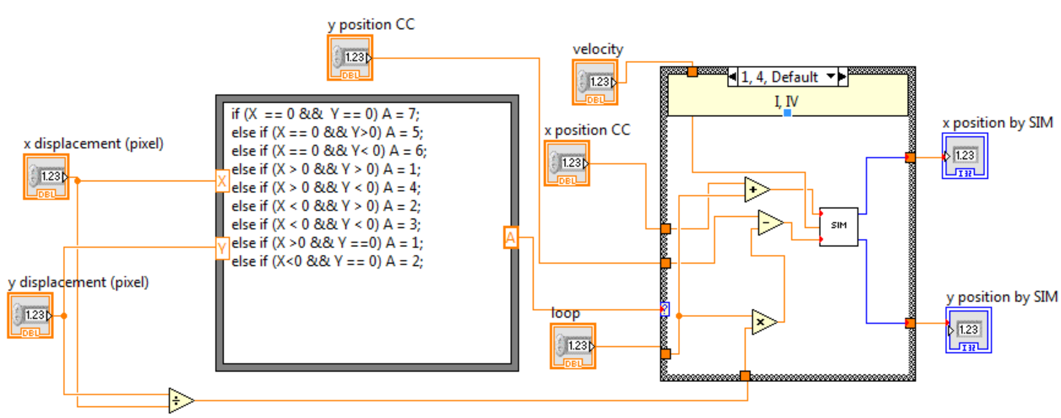


Figure 5. The block diagram of the cursor simulation program (SubVI for the mouse cursor controlling program) that controls the motion of the mouse cursor

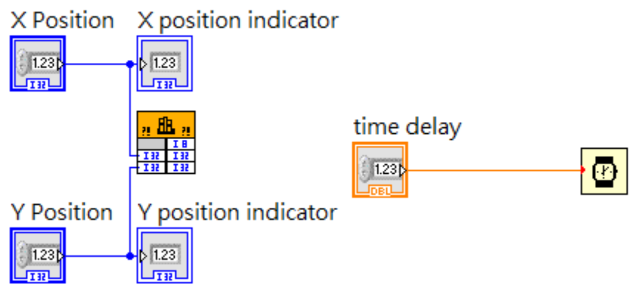


Figure 6. The block diagram of the simulation program (subVI for the cursor simulation program) that directly controls the displacement of the mouse cursor

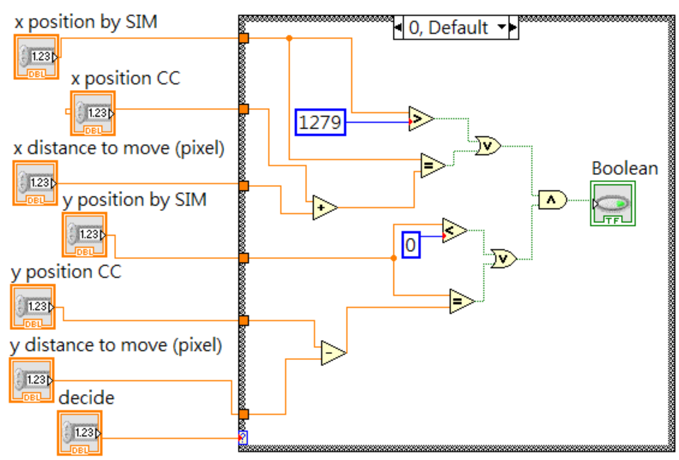


Figure 7. The block diagram of the stop program (subVI for the mouse cursor controlling program) that stops the motion of the mouse cursor when it touches the edge of the screen

iii. Description of the Operations of Our Block Diagram

Part 1. Construction of Our EMG Mouse Cursor Controller

Our first step was to detect EMG signals. We decided to use scotch tape to attach electrodes on our hands. We started with three electrodes, two for detecting the voltage of left motion only and one for reference. The reference electrode was always attached to the position that had no muscle. We attached it to our wrists. We knew that the EMG signals were easily masked by noise. Theoretically, EMG signals came from the differential mode of two electrodes while the noise came from the common mode. So if we could amplify the differential mode while reject the common mode, we should be able to detect EMG signals. We found that instrumentation amplifier (AD62AN) was a good candidate because of its high common mode rejection ratio [2]. We connected our electrodes to the V_+ and V_- leads of our instrumentation amplifiers and used the default 560Ω resistor to set the default gain. However, at that time, we did not understand how the resistors determined the gains. We just used the values as suggested from the instructions. Later we would see the importance of the gain.

