Human-Machine Interface, H.M.I.

enabled by

Epidermal Electronics System, E.E.S.

ECE445 Spring 2013

Final Paper

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1. INTRODUCTION

1.1 Purpose

The purpose of this project is to design an epidermal electronics system (E.E.S.) and apply this concept for human-machine interface (H.M.I.). The recent boom in motion sensing devices and video games has led to a development of many types of motion sensors such as Nintendo Wii game controller. However, users still need to hold the controller physically with their hands in order to control any machine or video game. Our project would allow those people with neurological and muscular disorders to control machines without having to physically access them. Moreover, we can use it for handling dangerous and risky materials that would be used in the field of science. It would make it easier to conduct EMG tests without the hassle of all the bulky equipment. Our team wishes to address this issue by directly mounting the electronic system onto skin epidermis such that human motions can be directly translated into the controlling system.

1.2 Function & Feature

Our project will be able to provide EMG readings that are comparably accurate to formal EMG equipment readings with the additional bonus of being portable. The E.E.S. consists of stretchable, meandering structures that naturally follow the soft, curvilinear skin morphology and this allows us to avoid using conductive gels which can cause irritation and other side effects on our skin. This eradicates the discomfort that is associated when using conventional electrodes to measure the E.M.G signals. The E.E.S. will give high-quality and highly accurate electrophysiological signals for an extremely long time (a week) without the use of adhesives and/or tapes because of its capability to be laminated, conform ally, onto the skin. The E.E.S. has

some other additional features that help the portability; ultrathin, lightweight, and low modulus that has the matching mechanics to the skin epidermis. In addition to the E.E.S., Our project consists of a portable Signal Conditioning Unit (S.C.U) and easily programmable microcontroller is included in our design. The ease with which a microcontroller can be programmed would allow users to modify the program to cater to their individual muscle amplitude signals. Our goal is to control quad-rotor using EMG signals measured on forearm by E.E.S.

1.3 Subprojects
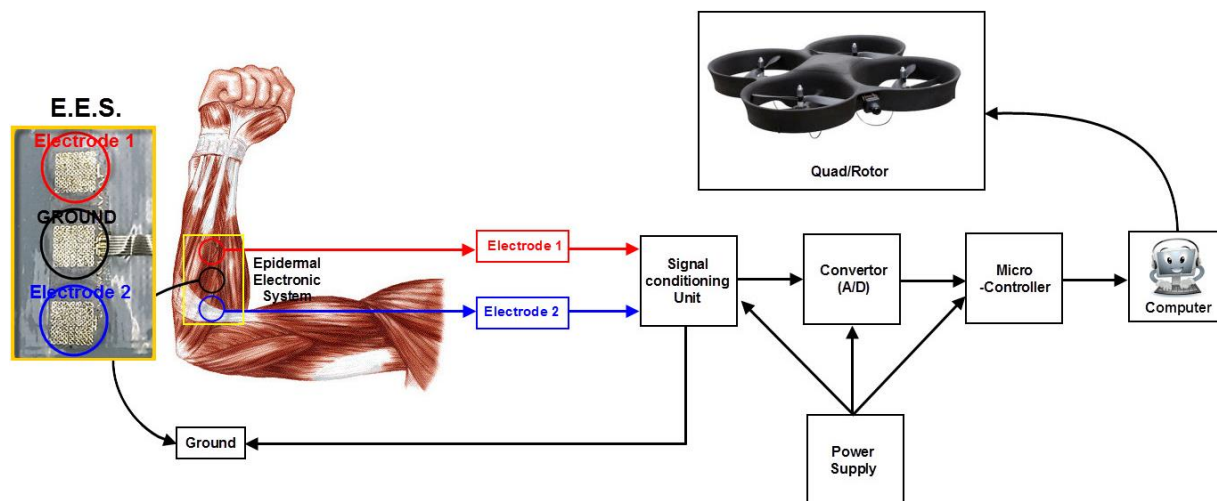
Fig1. Overall Dagram

1.3.1 E.E.S. (Epidermal Electrode System)

The EMG sensor will include three electrodes, each in a form of a filamentary serpentine (FS) mesh with exposed metal that contacts the skin directly, for measurement (MEA), ground (GND), and reference (REF)

1.3.2 S.C.U. (Signal Conditioning Unit)

This unit will receive signals from EES, detect certain amplitude, and amplify the signal. This Unit consists of a band pass filter, gain amplifier, and noise filter system

1.3.3 (A/D) converter

It is essential for the received signal to be converted to digital in order for it to be analyzed. This unit will convert the received analog signal (bio-potentials) from the skin and convert it to a digital signal that is then be analyzed by the microcontroller

1.3.4 Micro-controller

The regulation of the received signal will be done with the microcontroller. It will compare the received signal and with the assistance of predefined programming the necessary action is brought about.

1.3.5 Power supply

The power supply will provide power to the various components of the circuit. For S.C.U., each chip must get power, greater than 4.8v. We used two 5volts batteries. Also, 5v needed for micro-controller.

1.3.6 Computer & Quad/Rotor

The commands will go through the computer in order to control machine wirelessly. For now, we are planning to use quad-rotor as our machine.

2. DESIGN PROCEDURE & DESCRIPTION

2.1 E.E.S.

We employ one of the principle techniques of electrodes in order to measure electrophysiological processes in the muscle (electromyograms, EMGs).In order to minimize impedances between the electrodes and the human body and to optimize signal-to-noise measurements, it is essential that the electrodes have conformal contact with the human skin. As a result, we integrated conventional electrodes while maintaining the features described at the beginning of this report. The E.E.S. includes three electrodes, ((REC, electrode1), ground (GND), and reference (REF, electrode2)). each in a form of a serpentine like mesh with exposed metal, that will adhere to the skin directly.

