Motion Tracking Glove for Human-Machine Interaction: Grasp & Release

Submitted By: Arefin Shamsil (0672602)
Partner: Thilakshan (0561599)

Department of Electrical and Computer Engineering
Faculty Advisor: Dr. Patriciu
Project Coordinator: Dr. Doyle

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Abstract

A common problem seen among the lower extremity paralyzed individuals and the elderly with subsequently reduced movement abilities is that they must rely on others to do a simple task such as getting a glass of water from across the room. As a result of their physical limitations, they lose their independency and more so become burden for the others. Data Glove Controlled Dynamic Robotic Arm can virtually restore their movement abilities without them having to move from their place at all. Data Glove Controlled Dynamic Robotic Arm is composed of two major sophisticated systems that include the wearable Data Glove Dynamic Controller and the Wirelessly Moveable Robot Arm with built-in visual feedback system. In this project, a Data Glove has been designed with two flexor sensors, signal conditioning circuit, 3-axis accelerometer and 1-axis gyroscope IMU and Arduino Duemillanove ATmega328 microcontroller. In addition, a simulated stick figure virtual model of the Robot arm unit has been developed in Arduino-Processing IDE interface. For the implementation of the Data Glove controller, the flex sensors has been mounted on the index finger and thumb of the data glove. These sensors are variable resistors that outputs decreased resistance value when bent. Connecting these sensors through a signal conditioning circuit, two analog voltage signals are extracted that range between 0V-5V. Thus, when the user bends a finger, a corresponding analog voltage is generated. Feeding these analog inputs to the microcontroller ADC subunit, digital representation of the signals can be obtained. Based on the digital value corresponding to specific analog voltage outputs from the finger sensors, the microcontroller can be programmed to control the speed and planar rotational position of the servo motor linking the gripping fingers of the robot.

Acknowledgements

I would like to thank Dr. A. Patriciu as our project supervisor and Dr. T. Doyle as our project coordinator. I show by respect and gratitude to Dr. Patriciu for the guidance, advise and equipments that he has provided us during the development period of this project throughout the year. I also would like to thank the Technical Staff Tyler Ackland, Steve Spencer and Chris Foulton of ECE department at ITB who provided various additional circuit equipments and lab computer assistance during the year.

I would like to thank, in addition, my colleague Thilakshan Kanesalingam who developed the accelerometer & gyroscope IMU part of the Data Glove and provided assistance and support for the execution of the project.

Keywords

Data Glove: glove that contains various sensors and captures finger articulation, hand motion and orientation

Flex Sensors: resistive sensors that changes resistance value when bent

IMU: initial measurement unit integrated with accelerometer and gyroscope

Accelerometer: circuit element that gives gravitational acceleration as an object is moved

Gyroscope: circuit element that gives rotational orientation of an object

Arduino Duemillanove microcontroller: microcontroller board to control physical or virtual objects

Hardware/Software Interface: bridge that links hardware stimulation to virtual action

*SCC (serial Communication channel):*communication channel that links microcontroller to PC and allows information passage between them

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Chapter 1: Introduction

1.1 Background

Over the past decade of the new millennium, the world has seen the ever increasing population around the globe. However, along with this increasing population trend, came forth a whole new domain of technological innovations and improvements for the betterment and sustenance of this population. Specifically, the innovations in the Computer & Gaming industry and Health Care industry is so overwhelming that human life has become a lot easier and appreciating. In medicine, for instance, the integration of medical science and engineering has enabled almost anything from simple and efficient electronic record keeping to complicated telerobotic surgery. Nevertheless, with increasing population, human lives still face constant dangers, accidents and diseases that are ever increasing at an alarming rate. Unfortunately, little of these damages can be prevented but the remaining victims of these events need to have an optimum medical care or a solution such that they can have a best compromised quality of life.

According to BBC report on US traffic accidents, car accidents are the leading cause of acquired disability nationwide in USA alone. Such disabilities include paralyzed or impaired limbs, partially paralyzed body, vision or auditory impairment and many more. Though they might have survived the fatal consequences, they must now live depending on others for the rest of their life. Similarly, statistical counts of individuals with impaired lower limbs from birth, or acquired lower limb malfunction during lifetime are shockingly high. According to CODI (Cornucopia of Disability Information) website, supported by the Western New York Regional TRAID Center at the Center for Assistive Technology, University of Buffalo, there are about *"1 million wheelchair users*

1 out of 250 persons has lower limb disability

10,000 people every year are spinal cord injured

82% of spinal cord injuries are male

307,000 under age 44 use wheelchairs--[US Dept of Health]."

Furthermore, survivors of serious diseases such as polio, Guillain–Barré syndrome, Botulism, Myasthenia gravis, Transverse Myelitis etc, may suffer from a lifelong lower limb disability problem and are forced to accept a lifestyle bounded by movement limitations.

In this project, a plausible solution has been derived that could allow these individuals to experience the freedom of movement and perform their independent tasks without actually having to move at all. To develop this concept, existing methods of Virtual Gaming and Human Machine Interactive Robotic systems have been considered. Through journal publication research and web research, it has been confirmed that such system can be developed by implementing a motion capturing Data Glove and interfacing it with a conceptual virtual Dynamic Robotic Manipulator. The idea is that by wearing the Data Glove, patients/users will be able to control a real Dynamic Robot Manipulator on the floor by simply moving their hand. While wearing the glove, the user should be able to articulate the end factor of the Robot manipulator and by moving the hand forward, backward and sideways, the user should be able to steer the manipulator around in planar space.

1.2 Project Objectives & Scope

Technological revolution has made an enormous positive effect within the field of medicine and a major part of it comes from the integration of medicine and engineering. This integrative link between these two fields of practices is the practice of Biomedical Engineering. It has vastly provided direct engineering solutions to many health care necessities (i.e. physiological signal and response measuring and monitoring system). In addition, it has provided engineering solutions to human health problems to make their everyday life better (i.e. pacemaker, bionic arm). Maintaining this common trend, this project's first objective is developing a way to make the lower limb disabled individuals' lives more interactive with the reality around them. By providing them with an assistive device that replaces their need for painful and frustrating movement, their lives can be made easier as the environment around them is brought right before their eyes on a monitor through real-time video feedback from the device while it is being controlled with a simple hand glove.

The second objective of the project is to make a Data Glove controller that is cost effective and yet fully functional. Current lowest market price for just the Data Glove is $585 which also requires drives, software, accessory case and USB cable. With all the required materials, the final price goes up to approximately $800, which is beyond affordable range for a general purpose. In terms of functionality, a commercial Data Glove gives a good resolution of motion capture and tracking of the finger flexion, hand position and orientation. However, same system can be developed at home with appropriate hardware under $200. In addition, available open source interface software can be used to interface Data Glove to microcontroller and then microcontroller to the PC. This paper demonstrates in details the development of such Data Glove with cheap hardware equipments and interfacing it to the computer through Arduino Duemillanove microcontroller board and open source software.

Finally, the scope of this project is not to develop a fully functional dynamic robot controllable by a Data Glove, but to develop and build a simple design of Data Glove prototype controller that can demonstrate the first objective in a virtual domain. However, the scope of a Data Glove extends beyond motion tracking in virtual domain or controlling robotic manipulator end factor. It can very well be used in the field of telerobotic surgery. With fabricated force sensors and fibre optical bend sensors inserted in the glove, a surgeon can perform complicated telerobotic surgeries over a long distance without even being touching a hand held controller.

1.3 Method of Solution

The project consists of two major parts—Data Glove implementation and simulation of virtual Robot Manipulator design. These two parts are further subdivided into two smaller parts:

* Implementation of motion capturing Data Glove fingers and real-time articulation of stick figure representation of virtual robot manipulator grippers.
* Hand motion and orientation tracker and interfacing it with real-time virtual stick figure model.

To execute the project step by step, a process diagram has been developed. It is shown below.