After sending our EMG analog signals to the DAQ in AI7 analog input, we chose continuous sampling option with 10k samples to read and 10k sampling frequency. The reason why we chose continuous sampling was that the EMG signals, unlike sine wave or square wave, are not periodic. We tried to use the N Sample option but it could never sample any reasonable facsimile. Also, we knew that the frequency range of EMG spectrum is from 0 to 500Hz [3]. So we used 13th order 50Hz to 70Hz Butterworth band-stop filter to filter 60Hz noise and use 6th order 50 to 150Hz Bessel band-pass filter to purify EMG signals. We used Butterworth filter to filter noise because it could cut-off the noise quickly. However, as for band-pass filter, we used Bessel filter because the Bessel filter had the best step response.

Next, we set the amplification coefficient to be around 100 to amplify the purified EMG signals. With instrumentation amplifiers and LabVIEW filters, we were able to detect EMG signals for left motion. We then rectified the raw EMG signals and took their RMS voltage values in LabVIEW program. We decided to use their RMS voltages to control the direction, displacement, and speed of the mouse cursor. We created an indicator after the RMS operation to see what the signals looked like.

After processing our raw EMG signals, we ran the LabVIEW program to test our project. We found that as we ran the program, without moving our hands, there was a very high RMS voltage, about 1V to 3V, for approximately 1 second and then it suddenly dropped to about 0.03V to 0.09V. The high RMS voltage was resulted from the ripples of our filters. The low RMS voltage came from the noise of the environment. Again, noise could only be reduced but never be eliminated. Hence, in our LabVIEW program, we set upper limit for the RMS voltage to be 1.00V and the lower limit to be 0.10V to eliminate the initial step response of filters and the noise. If the RMS voltage was higher than 1.00V or lower than 0.10V, it would be set to 0.

Subsequently, we added two more electrodes for the right motion and used AI6 analog input to receive the EMG signal. For direction, we compared their RMS voltages and chose the larger one as the direction of the mouse cursor. The LabVIEW program was able to discriminate EMG signals between left and right motions.

Then, for displacement, to precisely convert our RMS voltage signals to the movements of mouse cursor, we did experiments on left, right, upward, and downward movements, each 30 times, and recorded their RMG voltages. The experimental data will be shown in the next section. According to our data, the RMS voltages of processed EMG signals were around 0.12V to 0.60V. We then compared to the size of the screen, which was about 1280pixel × 800pixel. Since we divided the RMS voltage signals by 10 for noise reduction purpose, we set conversion coefficient 13000pixel/V which was actually 1300pixel/V for the RMS voltage signals. We should point out that, from our experiments, if the coefficient was too large, we could not control the mouse cursor precisely. If the coefficient was too small, we could only move a very short distance even if we use much strength to move our hands. Hence, 1300pixel/V would be the best choice.

For speed, we tested the maximum and minimum speed that we could move our mouse cursor by moving the mouse. We found that the maximum speed was about 1100pixel/s and the minimum was about 100pixel/s. We believed that the larger the RMS voltage was, the faster the mouse cursor should be. Therefore, we set the conversion coefficient of the speed to be 18000pixel/(s·V) which was actually 1800pixel/(s·V) for the RMS voltage signals. We tested the maximum and minimum speed we could move, each 10 time, and found that the maximum speed was (840±40)pixel/s and the minimum speed was (189±4)pixel/s. Our experimental data can be found in the next section.

Later, we expanded our program in four directions. We added upward direction to AI5 and downward direction to AI4 analog input. The only thing we modified was that we compared the RMS voltages from four directions and selected the largest one to determine the direction of the mouse cursor. Overall it worked quite well though sometimes there were some errors. For example, if we wanted to move it downward, it might move to the right. We would need to recalibrate amplification coefficients in the LabVIEW program to make it function better.

After converting our RMS voltage into pixel, we connected it to our mouse controller subVI and proceeded to mouse cursor control. Our mouse cursor controlling program consists of 3 subVIs. The one labeled “CC” stood for current cursor position which recorded the current mouse course position. The next subVI CSIM, which meant cursor simulation, made the mouse cursor to move in very small steps so that it looked like moving continuously. The last one was STOP. It stopped the mouse cursor when it touched the edge of the screen. With these three functions, our EMG mouse cursor controlled acted like a real mouse to control the mouse cursor.