The fabrication process begins by spin-coating PDMS on a glass slide or Si wafer as a substrate. Polyamide (PI) must be spin-coated on top of the UV exposed PDMS, in order to evaporate gold on substrate by electron beam (e-beam) lithography. The gold pattern will be made by using photoresist mask and wet etching, and it will be encapsulated with polyamide (PI) to protect gold pattern from any type of defects. This encapsulation is done by using a photoresist mask and oxygen plasma etching. The E.E.S. device, then, is picked up from substrate and the chromium-silica is evaporated with the electron beam. This makes it easier to bond the device on to the elastomer. Following this the E.E.S. will be laminated on to the UV exposed elastomeric substrate (0.5-1.0mm thick) to promote bonding, and the water soluble tapes are removed by applying water. An ACF cable will be attached to the gold pads of E.E.S. and will connects the device to a PCB board.

2.2 S.C.U.
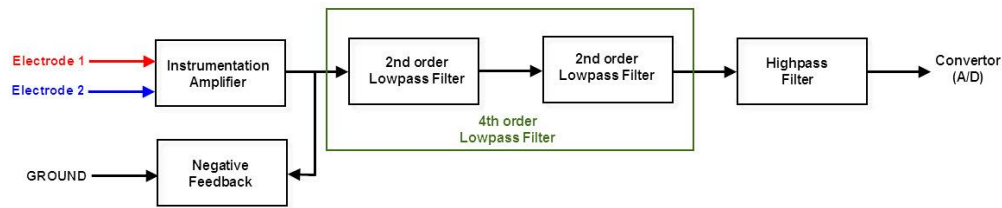
Fig2. S.C.U. Diagram

The Signal Conditioning Unit detect received signal from the E.E.S and filtering and detecting the signal in range, cut-off frequency (10Hz ~ 500Hz) while amplify the gain to 10000.

Instrumentation Amplifier : Instrumentation amplifier is a type of differential amplifier that eliminates the need for input impedance matching and thus makes the amplifier particularly suitable for use in measurement and test equipment. There are two amplifiers for this part; the main amplifier, AD620 instrumentation amplifier and typical operational amplifier, op741. The low noise of the AD620 allows its use in ECG monitors where high source resistances of 1 MΩ or higher are not uncommon. The AD620's low power and low supply voltage requirements make it an excellent choice for battery-powered data recorders.
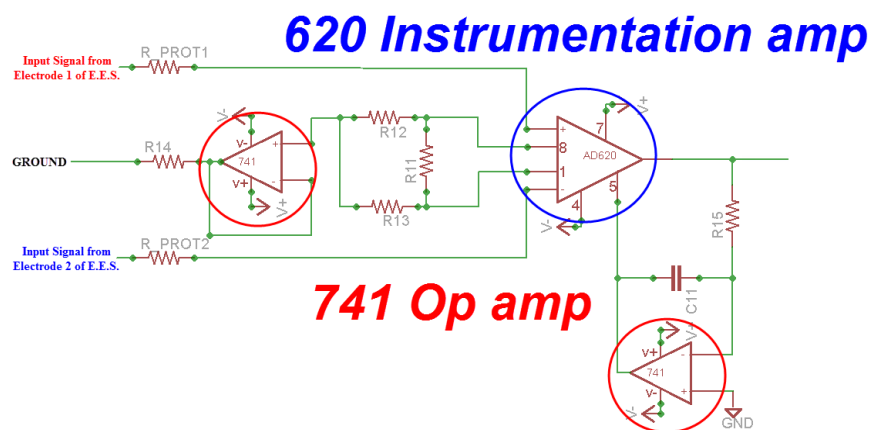
Fig3. Instrumentation part

<u>Negative Feedback</u> : The negative feedback circuit is defined as taking the op-amp's output voltage and coupling it to the inverting input and it is the key to having a self-stabilizing system. This ability to stabilize the system allows the op amp to function in the active region and prevents it from being saturated. Another advantage of using an op amp with negative feedback is that the op amp voltage gain does not matter
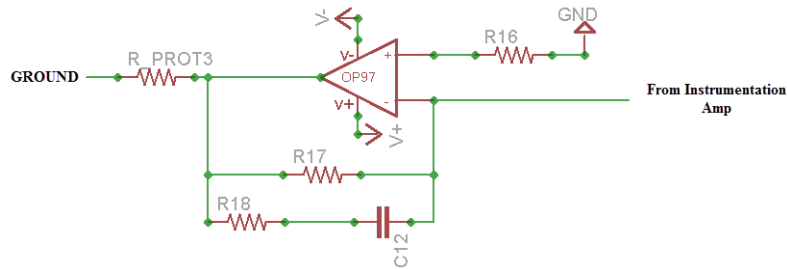
Fig4. Feedback part

<u>Band-pass Filter</u> : The Band pass filter is a device that accepts all signals with frequencies within range and rejects signals that are outside this range, 10Hz ~ 500Hz. We designed band-pass filter with two 2nd-order low-pass filter and typical high-pass filter.

$$f_c = \frac{1}{2\pi\tau} = \frac{1}{2\pi RC}$$

<u>Low-pass Filter</u>: The low pass filter is in charge of attenutating all the signals above the cut off frequency, 500Hz, which is determined by an RC constant. Our circuit consists of two 2nd order low pass filters, and connected together to create a 4th order low pass filter. A second-order passive low pass filter the gain at the cutoff frequency will be equal to 0.7071 x 0.7071 = 0.5Vin (-6dB). The formula that is used to calculate the gain of this filter is Vout/Vin.