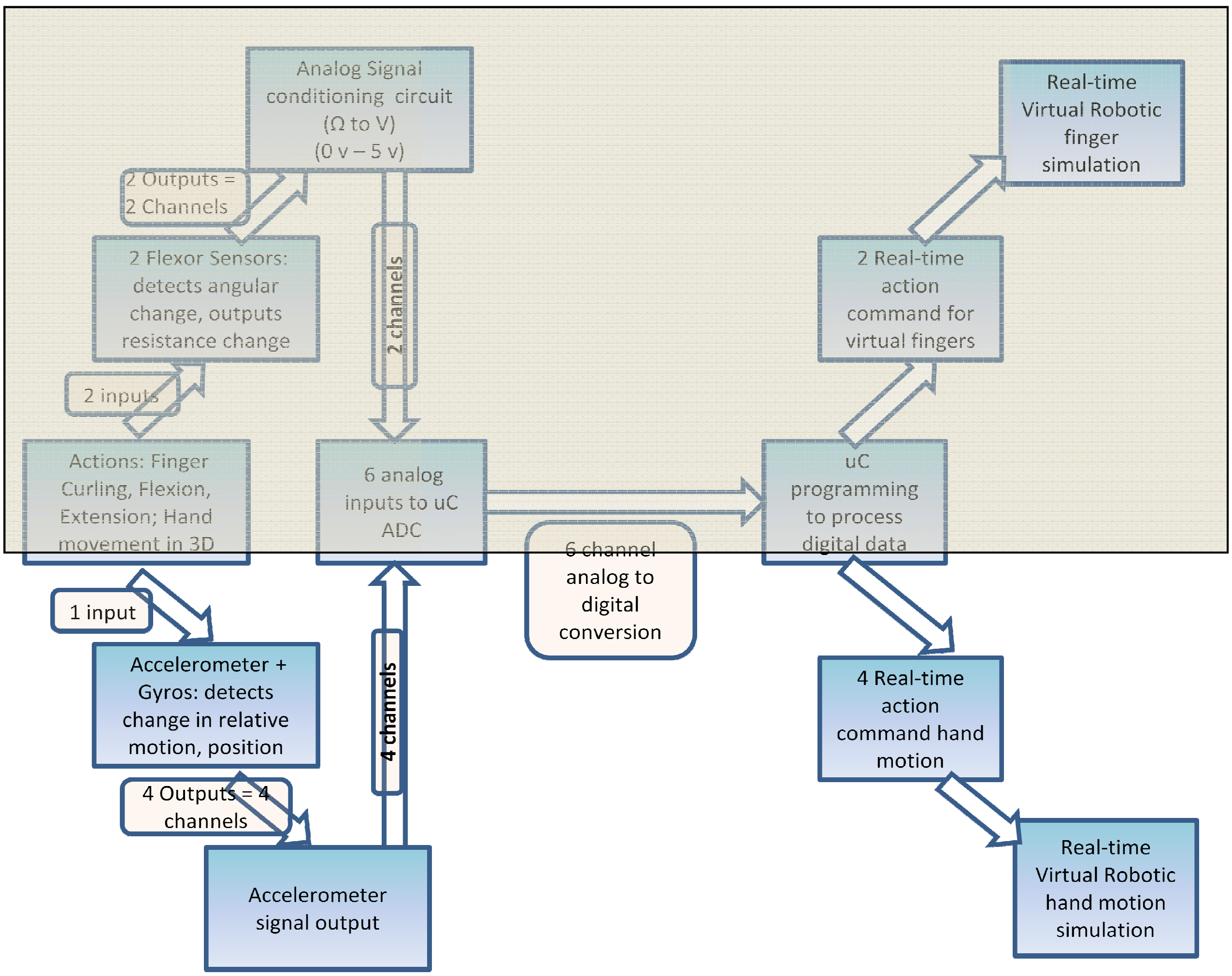


Figure 1.1: Overall process diagram (earlier plan for the project execution)

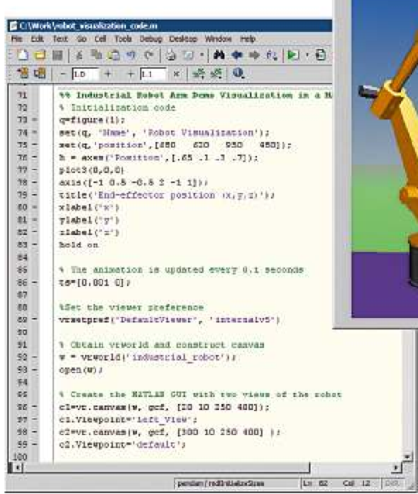
The process diagram above demonstrates the earliest design plan of the project. It demonstrates the path-lines of the inputs and outputs, their sources and destinations. The author's responsibility includes the implementation of the process included in the box.

1.3.1 Sensor Selection

The motion capture of finger articulation and hand movement cannot be tracked by a single sensor. For capturing finger articulation, an appropriate method would be to use flex sensors that produce real-time change in its parametric value when bent. Usually flex sensors are resistive sensors that change their resistance value when bent. Therefore, it must be converted to voltage for further signal analysis or modifications. On the other hand, tracking the movement and orientation of hand in space can be accomplished by an accelerator and/or gyroscope. Since a traditional analog output or response is a voltage waveform, it is necessary to obtain real-time voltage outputs from the flex sensors and the accelerometer. In order to obtain real-time voltage response from the flex sensors, a signal conversion circuit has been designed and developed which converts ,on the fly, the resistance value of the sensor into voltage.

1.3.2 Hardware/Software Interface Design

Controlling any virtual or real object using an external controller requires a communication channel between the controller and the controllable object. This channel is the interface that links the two separate systems. There are several sophisticated and efficient methods available through MATLAB-SIMULINK software systems that allow a programmer to both establish a real-time virtual interactive system and link in to an external controller. The end result, if accomplished, is utterly impressive as depicted below.



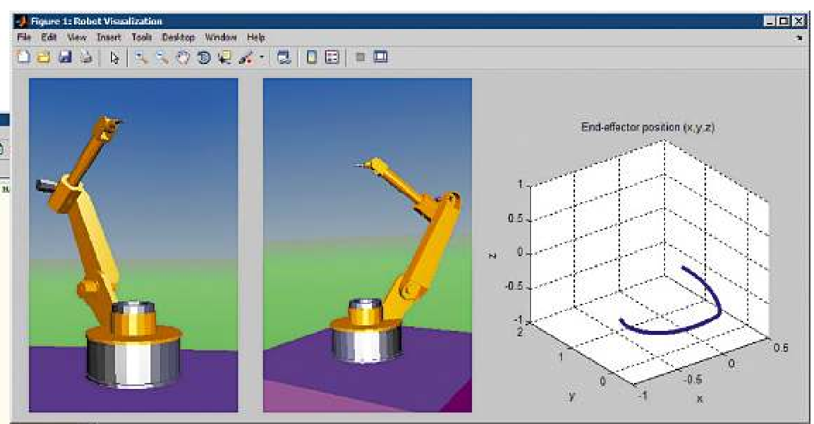
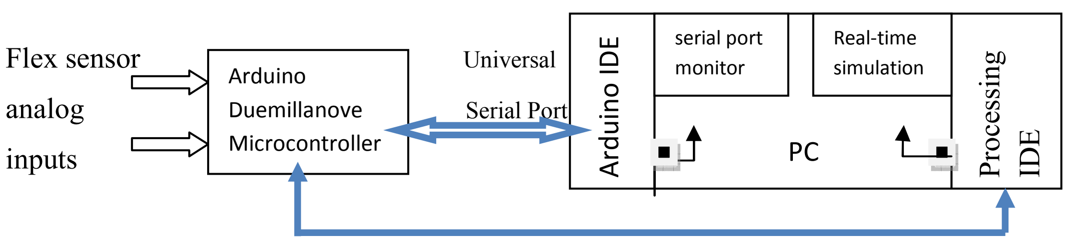


Figure 1.2: 3D robotic simulation in MATLAB/SIMULINK program. Courtesy of MathWorks official website. (http://www.mathworks.com/products/3d-animation/description6.html)

However, execution of these methods are rather complicated, time consuming and expansive. Therefore, for this project, a simplistic approach has been adapted. The hardware/software interface can be developed using the microcontroller Arduino Duemillanove, Arduino IDE and Processing IDE. The idea of the method is as following:

- The analog output from the flex sensors (and accelerometer) are supplied to the microcontroller.
- The microcontroller is connected to the PC via a USB port for serial communication .
- The Arduino IDE (a C based programming environment) is used to program the microcontroller
- Arduino IDE has a serial port monitor that is used to monitor the real-time response of the hardware in numerical values.
- Virtual stick figured robotic hand is implemented in Processing IDE (another C based programming environment). Using serial communication command in Processing, a serial communication channel (SCC) can be established between virtual stick figure robotic hand, developed in processing, and the microcontroller connected to the sensors.

The generalized datapath for Serial Communication between PC and microcontroller is shown below. As described above, following diagram is the overview of the method used to implement the hardware-software interface.



Communication channel between microcontroller and Processing Through USB

Figure 1.3: Hardware/Software Interface of this capstone project

Chapter 2: Literature Reviews

Data Glove is one of the most exciting research topic at this current time. With accelerated growth in the electronic industry, consumers demand to interact with virtual objects or remote machinery in a realistic fashion. Examples of which include virtual gaming, touch panel computers, human machine interaction, telerobotic surgery, virtual surgical training and many more. Through literature research for this project, it has been discovered that many research based on Data Glove, related to each of the developments mentioned above, has been done. Some of those research paper, as they were reviewed for this project, include: Data Glove with a force Sensor [1], 3D hand motion tracking and gesture recognition using a Data Glove [2], Motion Sensitive Glove based Korean finger-spelling tutor [3], Teleoperation of robot based on Data Glove and virtual reality [4], Hand-in-Glove Human-Machine Interface and Interactive Control [5] and Development of a functional neuromuscular stimulation system using Data Glove [6].

Among these research papers, paper [1] and paper [6] were most valuable toward the development of this project. As explained in detail below, circuit topologies and data acquisition algorithms were adapted from these research papers during the early stages of the project development. However, during design phase, significant changes have been done on the demonstrated topologies and algorithms in order to make the purchased sensors work properly.

2.1 Research Paper [1]

Data Glove With a Force Sensor

(*Kostas N. Tarchanidis, Member, IEEE, and John N. Lygouras, Member, IEEE)*

The objective of this paper is to demonstrate the development stages of a data glove equipped with force sensors and bend sensors. This paper demonstrates that using flex sensors mounted on the glove, the finger articulation can be captured. In addition, using force sensors mounted on the glove, the force produced due to gripping mechanism of the hand can be obtained and transferred through serial communication port and replicated within a remote mechanical gripper. As a result, wearing the Glove, if an object is held with a certain force input (i.e. 4N), a remote mechanical robotic arm should also produce the same grasp force. As mentioned in the paper, this development can be used in robotics, telecheric, biomechanics, rehabilitation and virtual reality applications. The following is the prototypical design of the Data Glove used in the project.

Figure 2.1: Prototype Data Glove. Flex sensors mounted on the glove and white coloured force sensor taped around thumb.