We were delighted that we could move the mouse cursor in four directions with the distance and speed as we desired. However, the next day, without changing anything of our project, we were unable to control our mouse cursor. As we read out the RMS voltages from the indicator, we found that they were way higher than the previous day. The voltage level was so high that it masked our control. We debugged and figured out reasons why this occurred.

Part 2. Debugging, Testing, and Improving of Our EMG Mouse Cursor Controller

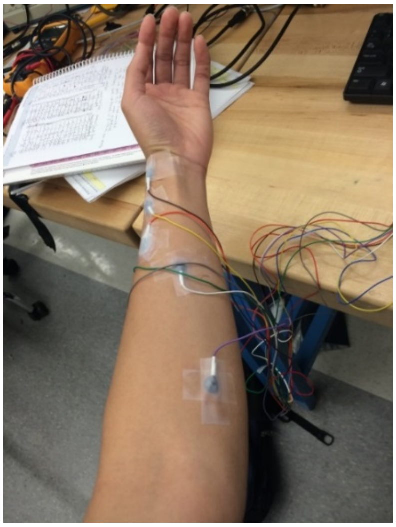
We had gained a lot of experience for EMG signal processing and noise reduction from our debugging process. First, we did not set the right gains for our instrumentation amplifiers. If we used the same resistors on each instrumentation amplifier, we would amplify the signals from each direction equally. However, we noticed that the left motion sometimes made the instrumentation amplifier on rail (-10.2V) in a noisy environment because it had the largest EMG signal. So we must increase the load of the instrumentation amplifier for the left direction to decrease its gain.

Thus, we experimentally figured out that the optimal resistor values for each instrumentation amplifier. They were 2.2kΩ, 3.5kΩ, 2.2kΩ, and 4.7kΩ. We also measured the gains of these amplifiers using the offset adder and oscilloscope. The experimental data will be presented in the next section. We followed the formula $G=\frac{V_{out}}{V_{in}}$ and found that their gains were about 51.1, 46.7, 21.0, and 20.4 respectfully.

Secondly, as for noise, we often unintentionally touched the electrodes, which created a very large noise to our LabVIEW program. In addition, it was very interesting that laptops, especially with touch screens, could generate so much noise that made the instrumentation amplifiers on rail. So after we discovered these interesting phenomena, we turned off our laptops when we were doing the lab. We also forgot to decouple the circuit, which might also be a reason why we saw bad signals. More interestingly, we noticed that we were able to significantly reduce the level of noise when we used two pieces of scotch tape to attach our hands and electrode in a cross manner "+". Moreover, the scotch tape of one electrode should not touch the other one. Otherwise, the motion of one direction would affect the motion of the other direction when we moved our hands.

Also, because the conditions of our body and the laboratory environment changed in everyday, we needed to recalibrate the amplification coefficient to fit the motion of the mouse cursor.

Finally, we found that moving our hand to one direction would generate EMG signals to all electrodes with different RMS voltages. Hence, to improve the functionality of our project, we found the optimal position to attach our electrodes for left, right, upward, and downward motions to receive signals so that they would have the least correlation to each other. We tried many different positions and concluded that the following positions of electrodes worked best:



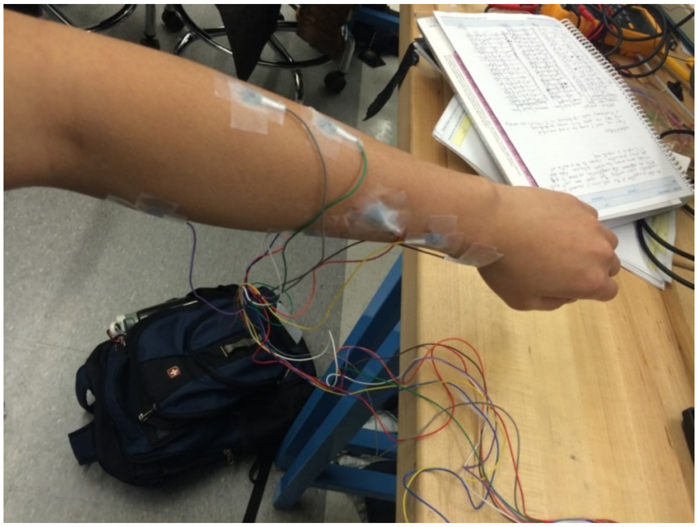


Figure 9. The best electrodes positions to move left, right, upward, and downward in our final project in two different views

iv. Experimental Measurement and Data Analysis

We did three experiments in the lab. The first one was to measure the RMS voltage of the motion of left, right, upward, and downward. Here is our experimental data.