$$g \equiv \frac{V_{out}}{V_{in}} = \frac{V_C}{V_{series}} = \frac{I X_C}{I Z_{series}} = \frac{1/\omega C}{\sqrt{R^2 + (1/\omega C)^2}} = \frac{1}{\sqrt{1 + (\omega RC)^2}}$$
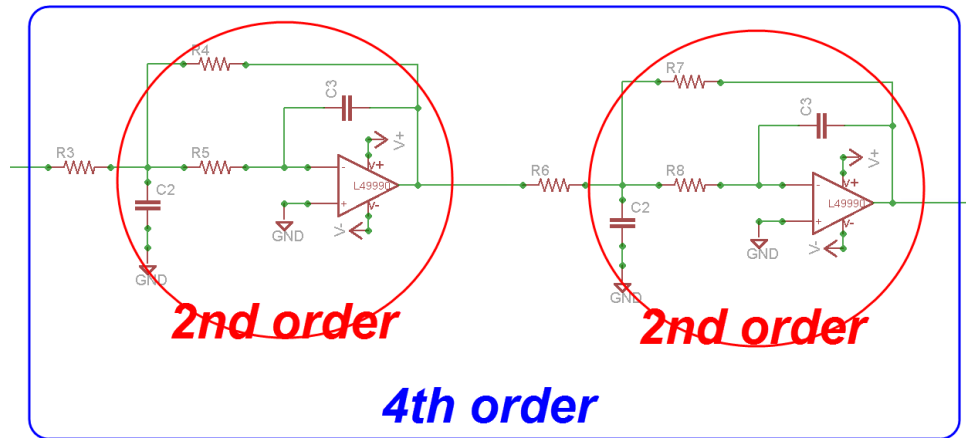
Fig5. Low-pass Filter part

High-pass Filter : The typical high-pass filter attenuates below cut-off frequency, 10Hz and passes high frequency signals.

$$g \equiv \frac{V_{out}}{V_{in}} = \frac{V_R}{V_{series}} = \frac{IR}{I\,Z_{series}} = \frac{R}{\sqrt{R^2 + (1/\omega C)^2}} = \frac{\omega RC}{\sqrt{1 + (\omega RC)^2}}$$

When designing active filter circuits it is important to choose the correct op-amp for the circuit as the loss of high frequency signals may result in signal distortion. The gain of the LME49990 reduces until it reaches unity gain, or its transition frequency which is about 1MHz. This causes the op-amp to have a frequency response curve very similar to that of a first-order low pass filter.

Fig6. High-pass part

2.3 Micro-controller

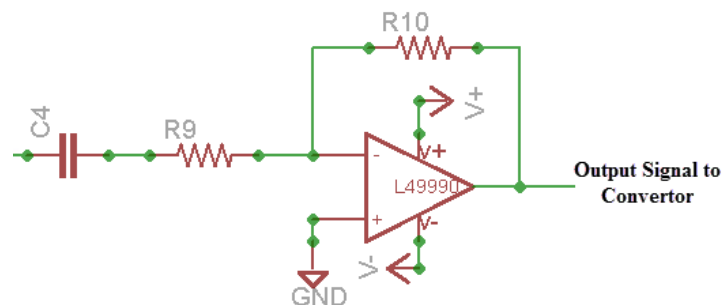This module of our circuit is extremely important as it is responsible for analyzing the input signal, converting it to a digital signal and displaying the action that user wishes to reciprocate with the robot.

Convertor (A/D) : The signal from the input signal is applied to the analog input pin of our convertor. Our Analog-to Digital convertor is a part of our microcontroller circuit and does not require any extra wiring to be included as a part of our circuit. The convertor program is loaded into the microcontroller and the convertor will ouput a digital signal that ranges from 0-5 volts based on the inpuit signal.

Arduino Uno : The microcontroller that we use is an Arduino Uno. The micro-controller will take the digital from the Analog-to-Digital signal converter and then analyze it using the predetermined commands that were programmed into the Arduino Uno. This microcontroller will then output the direction associated with the movement which will influence our device and perform the necessary action on the device that we wish to control. The Arduino Uno consists of comparators which will compare the amplitude of the input to the expected amplitude ranges of the signal and it will create the necessary action.

The Arduino Uno consists of two sets of provided software: "Arduino" and "Processing". The "Arduino" software is used to program our microcontroller with the ability to read our analog input from the S.C.U and convert it to a digital signal which is subsequently analyzed. The Processing software is used to display the output of the microcontroller and converts it into a result that can be displayed on a threshold graph and appropriately display the intended direction

on the screen. The signal is displayed on the graph in the form of a bar that will adjust its position based on how the user flexes his muscle.
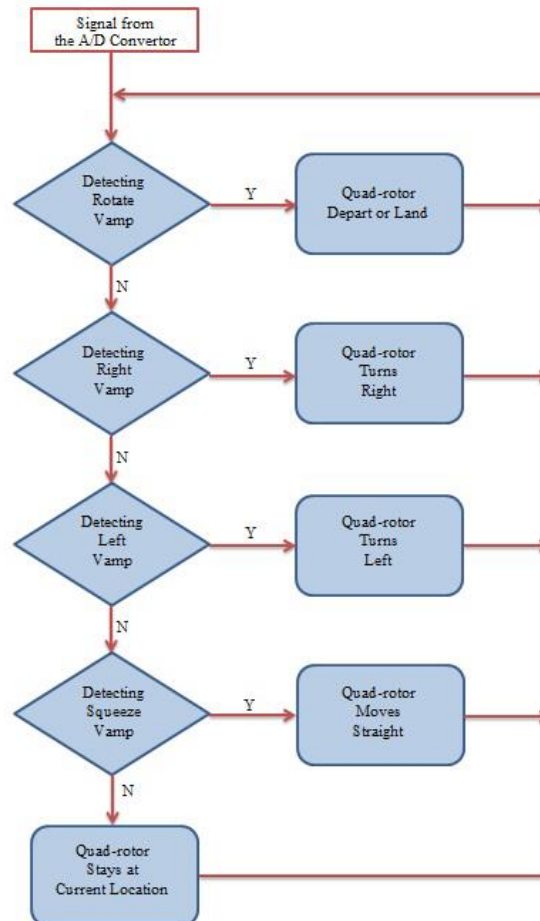
Fig7. Flowchart