The simplistic system design of the project presented in this research paper is as following:

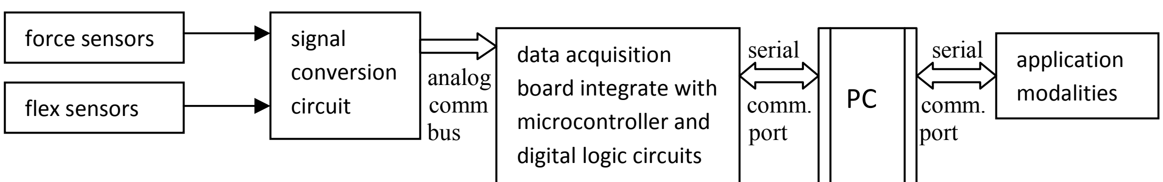


Figure 2.2: System design of Data Glove with force sensors as presented in the research paper

Although this paper gives the detailed description of force data acquisition algorithm, it however is not the focus of the capstone design project. Nonetheless, the following circuit topology presented in this paper has been adapted for the capstone design project. The circuit is composed of three subdivided op-amps circuits known as *the buffer*, *the adder* and *the amplifier*. The buffer circuit simply act as a voltage follower to output the voltage produced at the voltage divider circuit. The adder circuit adds positive voltage value to the buffer circuit so that the low negative voltage is offset by the comparably higher voltage of the adder output. Finally, the small voltage is amplified through the amplifier circuit and gives a amplified voltage that falls between desired voltage range.

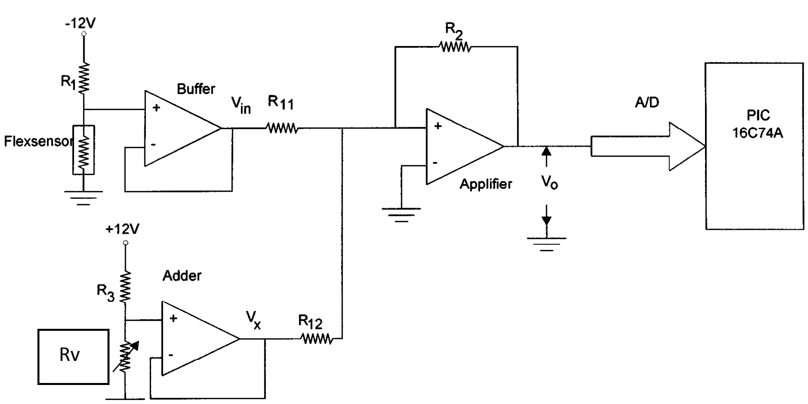


Figure 2.3: Signal Conversion circuit (converts resistance to voltage)

The circuit above has the transfer function of $v_0 = -\left[\frac{R_2}{R_{11}}V_{in} + \frac{R_2}{R_{12}}V_x\right]$, where Vx is the adder output, Vin is the buffer output produced by the flex sensor activity and Vo is the final output of the overall circuit. There is a technical reason why the buffer circuit must have a negative voltage supply and the adder circuit a positive voltage supply. When the buffer circuit outputs a negative voltage, the adder circuit provides a fixed positive voltage that would correct the offset value produced by the buffer circuit and output a positive voltage to be amplified. If the adder component was not included in the circuit, then the buffer output would have been either positive or negative depending on the voltage supply value. As a result, there would be no offset value to fix this problem. On the other hand, If the adder input voltage supply and the buffer input voltage supply were identical, then there would be either a very high positive output or a very low negative output and the amplifier would then further skew the result. As a result, the output voltage cannot be fixed within 0v - 5v needed by the microcontroller. In addition, the flex sensors are very inefficient sensors and constantly change their parametric value based on their form (i.e. bent, flat, twisted etc.) which would then make it impossible to obtain desired result. However, input voltage polarity for the buffer and adder circuits, so long they are opposite of each other, can be interchanged with minor change in the variable resistor denoted as Rv. In the transfer function mentioned earlier, the resistor ratios must be kept as following: $R_2 / R_{12} = 1$ and $R_2/ R_{11} = 1.25$. This allows proper voltage amplification of the signal since Vin is the input needed to be amplified, whereas Vx is not.

Beside the circuit topology, data acquisition algorithm for microcontroller ADC has also been adapted for the capstone design. The following flow chart demonstrates that upon receiving the input, a decision has to be made to check if the received byte is of certain value or range. If it is then approach to analog to digital conversion; otherwise receive byte again. During A/D conversion, the byte length of the digital value is checked (although it is not mentioned in the flow chart). If it is of the desired value, then the real-time digital response can be sampled and sent to PC, otherwise reconversion is to be done.

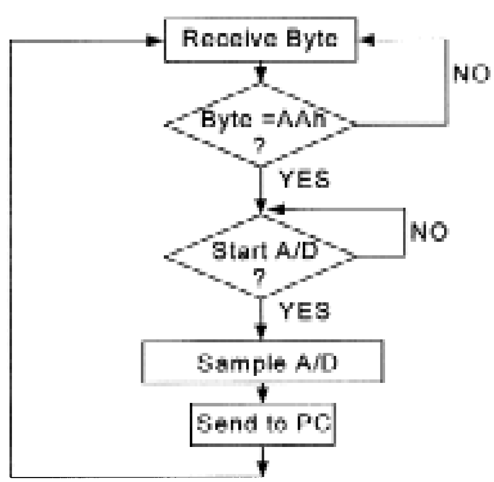


Figure 2.4: Data Acquisition Algorithm

2.2 Research Paper [6]

Development of a Functional Neuromuscular Stimulation System for Independent Ambulation of Patients with a Spinal Cord Injury

(Alejandro Garcia Blanco, Gildardo Jiménez, Pedro Ochoa Moreno)

The objective of this paper is to develop a simple, portable and economically accessible device that permits the limited movement of the inferior extremities on patients with lumbar spinal cord injuries. To make the project successful, a Data Glove equipped with force and bend sensors is necessary. This paper explains that wearing the Data Glove, when a patient with lower extremity paralysation, flexes his finger it produces spikes of real-time high voltage signals. These signals can be programmed as the muscle stimulation pulses. When these electric shock stimulation pulses are supplied to the paralysed leg muscles through extracutaneous electrodes, the underlying nerves are activated for a short time allowing the patient to move his legs. This paper also describes that, a fully functional hand can move in countless ways. Capturing all those motions is quite impractical. However, some distinctive movements are finger flexion, extension, adduction, abduction and wrist flexion and extension. All these motions can be programmed to produce electric stimulation pulses with distinct level of strengths. Therefore, multiple signals can be produced via simultaneous movements of the five fingers of the hand and supplied to multiple different leg muscles. This will allow movement of both legs or combined movement of the same leg. Shown below is the diagram of the described movement mapping developed in this paper.

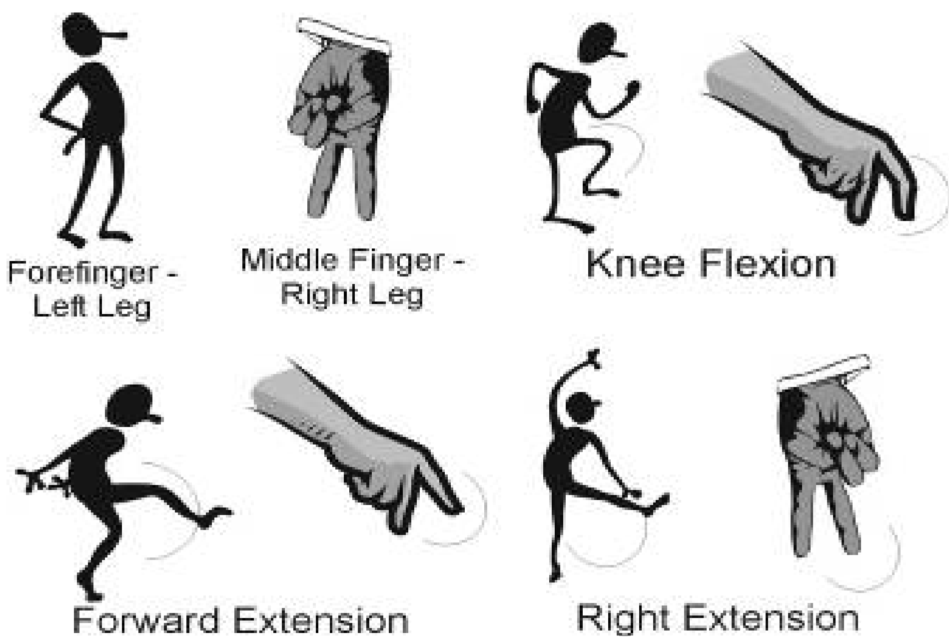


Figure 2.5: Mapping of finger movements based on desired leg movements.

In order to achieve such movement mapping, a Data Glove has been designed as following. There is a flex sensor for each finger (Figure 2.6 A) and also between each finger (Figure 2.6 B). This design will allow capturing flexion and extension and also abduction and adduction.

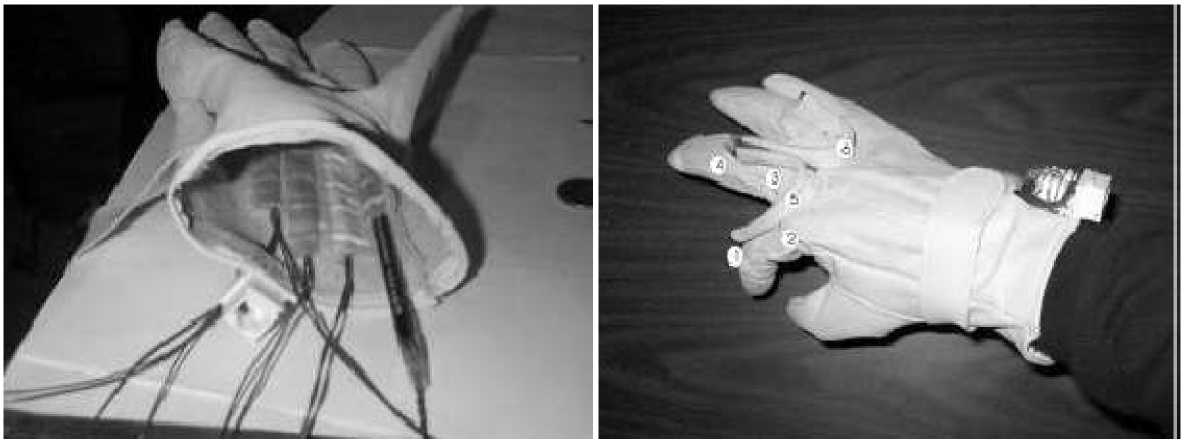


Figure 2.6: (A) Inside sensors (B) Outside sensors

This paper introduces a different yet simplistic design of the signal conversion circuit which requires only one op-amp. The design is shown below.