Experimental Data for RMS Voltage for Different Direction Motions															
RMS Voltage (V) for Left Motion				RMS Voltage (V) for Right Motion				RMS Voltage (V) for UpwardMotion				RMS Voltage (V) for Downward Motion			
Left Signal	Right Signal	Up Signal	Down Signal	Left Signal	Right Signal	Up Signal	Down Signal	Left Signal	Right Signal	Up Signal	Down Signal	Left Signal	Right Signal	Up Signal	Down Signal
0.55	0.13	0.27	0.15	0.07	**0.23**	0.16	0.18	0.11	0.22	**0.47**	0.13	0.06	0.08	0.09	**0.23**
0.49	0.12	0.17	0.16	0.11	**0.21**	0.18	0.12	0.07	0.13	**0.29**	0.09	0.12	0.14	0.17	**0.28**
0.34	0.15	0.21	0.17	0.07	**0.28**	0.16	0.07	0.08	0.16	**0.44**	0.13	0.08	0.09	0.12	**0.24**
0.28	0.11	0.18	0.12	0.08	**0.25**	0.19	0.18	0.08	0.23	**0.65**	0.16	0.1	0.07	0.09	**0.3**
0.71	0.15	0.16	0.18	0.04	**0.11**	0.09	0.08	0.05	0.12	**0.41**	0.08	0.07	0.09	0.12	**0.3**
0.3	0.1	0.1	0.19	0.02	**0.17**	0.07	0.02	0.09	0.25	**0.48**	0.2	0.2	0.09	0.13	**0.26**
0.42	0.13	0.18	0.07	0.06	**0.29**	0.09	0.03	0.07	0.19	**0.33**	0.12	0.12	0.13	0.11	**0.33**
0.31	0.09	0.12	0.09	0.06	**0.22**	0.16	0.07	0.07	0.16	**0.41**	0.08	0.09	0.09	0.11	**0.18**
0.16	0.08	0.13	0.07	0.06	**0.16**	0.1	0.13	0.06	0.14	**0.5**	0.1	0.12	0.11	0.15	**0.27**
0.12	0.07	0.11	0.03	0.07	**0.16**	0.13	0.12	0.05	0.11	**0.37**	0.05	0.09	0.12	0.12	**2.23**
0.15	0.05	0.11	0.04	0.04	**0.15**	0.13	0.06	0.12	0.12	**0.29**	0.18	0.09	0.1	0.2	**0.37**
0.2	0.1	0.12	0.04	0.06	**0.15**	0.15	0.09	0.05	0.13	**0.31**	0.11	0.1	0.1	0.15	**0.18**
0.16	0.12	0.15	0.1	0.09	**0.28**	0.15	0.07	0.08	0.11	**0.34**	0.08	0.14	0.06	0.12	**0.33**
0.27	0.1	0.13	0.11	0.1	**0.4**	0.22	0.36	0.13	0.23	**0.5**	0.15	0.12	0.05	0.11	**0.33**
0.27	0.11	0.16	0.09	0.09	**0.33**	0.2	0.18	0.06	0.08	**0.39**	0.08	0.06	0.09	0.15	**0.21**
0.39	0.1	0.11	0.22	0.04	**0.24**	0.08	0.06	0.11	0.17	**0.4**	0.18	0.26	0.24	0.24	**0.45**
0.17	0.08	0.08	0.05	0.07	**0.45**	0.18	0.13	0.06	0.11	**0.35**	0.08	0.07	0.13	0.16	**0.44**
0.27	0.09	0.1	0.23	0.06	**0.34**	0.11	0.13	0.06	0.12	**0.35**	0.04	0.13	0.13	0.14	**0.51**
0.36	0.07	0.18	0.14	0.07	**0.28**	0.13	0.13	0.07	0.12	**0.45**	0.09	0.14	0.13	0.09	**0.29**
0.25	0.09	0.11	0.09	0.05	**0.24**	0.09	0.13	0.05	0.12	**0.38**	0.05	0.12	0.13	0.17	**0.24**
0.3	0.12	0.16	0.06	0.06	**0.17**	0.1	0.09	0.04	0.12	**0.39**	0.05	0.15	0.12	0.13	**0.4**
0.19	0.11	0.12	0.09	0.14	**0.46**	0.14	0.13	0.04	0.11	**0.29**	0.06	0.06	0.09	0.13	**0.3**
0.36	0.12	0.15	0.22	0.05	**0.24**	0.1	0.11	0.07	0.17	**0.32**	0.08	**0.22**	0.08	0.11	0.14
0.21	0.1	0.14	0.07	0.07	**0.25**	0.11	0.13	0.05	0.16	**0.31**	0.1	0.18	0.09	0.1	**0.37**
0.17	0.09	0.14	0.1	0.08	**0.48**	0.23	0.12	0.13	0.25	**0.59**	0.14	0.12	0.15	0.18	**0.36**
0.17	0.09	0.15	0.09	0.07	**0.24**	0.11	0.11	0.11	0.13	**0.29**	0.17	0.13	0.11	0.12	**0.3**
0.5	0.13	0.18	0.13	0.05	**0.13**	0.09	0.05	0.06	0.12	**0.37**	0.06	0.15	0.12	0.12	**0.25**
0.24	0.11	0.18	0.12	0.05	**0.21**	0.12	0.09	0.05	0.1	**0.35**	0.09	0.13	0.13	0.15	**0.32**
0.39	0.1	0.14	0.21	0.04	**0.13**	0.06	0.13	0.05	0.09	**0.46**	0.05	0.1	0.1	0.12	**0.29**
0.37	0.12	0.12	0.13	0.04	**0.16**	0.12	0.05	0.1	0.14	**0.39**	0.09	0.1	0.12	0.07	**0.24**