2.4 Software

<u>Arduino Software</u> : The input from the S.C.U is received on the input pin A0 and sends out voltage through COM port (USB) to computer. The analog input is read and it displays the signal on the serial monitor. It then transfers the data through COM 5 to the computer. This is evident by observing the code in the Appendix C

<u>Processing Software</u> : The computer receives the signal from the Arduino through the USB and

displays the signal on a threshold graph and prints out direction that user moves muscle. Displays received input signal on a threshold graph. The bar on graph shifts as muscle is flexed by the user and the program displays the action of the user based on the how far the bar moves on the graph.

3. VERIFICATION

3.1 E.E.S.

The thickness of E.E.S. electrodes must be less 2µm to achieve conformal contact on skin. The original plan was using profilometer to measure thickness after the fabrication process is done. However, it was not necessary to measure physically due to the settings of e-beam evaporator and spinner. While using these equipment, it was possible to set exact thickness of gold and PI through the interface of the equipment. Therefore, 0.3µm thick of Au was evaporated, and 0.5µm thick of PI was spincoated before evaporating Au and after wet etching of Au.

The E.E.S. electrodes was tested using a commercial transmitter (BioRadio 150), a receiver (USB-type), and a laptop computer with data recording software are used for the testing. Measured signals from my forearm, transmit to the receiver which is connected to a laptop computer. Using this setup, data is analyzed for both conventional and E.E.S. electrodes. Additional blue silicon tape is used to cover the E.E.S. electrodes to maintain stable conformal contact on arm.

First, the verification was started with measuring noise to ratio of amplitude that produces from the device itself. The conventional electrodes had a noise level within -1mV to +1mV. With producing many E.E.S. electrodes and one of the best qualified device had a noise level within -0.3mV to +0.3mV.
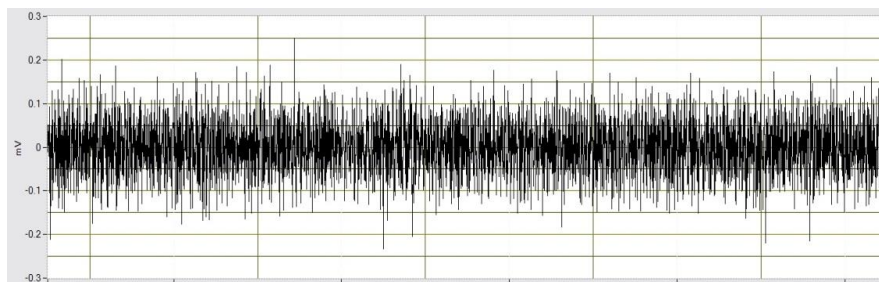
Fig8. Noise level recorded with E.E.S. electrodes

Comparisons of the electrical impedance of E.E.S. and conventional electrodes with gel type involve a pre-amplifier and sinusoidal inputs with frequency around 40Hz and amplitude abound 0.5Vrms. As figure shown below, the behaviors include expected high frequency oscillations with amplitudes between 500µV to 1mV.
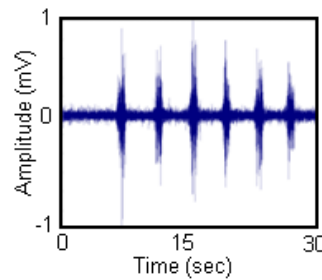
Fig9. EMG recording with conventional electrodes

The EMG signal measured with E.E.S. electrodes attached on forearm showed the close enough data, we could be able to see the possibility of replacing conventional electrodes to E.E.S. electrodes without losing any sensitivity of detection.
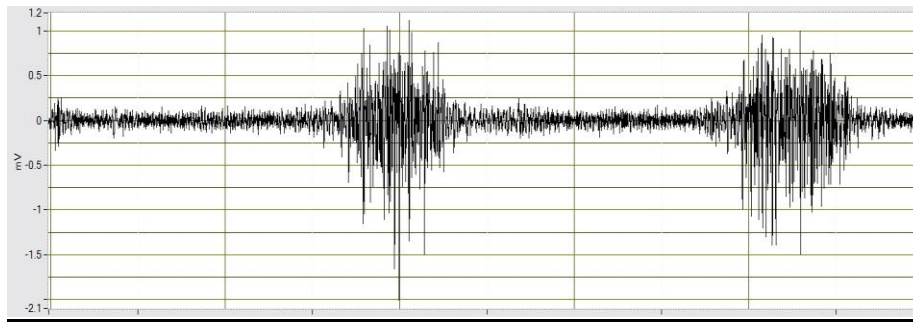
Fig10.EMG recording with E.E.S. electrodes

Moreover, As a proof of Human-Machine Interface, two sets of the E.E.S. electrodes are mounted on my muscles of left and right forearm. The EMG signals of both electrodes are recorded for four classifications of spatial actions: bending the hands to the left, bending the hands to the right, rotating both hands in a circle, and squeezing both fists.
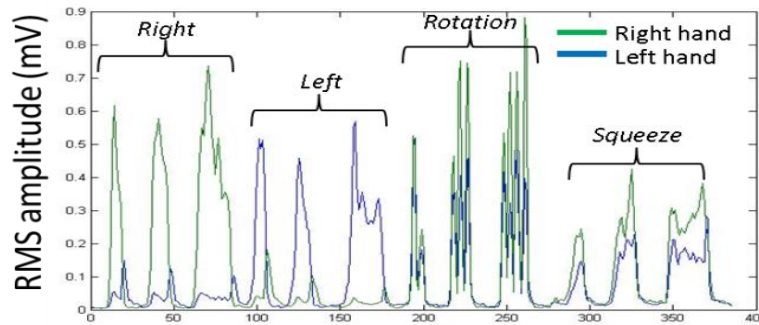
Fig11.EMG recording with E.E.S. electrodes

As shown, it was clear by examining these signals that the four spatial actions can be classified as distinct motions. However, when signal is transmit to the Microcontroller, we must consider the range of amplitude can differ by users depending on muscle strength.