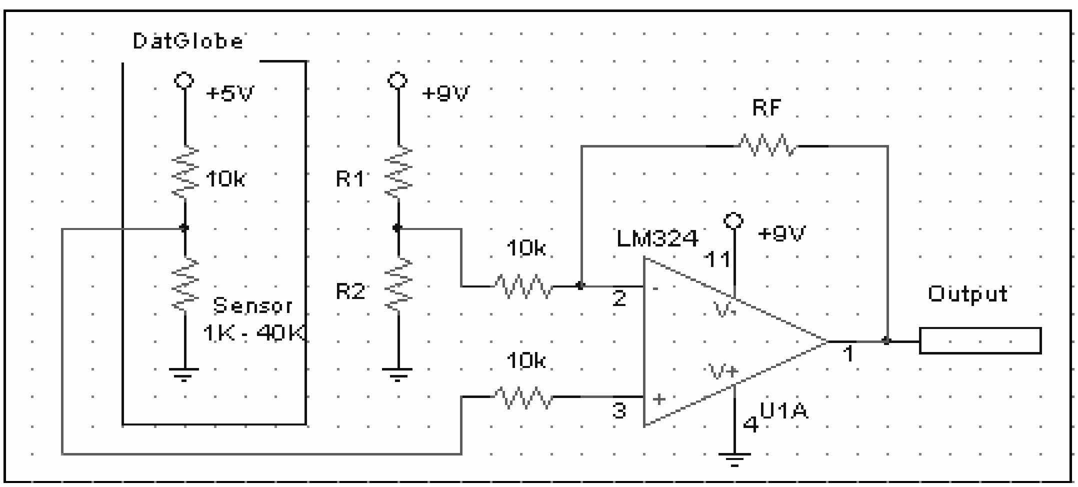


Figure 2.7: Signal conversion circuit (Ω - V)

The drawback of this circuit is that it will only work for efficient flex sensors as used in the project. In other sense, the parametric nominal value of the flex sensors must be same at all the time! This is why development attempt of this circuit for the capstone project was a failure. However, the expected output behaviour of a bend sensor has been learned from this research paper. The one provided in this paper is shown below.

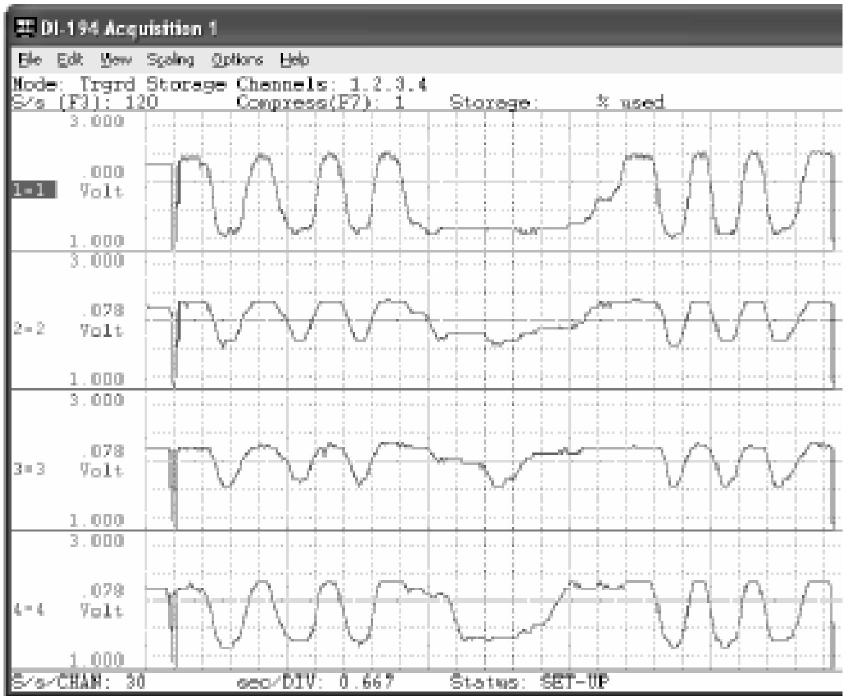


Figure 2.8: Sensor behaviour based on finger movement. Four sensor outputs for four sensors have been demonstrated in this picture.

Chapter 3: Project Development

3.1 Equipment Design

3.1.1 Data Glove Design

In order to capture finger motion, it is necessary to design a glove equipped with bend sensors. Observing the Data Glove designs presented in the research papers, a tight but stretchable hand glove has been obtained. Then two bend sensors have been mounted over the forefinger and thumb by sewing fabric pockets over the glove fingers. The tightness of the glove is necessary for close contact with the fingers when worn and stretchiness of the glove is necessary to allow complete free motion of the fingers. It is necessary that the sensors remain tightly pressed over the fingers so that it can capture the finer definition of the angular change, as precisely as possible, during the flexion of individual fingers. The sensor over the thumb is placed such that it captures the *abduction* and *adduction* motions of the thumb which is necessary to curl the fingers together and grasp something. The designed glove has been shown below.

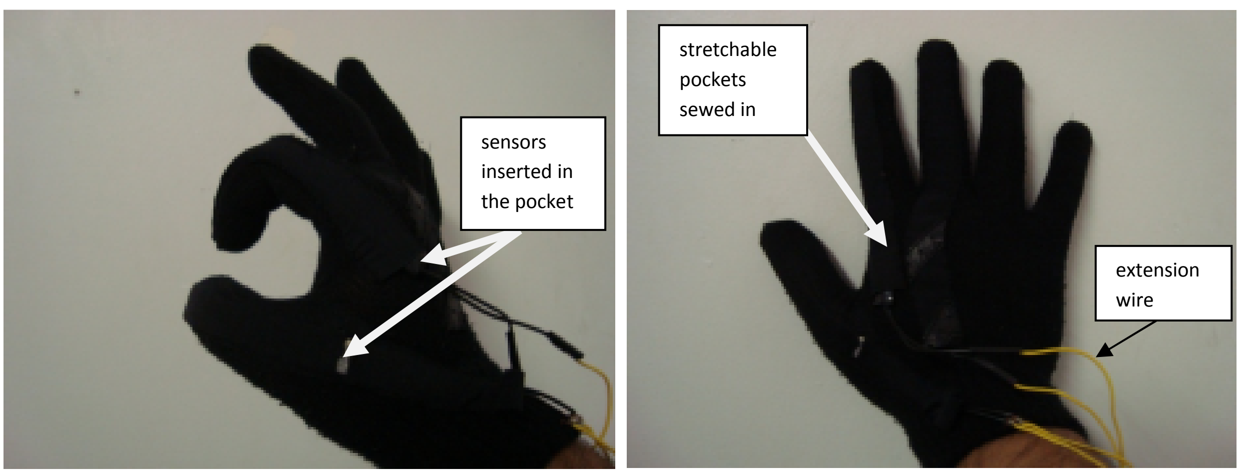


Figure 3.1: Designed Data Glove

3.1.1 Sensors

The sensors that have been used are flex sensors which are special types of resistors that sustain a nominal resistance value at flat state. However, when gradually bent, this resistance value will decrease to a minimum value. These flex sensors are bidirectional flex sensors; therefore, output a value when they are bent both back and forth. The lowest to highest values for thumb and forefinger sensors are 15K-50K ohms and 50K - 10M ohms, respectively. These sensors are also force sensors; therefore, when pressed, they would decrease resistance. The issue with these sensors is that they are very unstable. The measured nominal values at flat state and functional range values keep changing. This is why, one of the design objective is to maintain these sensor outputs at a defined functional range.

Figure 3.2: Selected Flex Sensors

3.1.2 Voltage Regulators

Hooking up the Data Glove to a stationary input power supply is somewhat impractical since it eliminates the portability of the device. This is why it is necessary to drive the Data Glove circuitry with batteries. To power up the circuitry with batteries, appropriate voltage regulators are necessary so that the voltage supply remain consistent despite the decreasing battery life. Based on the circuit topology selected (section 2.1), there would be two voltage supplies with opposite polarity. Therefore, for this capstone project, a positive and a negative voltage regulator is necessary. The selected voltage regulator chips are LM317T (for positive voltage regulation) and LM227 (for negative voltage regulation).

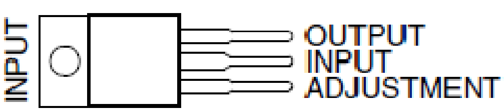
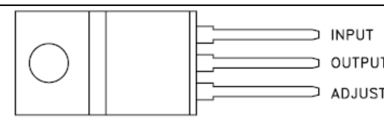
(A) LM317T	(B) LM237
	
	

Figure 3.3: Selected voltage regulators

3.1.3 Operational Amplifier Chips

Parametric values of the sensors—resistance (Ω) has to be changed in to voltage (V) so that an interface can be implemented between the selected microcontroller and the Data Glove sensors. As suggested in section 2.1, the selected circuit topology requires ideal op-amps. The best op-amp chips at cheapest price is found to be LF411CN. The following pictures show the characteristics of the chip.