We notice that there is only 1 error (in red) out of our 130 experiments. It is from the downward motion: when we tried to move the mouse cursor downward, it moved to the left. Hence our success rate is $\frac{130-1}{130}$×100%=99.23%, which is very high.

The second experiment we did was finding out the gain of instrumentation amplifiers. In order to find out the gain of our optimal load of instrumentation amplifiers, we used the offset adder and the oscilloscope to measure the input voltage V_{in} and output voltage V_{out} of each instrumentation amplifier eight times. The gain G is given by G=$\frac{V_{out}}{V_{in}}$. Here is our experimental data:

Instrumentation Amplifier Gain Measurement Test											
Left Motion Instrumentation Amplifier (1.8kΩ load)			Right Motion Instrumentation Amplifier (1.8kΩ load)			Upward Motion Instrumentation Amplifier (1.8kΩ load)			Downward Motion Instrumentation Amplifier (1.8kΩ load)		
V_{in} (V)	V_{out} (V)	G	V_{in} (V)	V_{out} (V)	G	V_{in} (V)	V_{out} (V)	G	V_{in} (V)	V_{out} (V)	G
0.106	5.57	52.55	0.226	9.64	42.65	0.202	4.45	22.03	0.202	4.43	21.93
0.0921	4.98	54.07	0.133	6.14	46.17	0.373	7.38	19.79	0.388	7.55	19.46
0.0611	3.68	60.23	0.0701	3.84	54.78	0.5	9.52	19.04	0.424	8.18	19.29
0.239	11.1	46.44	0.111	5.35	48.2	0.304	6.19	20.36	0.148	3.575	24.16
0.199	9.38	47.14	0.157	7.06	44.97	0.192	4.36	22.71	0.513	9.64	18.79
0.122	6.17	50.57	0.0871	4.46	51.21	0.251	5.31	21.16	0.374	7.37	19.71
0.225	10.6	47.11	0.256	10.8	42.19	0.149	3.62	24.3	0.246	5.18	21.06
0.134	6.75	50.37	0.202	8.79	43.51	0.586	11.0	18.77	0.586	10.8	18.43
Average Gain		51.06			46.71			21.02			20.35
Standard Deviation		1.64			1.57			0.69			0.72

Therefore, the gain of the left motion for instrumentation amplifier is 51±2; the gain of the right motion for instrumentation amplifier is 47±2; the gain of the upward motion for instrumentation amplifier is 21±1; the gain of the downward motion for instrumentation amplifier is 20±1.

Our last experiment is about the speed of the mouse cursor when we move it to the left. Here is our experimental data:

Maximum Speed (pixel/s)	Minimum Speed (pixel/s)
904.36	190.69
743	191.86
929.35	193.28
1081.69	182.441
962.36	168.96
763.87	171.325
708.931	200.64
711.8	176.262
723.765	200.889
913.919	211.579

Average Speed (pixel/s)	844.3045	188.7926
Standard Deviation (pixel/s)	37.3	4.26

Hence, the maximum speed of the mouse cursor to the left direction is (840±40)pixel/s and the minimum speed is (189±4)pixel/s.