The additional verification made with E.E.S. electrodes was the stretchability. Since the E.E.S. electrodes provide a conformal contact on skin, enough stretchability was necessary in order to detect signal precisely. The device was made with gold, so that it must have plasticity point when it is stretched in certain distance. Therefore, device was placed on stretcher to check the stretchability.
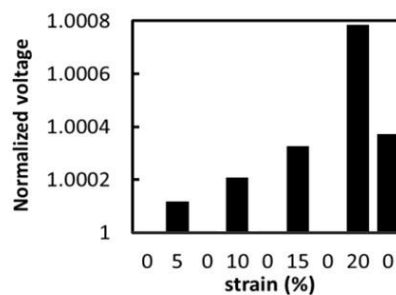
Fig12. Plasticity point at 20% of strain.

The result was good enough to use it as epidermal electronics such that 20% of plasticity point was observed with E.E.S. electrodes. Since we were planning to place the electrodes on forearm, it will be stretched much less than 20%. The change in voltage was measured with lock-in amplifier for the precise measurement.

3.2. Micro-controller

The microcontroller was tested using the procedure that was outlined in the requirements and verification table(Appendix E). We used a potentiometer as a stand-in for our analog input from the signal conditioning unit and connected it to the input port that would be ideally inputted with the input signal from the S.C.U. With the assistance of the "Arduino" program and the "Processing" software that is provided with our microcontroller, we were able to display our input on a threshold graph with a blue rectangular bar that moves and changes its position with respect to the input signal.The codes for each of these programs are available in appendices(C&D). We established ranges that the bar would be displaced based on the direction that our hand is turned or squeezed. The ranges correspond to our scales on the graph. We tested our circuit for two directions namely "Right" and "Left".
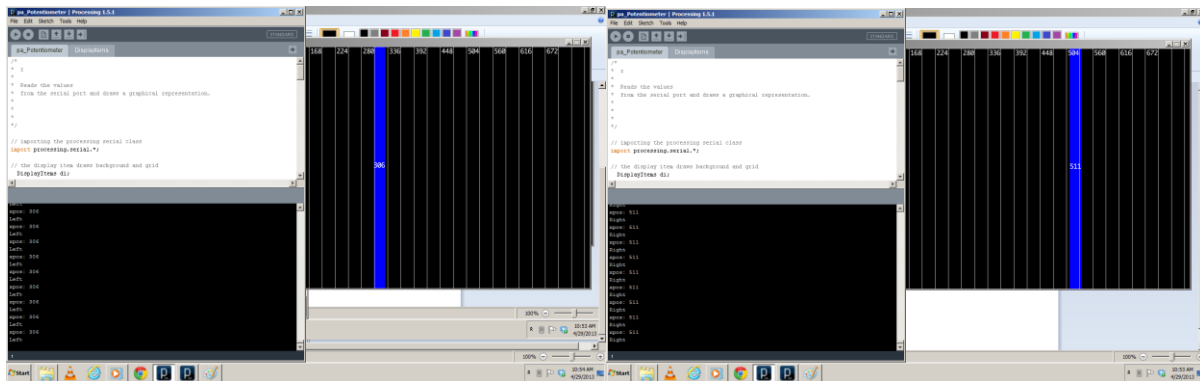
Fig13. Micro-controller testing

3.3. Failed Verification

S.C.U.

Our Signal conditioning unit was, unfortunately, shorted out when testing all of our modules together. The board was burned as a result of an improper grounding of the circuit and the high potential difference effectively burned a chip and our board. We were able to verify our S.C.U as an individual module as it worked within the parameters established in our requirement and verification table but the collaboration of our modules were not tested as a whole because of the accident. We were able to find a solution to our problem by using a bench top conventional amplifier and we tested our circuit as a whole. Unfortunately, the conventional amplifier was not specifically catered to our project requirements and the signal that was deciphered was unstable and inconsistent to be considered as viable data. While it proved that the individual modules of our circuit worked, it did not give us the desired consistent output.

4. Costs

4.1. Parts

Description	Component	#	Manufacturer	Vendor	Cost/Unit ($)	Total Cost
Negative Feedback						
Op Amp (OP97FSZ)	OP97	1	Analog Devices	Newark	2.67	2.67
Capacitor (C1206C103F3GACTU)	0.01uF	1	Kemet	Mouser	1.95	1.95
Register (TNPW120610K0BEEA)	10K Ohms	1	Vishay		0.55	0.55
Register (ERA-2AEB113X)	11K Ohms	1	Panasonic Electronic Components		0.6	0.6
Register (CRT1206-DY-2203ELF)	220K Ohms	1	Bourns		0.1	0.1
Instrumentation Amplifier						
Instrument Amp (AD620ARZ)	AD620	1	Analog Devices	Newark	7.24	7.24
Op Amp (UA741IDT)	741	2	STMicroelectronics	Mouser	0.6	1.2
Capacitor (GRM31C5C1H104FA01L)	0.1uF	1	Murata		1.67	1.67
Register (MCW0406MD2001BP100)	2K Ohms	1	Vishay/BC Components		0.94	0.94
Register (ERJ-8ENF2202V)	22K Ohms	2	Panasonic Electronic Components		0.1	0.2
Register (TNPW12061M00BEEA)	1M Ohms	1	Vishay		1.11	1.11
Bandpass Filter						
Op Amp (LME49990MA/NOPB)	L49990	3	Texas Instruments	Mouser	2.58	7.74
Potentiometer (M64Y503KB40)	P-50K	1	Vishay/Spectrol		1.78	1.78