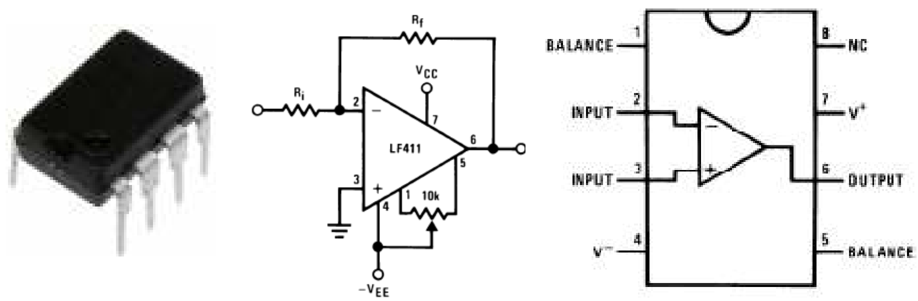


Figure 3.4: (A) LF411CN op-amp chip, (B) Internal circuit diagram, (C) Top view connection diagram

3.1.4 Accessories

In order to build the signal conversion circuit, several different circuit elements, connecting wires and breadboard are necessary. Each finger will contain a mounted flex sensor that has its own designated signal conversion circuit. According to the selected circuit topology, a single circuit contains a variable resistor to adjust the positive offset voltage produced by the adder circuit in the overall circuit diagram. For this purpose, potentiometers has been obtained of ranges 0-100K Ώ and 0-2M Ώ. Also, tens of resistors of values 220 Ώ, 320 Ώ, 1KΏ, 8KΏ, 10KΏ and 100KΏ have been obtained from Sayal Electronics and faculty electrical shop. Typical voltage regulation circuits require specific capacitors and resistors. Therefore, 1uF solid tantalum and 10 uF aluminium electrolytic capacitors have also been obtained from the faculty electrical shop.

3.1.5 PSpice

PSpice is a software for circuit design, circuit output simulations and tests. The demo student version of PSpice has been used to design all theoretical schematics of the signal conversion circuit. In addition, bias point analysis has been done to visualize voltage and current outputs at every node of the signal conversion circuit. PSpice makes the circuit design procedure more faster, error free and efficient since it eliminates early trial and error scheme—design-build-test, redesign-rebuild-retest.

3.1.6 LABVIEW

The analog voltage output must be monitored to visualize the real-time behaviour of the circuit and the sensors. To monitor the voltage output, LABVIEW, Arduino IDE and Processing IDE have been used. The prime advantages of LABVIEW is that it allows the user to graphically program the DAQ (data acquisition) module to display continuous sample of the analog input data sampled at desired sampling rate (hz) and sample number (N). This allows the user to visualize changes in the analog input data at microscale. In addition, analog data can be directly converted to digital data and the real time digital response in binary value and in waveform can be monitored. LABVIEW in the laboratory is also provided with pre-installed National Instrument data acquisition hardware; therefore, no external set up is necessary which makes data acquisition very easy.

Figure 3.5: LABVIEW and its attributes. Courtesy of National Instrument official website.
(http://zone.ni.com/devzone/cda/pub/p/id/31)

3.1.7 Integrated Development Environment

Arduino IDE is the C based open source development environment to program any microcontroller from Arduino microcontroller series. It has a serial monitor that can be used to monitor real-time response of the sensors. However, appropriate programs must be written and uploaded to Arduino microcontroller to setup a serial port communication channel between the microcontroller and the signal conversion circuit. Arduino IDE has been obtained from the official Arduino microcontroller website. Furthermore, Processing IDE is also a C based development environment to develop animation, simulation, real-time interaction with Arduino microcontroller etc. However, appropriate programs must be written to achieve desired functionality. Development in Processing IDE is relatively easy and therefore it has been selected for the development of simulated real-time responsive stick figure virtual robotic arm.

3.1.8 Microcontroller

Microcontroller is the bridge between hardware and PC in this capstone project. As mentioned earlier, Arduino Duemillanove microcontroller board with ATmega328 microcontroller chip has been selected for this project. It comes with its own inbuilt boot-loader and driver for the USB port. This board has 6 analog I/O pins and 14 digital I/O pins. Therefore, two analog input from the flex sensor circuit and four analog input from the accelerometer module will fully occupy all the useable pins. Furthermore, the available digital pins can be used for real-time LED simulation of the finger articulation.

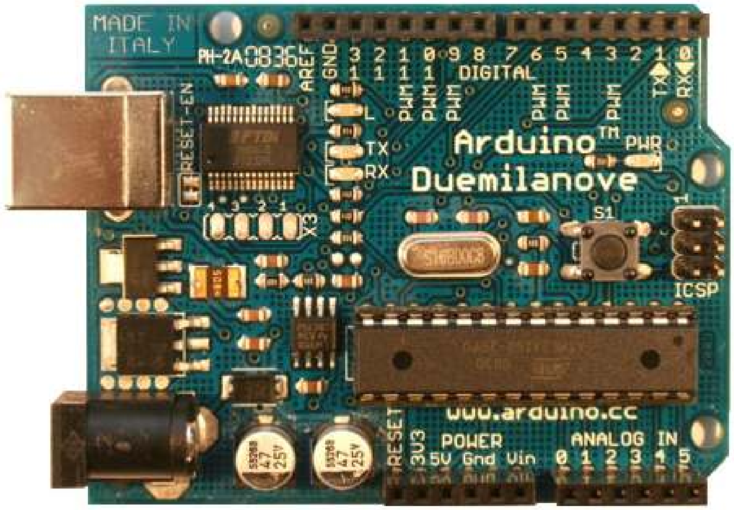


Figure 3.6: Arduino Duemillanove Microcontroller Board. All the pins are clearly visible in this picture. Courtery of Arduino official website. (http://www.arduino.cc/en/Main/ArduinoBoardDuemilanove)

3.2 Cost Management

Cost management of the project is a very important aspect of the overall project development. One of the project goal is to to develop the design concept significantly under the market price. The advantage of this goal is twofold: keeping the cost low while making the best functional outcome; make it affordable and a marketable product.

Table 3.1: Cost chart for the project

Author's part	**Partner's Part**
3 Bend sensors: \$12X2 + \$14X1 + tax + shipping = \$48.86	IMU: \$56
Wool glove: \$1.14	Voltage regulator : \$1.5
Batteries = \$7	Breadboard: \$12
Accessories: 100 kΩ, potentiometer, jumper wires Total = \$11 (sayal electronics)	USB cable: \$3
Voltage regulators = \$4.50 (digikey)	
Microcontroller: Arduino Duemillanove (\$35)	

In addition to the above purchases, other equipments have been obtained from the faculty technical shop facility. The following chart shows the exact number of materials used to build the analog signal conversion circuit. The materials that do not have any price listed, have already been included in the cost calculation chart above. Among the additional materials that have been borrowed from the technical shop facility, the prices of the resistors are negligible since the cost of individual resistors are very low compared to other elements.

Table 3.2: Circuit elements inventory

Equipments	Total Number	Price
LF411 (singer opamps)	6	6X$1.7 = $10.2
LM317T (positive voltage regulator)	1	$0.7
LM227 (negative voltage regulator) /purchased	1	
Potentiometer (0 - 100K) ohms / purchased	2	
Potentiometer (0 - 2M) ohms / purchased	1	
8K ohms resistors	4	Negligible
10 K ohms resistors	7	"
220 ohms	3	"
330 ohms	4	"
100K ohms	2	"
Batteries (9V) / purchased	4	

After adding the accountable prices from table 1.1 and 1.2, the author's total cost for the project is as following: $48.86 + $1.14+$7+$11+$4.5+17.5 (half price of microcontroller) + $10.2+0.7 = $100.9. Including the partner's part, the total project cost is ($56+$1.5+$12+$3+$17) + $100.9 = $184.86. Compared to the commercial product price ($585 for just the glove), the prototype developed in this project is significantly lower; therefore, satisfying the financial aspect of Project Management.

3.3 Initial Measurements & Tests

Table 3.3: Sensor measurements prior to circuit design and developments. (Flexion/extension)

Sensor states	Index flex sensor	Thumb flex sensor
Flat and out of the glove	84 KΩ	1528 KΩ
Flat and in the glove	80 KΩ	1528 KΩ
Flat in the glove while wearing it	70 kΩ	1420 kΩ
Fully bent and out of the glove	4 kΩ	50 kΩ
Fully bent in the glove	4 kΩ	55 kΩ
Fully bent in the glove while wearing it	12 kΩ	70 kΩ

The table above shows all the values obtained at different states of the flex sensors. This is how the actual nominal values of the sensors have been obtained. These are the values used to design circuit schematics.

3.4 Theoretical Design of Signal Conversion Circuit Schematic

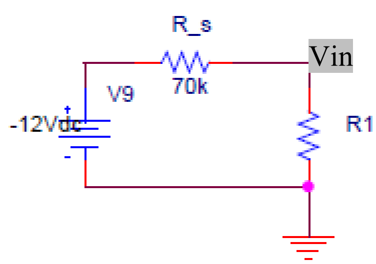
Before building the signal conversion circuit, it has been designed in PSpice and tested through DC bias point analysis to obtain the voltage output at all nodes. To determine the parameter values, transfer function and resistor ratios from section 2.1 has been used. Transfer function: $v_0 = -\left[\frac{R_2}{R_{11}}V_{in} + \frac{R_2}{R_{12}}V_x\right]$ where : $R_2 / R_{12} = 1$ and $R_2 / R_{11} = 1.25$. The first trial of calculations to obtain the circuit parameter values has been shown below. It corresponds to the measured flex sensor value of the index finger. Similar calculations has been done for the measured value of the thumb flex sensor. The calculated values give a rough idea of what the parameter values should be at ideal and practical cases.