Theories behind Our Final Project

Because our project involves signals from our muscles, we study some basic theory of biological electricity. We did some research and found the biological explanation for the signals generated by muscles. It is due to the action potential of our muscle fibers. The following paragraph is the explanation quoted from Dr. Li-Qun Zhang at Northeastern University:

"The EMG is generated when a motor neuron action potential from the spinal cord arrives at a motor end plate. Its arrival causes a release of ACh (Acetylcholine) at the synaptic cleft which causes a depolarization (Action Potential). This action potential electrically travels downward from the surface in a transverse tubule. This in turn causes a release of Ca^{2+}, causing cross-bridge binding and the sarcomere of the muscle to contract .An electromyography (EMG) is a measurement of the electrical activity in muscles as a byproduct of contraction. An EMG is the summation of action potentials from the muscle fibers under the electrodes placed on the skin. The more muscles that fire, the greater the amount of action potentials recorded and the greater the EMG reading [4]"

In our opinion, basically, when we flex our biceps, we move the ions inside our muscle fibers and thus create a voltage across our muscle fibers. If we stop flexing our biceps, the ions in our muscle fibers should reach the equilibrium and has zero voltage. That is why we detect EMG signals only when we move our hands. If we stop after moving our hands, we can no long detect any signal. It is consistent with our experimental results. Also, that is why we need to place the reference electrode to the position that has no muscle because no matter how we move our hands, its voltage stays constant.

Conclusions

We studied EMG technology and successfully built, tested, debugged, and improved our final project EMG mouse cursor controller. We can move the mouse cursor to left, right, upward, and downward as we desired by attaching 9 electrodes, two for each direction and one for reference purpose, to our hands, use instrumentation amplifier and LabVIEW program to process the raw

EMG signals, convert the processed EMG signals to pixels, and execute them in our mouse cursor controlling program.

Our EMG mouse cursor controller has three advantages. First, it has a high level of functioning. Its four directions controlling function is better than some projects that can only control two directions. In addition, compared to other projects controlling the motion of the mouse cursor in four directions, for example, "Mouse Control Cursor System Using EMG" by Tetsuya Itou and Muneaki Terao at Graduate School of Engineering, Osaka Electro-Communication University [5], Osaka, Japan, our EMG mouse cursor controller has a 99.23% success rate, which is much higher than their 70% success rate.

Aside from that, our EMG mouse cursor controller is easy to control. We just need to attach the electrodes to the optimal positions as shown above and move our hands. Unlike some projects that the users need to flex their biceps to controls the mouse cursor, even a very slight motion of our hands can move the mouse cursor. The user feels like using a real mouse to control the mouse cursor.

Finally, our EMG mouse cursor controller has some applications. We can use it to play some computer games, like Tetris, that only require the motion of the mouse cursors.

However, there are a few things that our EMG mouse cursor controller needs to improve. First, it really depends on the condition of our body and the environment; our project may not function well if different people use it in different places. Hence, we need to develop a program that can automatically calibrate the conversion coefficients by adjusting the desired and actual motion of the mouse cursor.

Also, there is a short time delay of our program. When we move our hand to one direction, it takes 1 to 2 seconds for the program to response. If we can shorten the response time, it will be much better.

Moreover, we wish to make our mouse cursor to move not only in four directions, but also in all directions. We may achieve this by comparing the vertical and horizontal RMS voltages separately and choose the larger two signals. Then we input these two signals into the x-displacement and y-displacement of the mouse cursor controlling program to execute the combination of the horizontal and vertical component so that we can let the mouse move in any direction in the screen. Our group cannot achieve this because we have not enough time to develop and test this function. Also, it will function exactly as a real mouse if we can add left click and right click functions to our EMG mouse cursor controller.

Finally, we want to make our project to have more advantages. For example, we want to achieve wireless control of the mouse cursor using Arduino and Bluetooth devices. Furthermore, we wish to place all hardware into a glove to make them portable. Therefore, our final goal is to develop a portable wireless EMG mouse cursor controller, which can be mass produced at low cost.

Most importantly, from this final project we have learnt a lot of biological knowledge, EMG processing ideas, and noise cancelling techniques. We understand the causes of noise and how to reduce it, the best position to place electrodes, and choice of filters. We developed strong critical thinking and problem solving skills

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