Potentiometer (PV36W105C01B00)	POT-1M	1	Murata		1.67	1.67
Capacitor (GRM31C5C1H104FA01L)	0.1uF	2	Murata		1.67	2.34
Capacitor (ECH-U1H154GX9)	0.15uF	1	Panasonic Electronic Components		1.44	1.44
Capacitor (ECW-U1C274JC9)	0.27uF	1	Panasonic Electronic Components		1.09	1.09
Capacitor (ECW-U1C334JC9)	0.33uF	1	Panasonic Electronic Components		1.13	1.13
Capacitor (C1210C475J3NACTU)	4.7uF	1	Kemet		0.85	0.85
Capacitor (C1210C106J8NACTU)	10uF	1	Kemet		1.09	1.09
Register (RP73PF2A174RBTDF)	174 Ohms	1	Teconnectivity	Newark	0.35	0.35
Register (RG3216P-2000-B-T1)	200 Ohms	1	SUSUMU		0.797	0.797
Register (CRCW1206422RFKEA)	422 Ohms	1	Vishaydale		0.1	0.1
Register (RP73D2B475RBTG)	475 Ohms	1	TEconnectivity /HOLSWORTHY		1.27	1.27
Register (ERA-8AEB1241V)	1.24K Ohms	1	Panasonic		0.328	0.328
Register (RP73D2A2K94BTG)	2.94K Ohms	1	Teconnectivity /HOLSWORTHY		1.35	1.35
Arduino Uno		1	Radioshack		29.99	29.99
Total Cost of Parts:						68.20

4.2. Labor

	$/Hour	Overhead	Total hours	Subtotal ($)
Woosik Lee	50	125	144	18000
Ohjin Kwon	50	125	144	18000
Nithin Reddy	50	125	144	18000
Note : Total hours = 12hous x 12weeks				

Overall : (68.20*2) + 40(Cost of PCB) + (18000*3) =$ 54176.4

5. CONCLUSION

Our project consisted of three main modules: E.E.S, S.C.U and the microcontroller module. We were able to show the correct implementation and functioning of each module individually.

5.1. Accomplishment

Our team was able to successfully show that each of our three modules worked in the fashion that we wished them to. The E.E.S was able to produce signals that were comparably accurate to typical EMG readings and we were able to clearly differentiate between the signals for each motion of our forearm. The S.C.U was found to filter out the noise and maintain the frequency of the signal to be within our cutoff frequency range of 10-500 Hz while maintaining a gain of 10000. The microcontroller was able to correctly read the signal and output the motion of the forearm and display the action that the user intends to influence the robot with.

5.2. Uncertainties

We were unable to display our entire project functioning as a holistic unit. Hence we are unsure of how stable and consistent that the output signal will be with the E.E.S signal. Another uncertainty that could arise is the ability of a single E.E.S and S.C.U unit to control a significant robot like a quad rotor. The ability to control a large robot would be possible by using two of these units. We are also uncertain about how feasible it would be to interface our product with the software for robots.

5.3. Ethical considerations

We adhere to the statements of the IEEE Code of Ethics that pertain to our project as follows:

- *"to be honest and realistic in stating claims or estimates based on available data"*

We will ensure that all calculations are accurate. All the conclusions drawn from experimental procedures will be supported by data calculations and simulations.

- *"To seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others."*

Since this is a group project, each member of the team will assist with the design and provide feedback that will help improve other member's designs and the overall design of our circuit. All material and information that was used will be appropriately credited in the References section.

- "*to improve the understanding of technology; it's appropriate application, and potential consequences*"

We will apply the skills that we have acquired and learned thus far and implement these skills to the best of our abilities and create an exciting E.E.S human interface design.

5.4. Future work

Our team envisions our project to be able to completely control a quad rotor. This task would require two flawless versions of our S.C.U and two sets of E.E.S electrodes for each of our forearms. The reason that we wish to use both our forearms to control a quad rotor is because the signal from one forearm is too unstable to be able to control a quad rotor.

We would, ideally, have to create a program that would allow us to interface our signal from the microcontroller and the robot that we wish to control. Another development that we wish to pursue would be to wirelessly transmit our signal from the S.C.U to our microcontroller and improve the portability factor of our project.

Appendix A: References

[1] Dr. Scott Day. Important Factors in Surface EMG Measurement. Bortec Biomedical Ltd.

[2] Hermie J. Hermens, Bart Freriks, Catherine Disselhorst-Klug, Gü̈nter Rau. Development of recommendations for SEMG sensors and sensor placement procedures. Roessingh Research and Development.

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[5] *Instrumentation Amplifier AD620*, datasheet, Analog Devices, Inc, 2004. Available at: http://www.analog.com/en/specialty-amplifiers/instrumentation-amplifiers/ad620/products/product.html

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[7] *E-Series Ultra-low Distortion, Ultra-low Noise Operational Amplifier LME49990*, datasheet, Texas Instruments, 2011. Available at: http://www.ti.com/product/lme49990

[8] *General Purpose Single Operational Amplifier UA741*, datasheet, STMicroelectronics, 2001. Available at: http://www.datasheetcatalog.com/datasheets_pdf/U/A/7/4/UA741.shtml

[9] Instrumentation Amplifier, Wikipedia web page. Available at: http://en.wikipedia.org/wiki/Instrumentation_amplifier

[10]   Low Pass Filter, Wikipedia web page. Available at: http://en.wikipedia.org/wiki/Low-pass_filter