<u>Typical theoretical calculations</u>

At first both the voltage source are chosen to be 12V (for adder circuit) and -12V (for buffer circuit). Since Vo should be within 0V - 5V, circuit parameters would be calculated for 5V—the highest output to be obtained from the circuit. Therefore, the transfer function equation becomes: 5 = - [1.25Vin + Vx]. Now, regardless of the Vin value, Vx value is selected to be 2.5V. This is because, Vx is the output of the adder circuit. It suppose to add in to the buffer circuit output and offset the voltage to make a positive voltage which will be the input for the amplifier circuit. Since the demand is to gain 5V at Vo, an educated guess is to choose Vx = 2.5V which will make the overall output 0V if the buffer circuit outputs approximately -2.5V. The ideal output value of the buffer circuit at 70K (flat state value of the index flex sensor) should be -2.5V such that Vo would be 0V.

Now the equation becomes: 5 = - (1.25Vin + 2.5). Therefore, Vin = -6V

Since the input circuit for the buffer op-amp is a simple voltage divider circuit, the Vin value is:



Vin = (R1/(R1+R_s)) X (-12); where R_s = 10K which is the fully bent state value of the index flex sensor. Now inputting all the values in the equation, -6 = (R1/(R1+10K)) X (-12);

0.5 = R1/(R1+10K);

Therefore, R1 = 10K. Since R2 = R12, R2 is selected to be 10K for simplicity.

This results R11 = R2/1.25 = 10K/1.25 = 8K.

During practical design of the circuit, these exact parameter values will not work because circuit elements are never ideal. Therefore, certain circuit parameters has to be changed to obtain practical values.

Using all these parameter values, the following circuit has been designed:

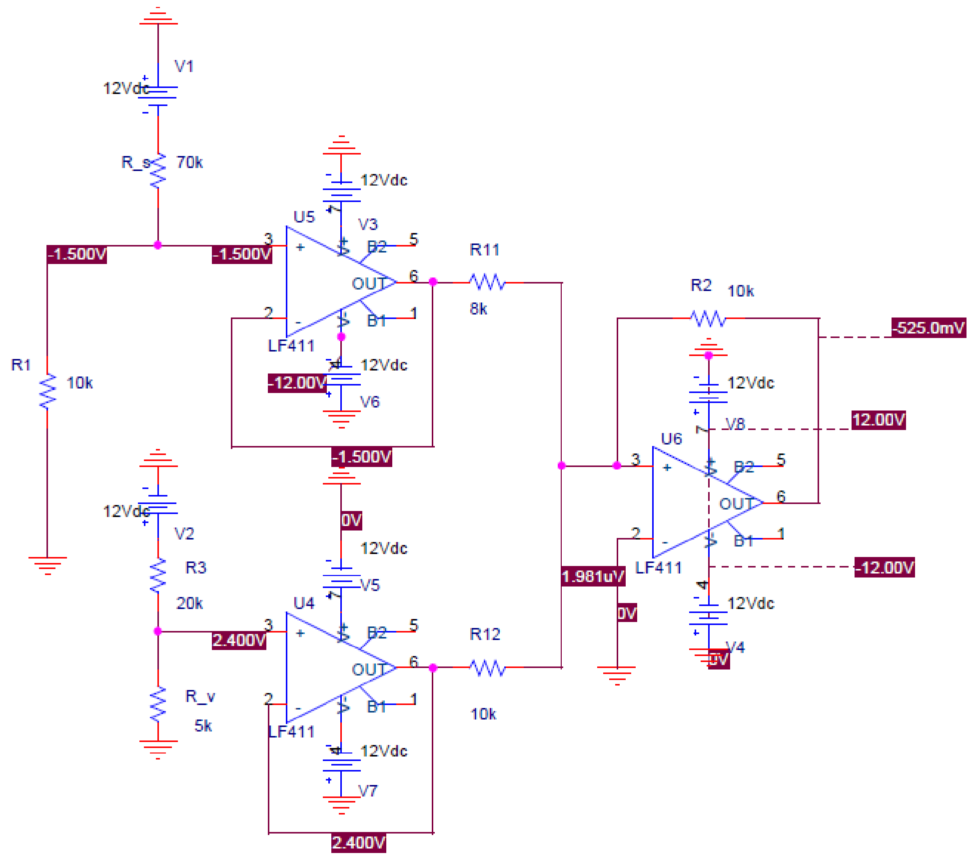


Figure 3.7: Theoretical circuit design and DC bias point analysis at flat state of the index finger

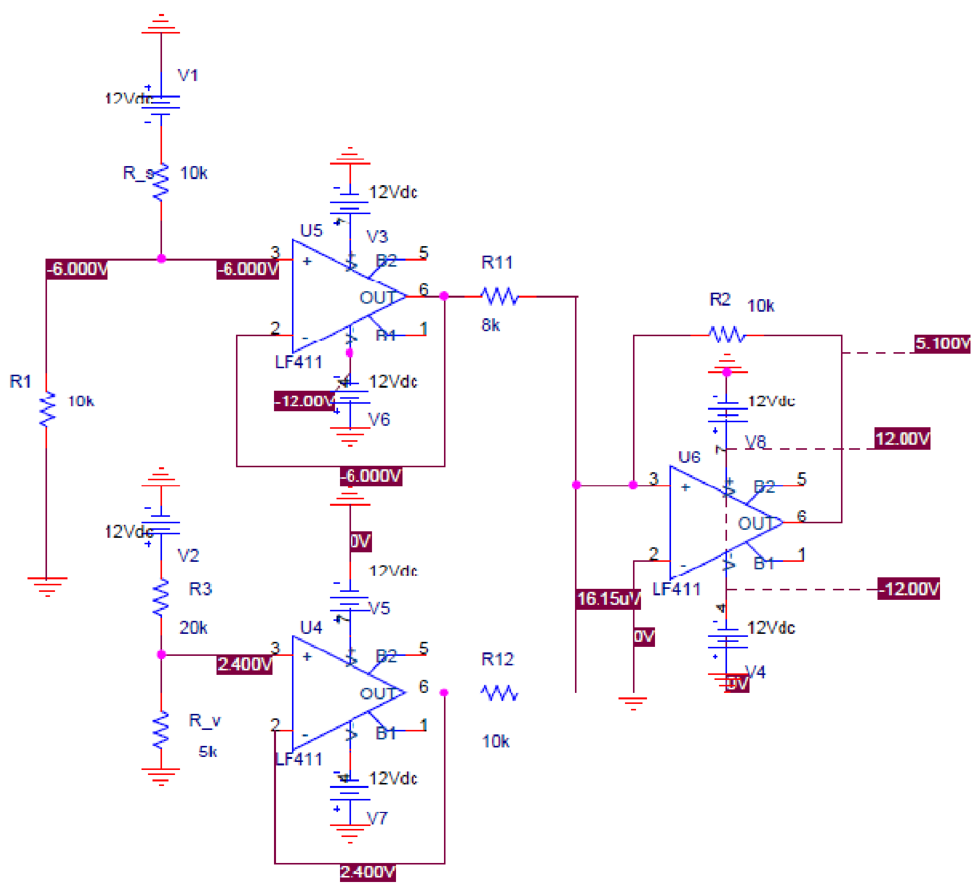


Figure 3.8: Theoretical circuit design and DC bias point analysis at bent state of the index finger

Chapter 4: Practical Designs & Implementation

4.1 Signal conversion circuit implementation

Circuit elements are never ideal. This is why when the theoretical designs were implemented, the outputs were significantly off from the desired values. After consistent debugging of the circuit, it was found that certain offset balances had to be provided to the pin 1 and pin 5 of the op-amp chips. In addition, the voltage supply selected as 12V and -12V were no longer functional because practically these inputs were giving a stationary output of -11.5V for the thumb circuit and stationary 9.95V for the index circuit. In order to fix this initial problem, the circuit was connected to the power supply and the voltage dials were slowly turned until there was a real-time response. Although, at first the outputs were ranging from -14V to -4V for the index circuit and still stationary for the thumb, further debugging has been performed by balancing the balance pins of all six op-amps of the entire circuit. This in fact solved the problem for index finger circuit. The output was found to be varying from -0.8 mV to 4.8 V. The working output was obtained with voltage inputs of 8.7V at adder circuit and -15.4V at the buffer circuit.

For the thumb circuit, more careful measurements had been made. It was found that the problem was arising from the sensor value which was 1.5 MΩ. It always made the circuit unstable by drawing a lot of current into the third op-amp. As a result, one of the chip heated up and burned during the implementation of the circuit. To fix this problem, two 100 KΩ resistors were placed in parallel with the 1.5 MΩ sensor. As a result the output was then found to be varying between 1.5V - 4.8V.

4.2 Voltage regulator circuit implementation

Voltage regulator circuit is necessary to power up the signal conversion circuit using battery. The voltage regulation circuits are usually provided in the designated chip datasheets. The goal was to produce 8.7V and -15.4V. Using the LM317T datasheet, the following circuit was implemented.

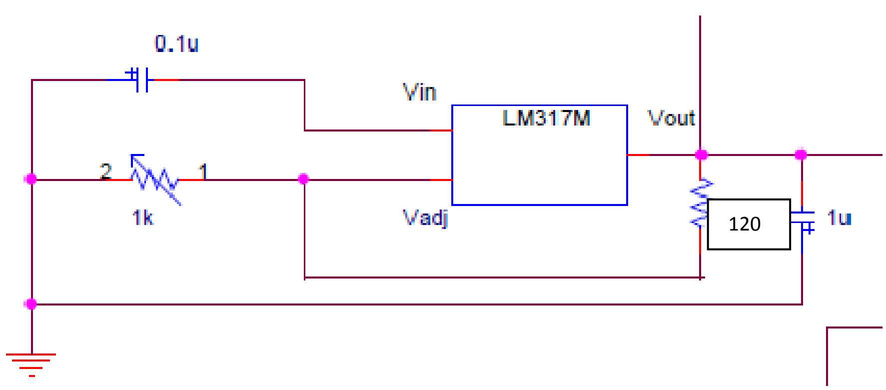


Figure 4.1: positive voltage regulation circuit.