[11]   High Pass Filter, Wikipedia web page. Available at: http://en.wikipedia.org/wiki/High-pass_filter

Appendix B: Overall schemetics of S.C.U
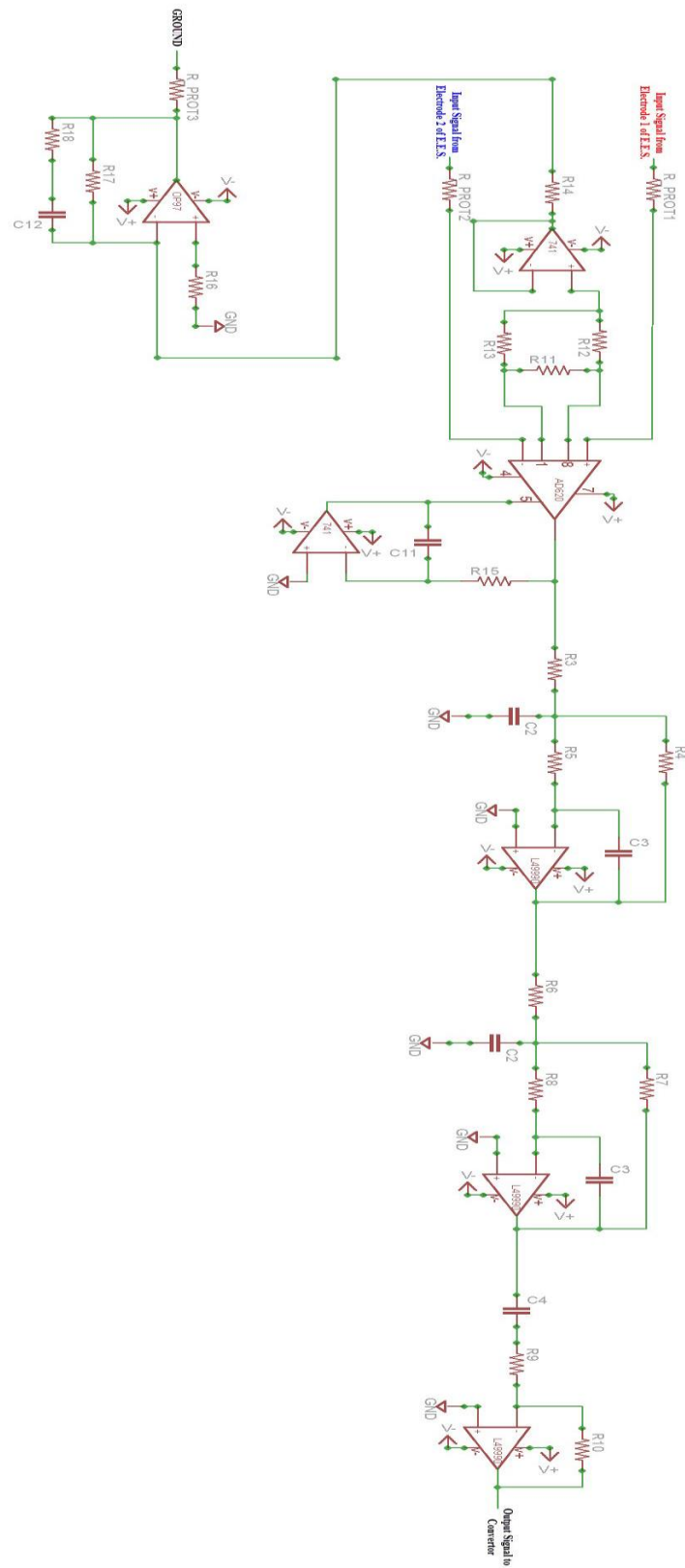
Appendix C: Arduino code for Arduino uno

```
// variables for input pin and control LED

  int analogInput = 0;

  int LEDpin = 13;



// variable to store the value

  int value = 0;



// a threshold to decide when the LED turns on

  int threshold = 512;



void setup(){



// declaration of pin modes

  pinMode(analogInput, INPUT);

  pinMode(LEDpin, OUTPUT);



// begin sending over serial port

  Serial.begin(9600);

}



void loop(){
// read the value on analog input
```

```
  value = analogRead(analogInput);


// if value greater than threshold turn on LED

if (value < threshold) digitalWrite(LEDpin, HIGH); else digitalWrite(LEDpin, LOW);


// print out value over the serial port

  Serial.print(value);


// and a signal that serves as seperator between two values

  Serial.write(byte(10));


// wait for a bit to not overload the port

  delay(10);
```