This circuit has a transfer function of $Vout = 1.25(1+ R2/R1)+ Iadj(R2)$

$3V \le (Vin - Vout) \le 40$ V (from the datasheet)

Iadj = 50uA(typical)

Iadj = 100 uA (max)

let R1 = 120Ω (recommended value)

therefore, $8.7 = 1.25(1+ R2/120) + Iadj\ (50uA)$

therefore, R2 = 714.624, but practically 1K was chosen.

On the other hand the negative voltage regulation circuit has been implemented as following.

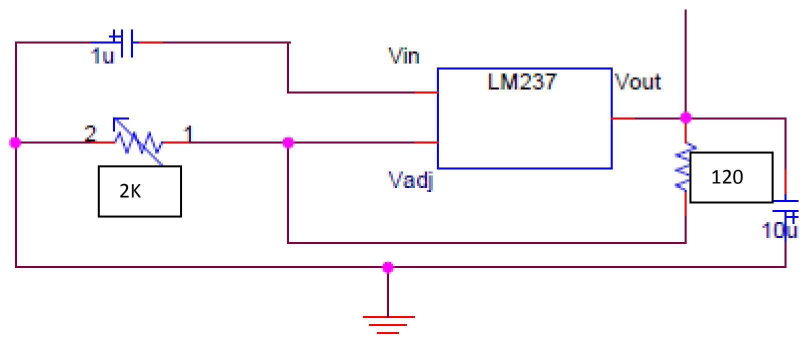


Figure 4.2: negative voltage regulation circuit.

From the data sheet, the circuit equation is $R2 = R1(-Vo/-1.25 - 1)$

since Vo = -15.4 V, and R1 = 120Ω recommended in the datasheet.

$R2 = 120\ (15.42/1.25 - 1) = 1360.32\ \Omega$. As a reasonable value, 2K was chosen.

After putting together the entire circuit in PSpice, the following schematic system diagram has been produced (shown in the next page).

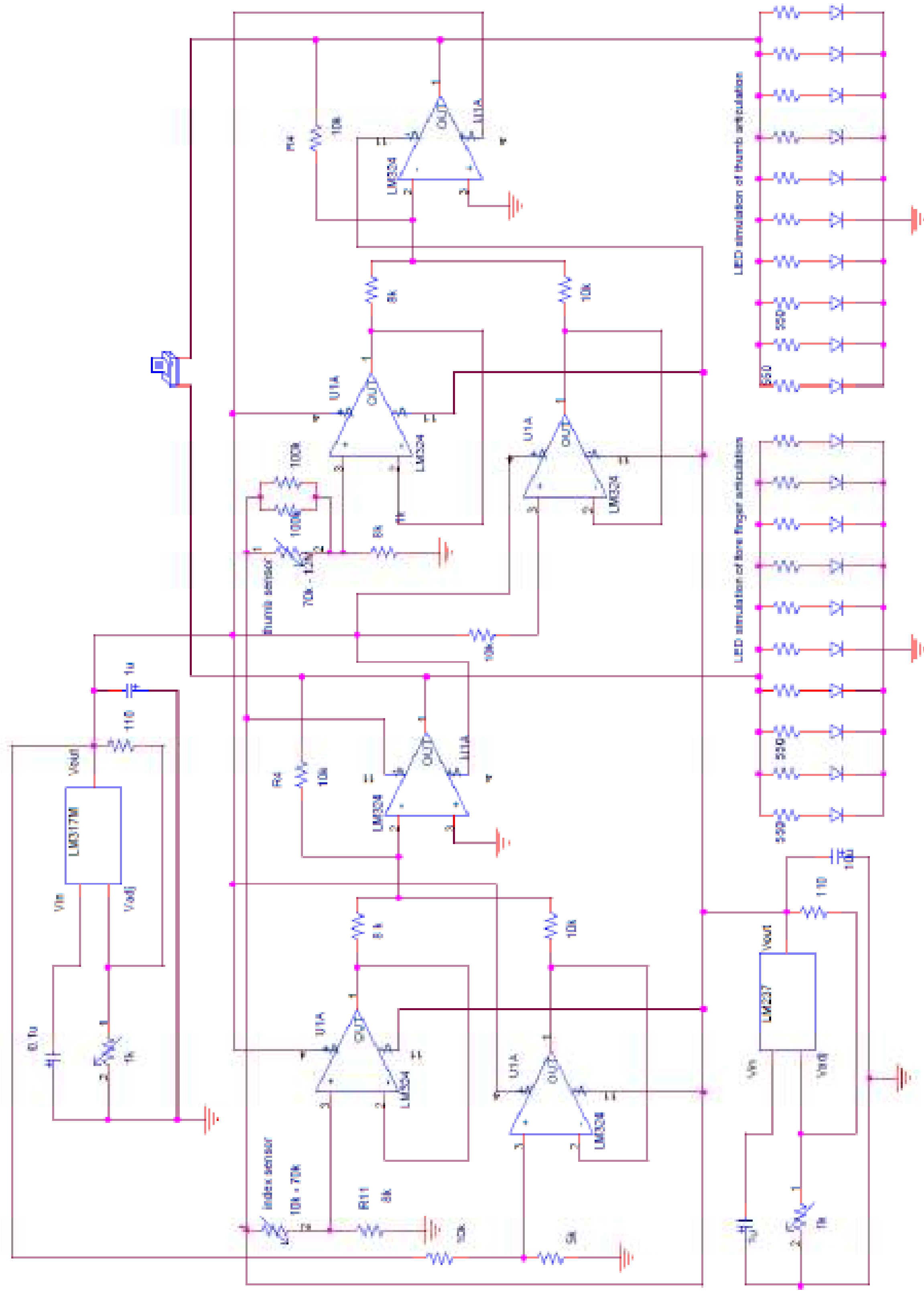


Figure 4.4: Over all system schematic diagram.

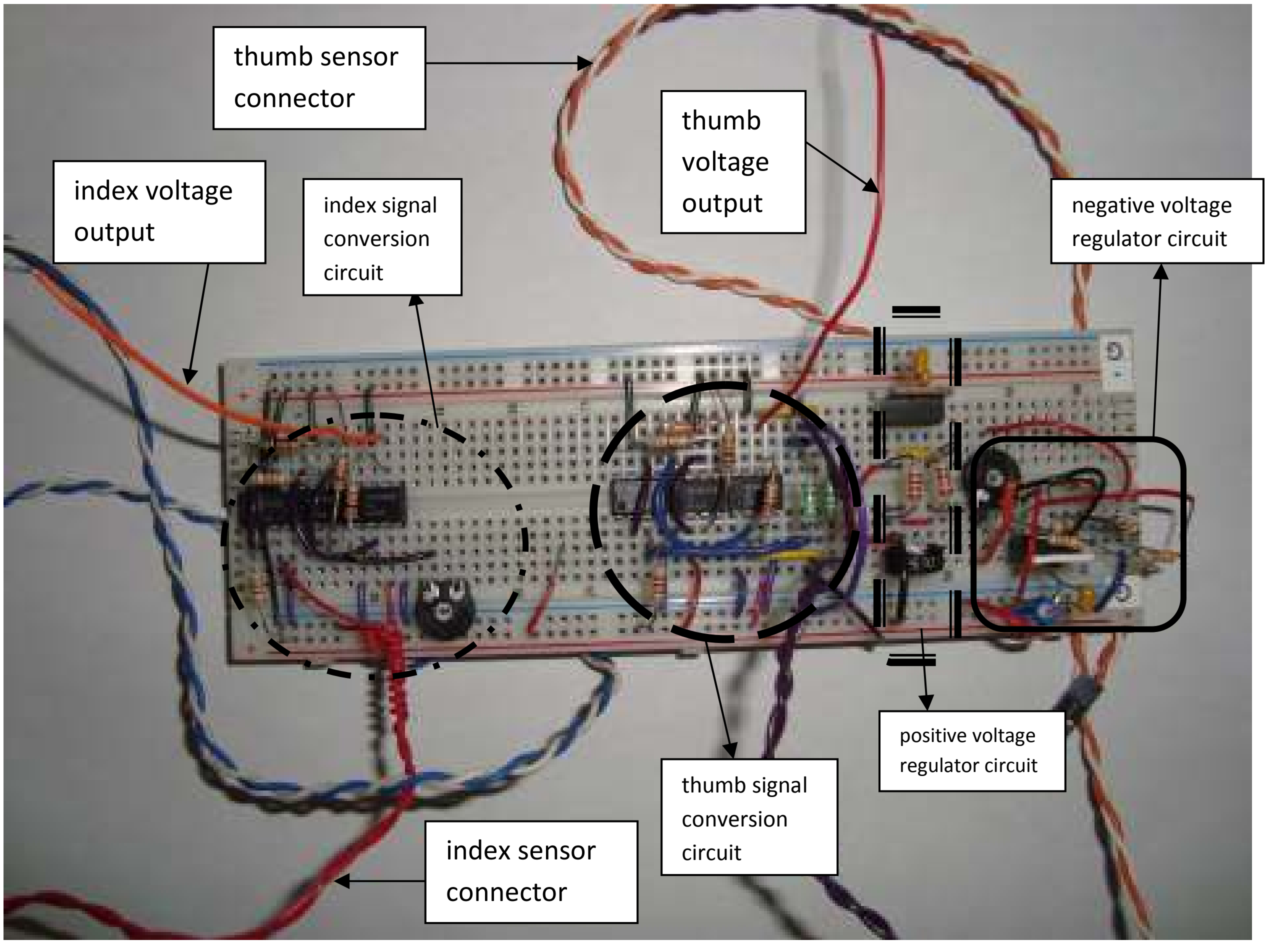


Figure 4.5: finalized working circuit

Figure 4.6: Partners contribution

Chapter 5: Data Acquisition

5.1 LABVIEW acquisition

When the voltage is obtained from signal conversion circuit, the outputs are connected to NI data acquisition hardware. In the LABVIEW start page, a blank VI is selected. When a white window opens up, a DAQ graphical module is place in the empty space. Under properties menu of this module, all the signal channels are selected along with continuous sampling rate and sample numbers. Both of them are selected to be 1K. At the end a graph prove is connected to observe the real-time response of the sensors. As per set up, the following DAQ method is obtained.