Appendix D: Processing Code for Display Graph

```
import processing.serial.*;


  // the display item draws background and grid

    DisplayItems di;


  // definition of window size and framerate

    int xWidth = 768;

    int yHeight = 512;

    int fr = 24;


  // attributes of the display

    boolean bck = true;

    boolean grid = true;

    boolean g_vert = true;

    boolean g_horiz = false;

    boolean g_values = true;

    boolean output = true;


  // variables for serial connection, portname and baudrate have to be set

    Serial port;


    int baudrate = 9600;
```

```
int value = 0;

String buf="";

int value1=0;


// variables to draw graphics

int xpos;


// lets user control DisplayItems properties and value output in console

void keyPressed(){

  if (key == 'b' || key == 'B') bck=!bck;   // background black/white

  if (key == 'g' || key == 'G') grid=!grid;   // grid ON/OFF

  if (key == 'v' || key == 'V') g_values=!g_values;   // grid values ON/IFF

  if (key == 'o' || key == 'O') output=!output;    //turns value output ON/OFF

}


void setup(){

  // set size and framerate

  size(xWidth, yHeight);

  frameRate(25);

  // establish serial port connection

  port = new Serial(this, "COM5", baudrate);

  println(port);

  // create DisplayItems object
```

```
  di = new DisplayItems();

}


void drawPotiState(){

  noStroke();

  fill(0, 0, 255);

  // draw rectangfle at xpos

   rect(xpos, 0, width/32+(xpos/200), height);

   fill(255);

   // and xpos as text

   text(""+xpos , xpos, height/2);

}


void serialEvent(int serial){

  // if serial event is not a line break

  if(serial!=10) {

   // add event to buffer

   buf += char(serial);

   } else {

   // if serial is line break set value1 to buff and clear it

   value1 = int(buf);

   buf="";

   }
```

```
    // convert value1 to xpos

    xpos = constrain ( ( ( ((value1-100)*(width+100))/width )  ,0, width-12);

    if(output) println("xpos: "+xpos);

    if (xpos > 200   )

  { if (xpos < 400)

    println("Left");

      else println("Right");

  }



}


// draw listens to serial port, draw

void draw(){

// listen to serial port and trigger serial event

  while(port.available() > 0){

      value = port.read();

      serialEvent(value);

  }

 // draw background, then PushButtonState and finally rest of DisplayItems

    di.drawBack();

    drawPotiState();

    di.drawItems();

}
```

```
class DisplayItems{

// variables of DisplayItems object

PFont font;

int gridsize;

int fontsize = 10;

String fontname = "Monaco-14.vlw";

String empty="";

int i;

// constructor sets font and fontsize

DisplayItems(){

    font = loadFont(fontname);

    gridsize = (width/2)/16+(height/2)/16;

    if(gridsize > 20) fontsize = 14;

    if(gridsize > 48) fontsize = 22;

    textFont(font, fontsize);

}

// draws background

void drawBack(){
```

```
      background( (bck) ? (0) : (255)    );

}


// draws grid and value scale

void drawItems(){

   if(grid){    stroke( (bck) ? (200) : (64) );

                fill((bck) ? (232) : (32) );


   // vertical lines

   if(g_vert){

      for (i=0; i < width; i+=gridsize){

      line(i, 0, i, height);

      textAlign(LEFT);

      if (g_values && i%(2*gridsize)==0 && i < (width-(width/10))) text( empty+i,
(i+fontsize/4), 0+fontsize);

   }}


   // horizontal lines

   if(g_horiz){

      for (int i=0; i < height; i+=gridsize){

      line(0, i, width, i);

      textAlign(LEFT);

      if (g_values && i%(2*gridsize)==0) text( empty+(height-i), 0+(fontsize/4), i-(fontsize/4));
```

```
        }}

    }

  }

}// end class Display
```

Appendix E: Requirements & Verification

Modules	Requirements	Verification
E.E.S.	The total thickness of device must be thinner than 2 micro.	Perform profile measurements using profilometer to verify the total thickness.
	The noise-to-ratio of E.E.S. electrodes must be in ±1mV which is a comparable with commercial EMG sensor.	Setup commercial transmitter and software. Compare signal-to-noise ratio for both commercial and E.E.S. electrodes, and observe the impedance of ±1mV.
	Connection from three electrodes to gold pads of E.E.S. must be made without any disconnections.	Run resistance measurements on probe station.
	Connection from gold pads of E.E.S. to ACF cable must be made without any disconnections.	Run resistance measurements by multimeter.
S.C.U.	The output of S.C.U. must have a signal that ranges from 10-500 Hz and has a gain of 10000.	Measure the output voltage of the circuit using a multimeter, and calculate the gain of the circuit after the output voltage is measured. Also, measure the frequency of the signal that is obtained from the signal conditioning unit with the assistance of the multimeter.
	Sub-Requirements	**Sub-Verifications**
	Instrument Amplifier: The instrument amplifier should increase the gain of the voltage by 10000.	Apply an input signal to the AD620 chip with the assistance of a function generator, and measure output voltage of the AD620. Calculate the gain of the amplifier using the output voltage and the input voltage. • $G = V0/(V(pin1)-V(pin8)]$
	Low Pass Filter: The voltage of the output signal should be constant when the frequency of the signal is less than the cutoff frequency of 500 Hz.	Apply input signal, lower frequency than 500 Hz, and measure the signal at the output of the circuit by the oscilloscope. After observing output voltage, change the input signal to get closer to the cutoff frequency and check output voltage difference. Either the voltage should not change or an output voltage close to zero.

	High Pass Filter: The voltage of the output signal should be constant when the frequency of the signal is greater than the cutoff frequency of 10 Hz.	Apply input signal, greater frequency than 10 Hz, and measure the signal at the output of the circuit by the oscilloscope. After observing output voltage, change the input signal to get closer to the cutoff frequency and check output voltage difference. Either the voltage should not change or an output voltage close to zero.
Convertor (A/D)	The analog to digital converter must convert the signals received from the S.C.U. into discrete time and discrete amplitude digital signal.	Apply an analog signal with the assistance of a potentiometer and verify that the signal conversion program that is programmed onto the microcontroller outputs a digital signal on the serial monitor.
Micro-Controller	The microcontroller must display the direction that the user wishes to move the robot based on the different signals received from the user.	With the assistance of the potentiometer, we will vary the input voltage signal and check if the microcontroller reads the signal and outputs the direction that corresponds to the voltage.
Power Supply	The power supply is the main power source for all the components in our system. It will adequately power all the parts of our system	Measure the Power to each of the components powered by the supply with the assistance of the multimeter.
	Sub-Requirements	**Sub-Verifications**
	Microcontroller Power: The Microcontroller with A/D Convertor must be power by a 5V power supply.	Measure the Vdd by the multimeter so check Vdd pin gets the required voltage of greater than 4.8V
	S.C.U. Power: Each individual chip must have greater than 4.8V. We must ensure that all the op amps and other IC's get the desired power.	