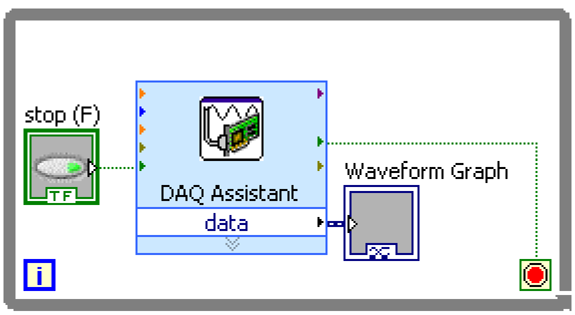


Figure 5.1: Graphical program to obtain real-time analog output

When this program is run, the followings were the results.

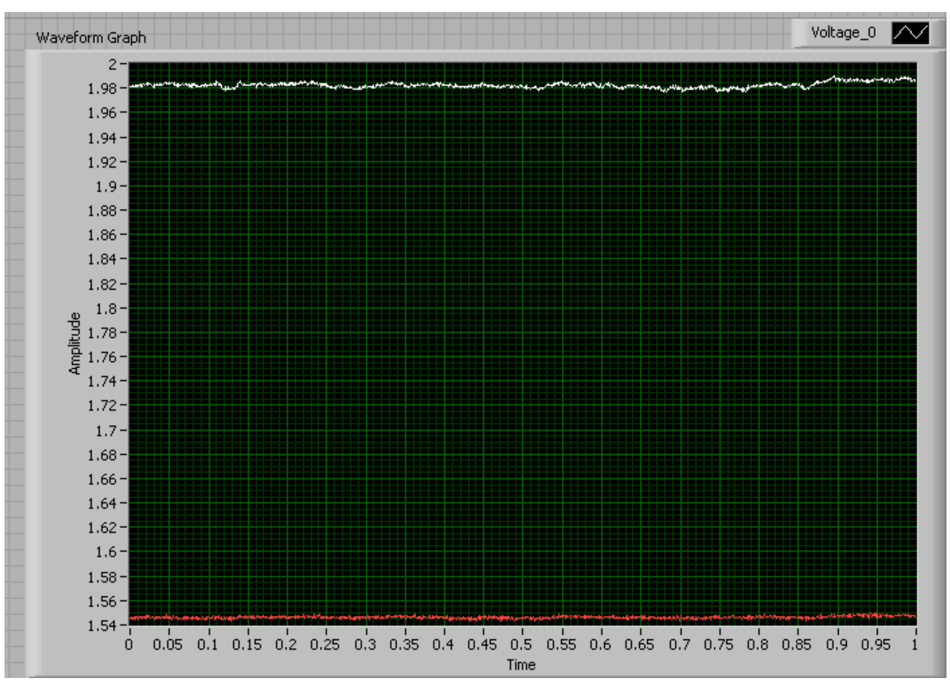


Figure 5.2: This picture shows both of the channels. The top line is the nominal state of the thumb sensor and the bottom line is the index sensor at nominal state.

Figure 5.3: This picture shows flexion of the fingers. As seen in the graph, when the fingers are flexed, the voltages increase and the graphs move upward. (the top line is thumb and the bottom one is index)

Figure 5.4: This shows the extension of the fingers. As the fingers are extended, the voltage response decreases.

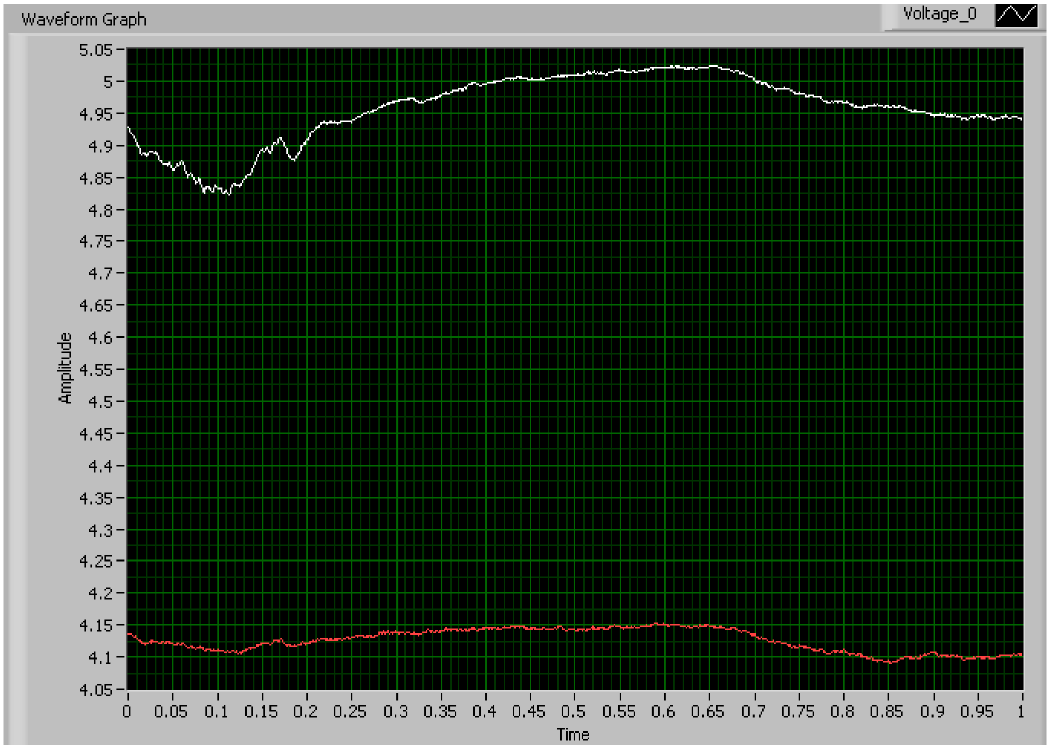


Figure 5.5: This shows the maximum value obtained when both of the fingers are fully flexed. As it can be seen in the picture, the highest voltages obtained are over 4V.

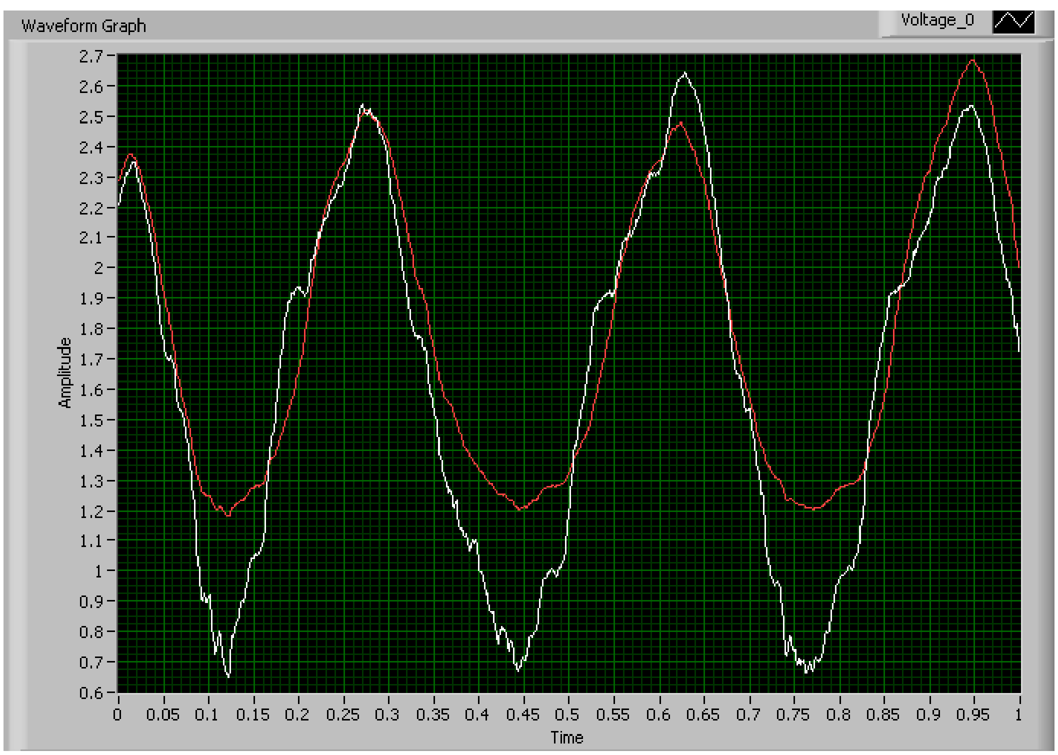


Figure 5.6: This shows the behaviour of quick flex. As the fingers are quickly flexed and extended, the voltage output follows in real time.

Based on all the real-time responses shown so far, it prevalent that the signal conversion circuit is indeed working and produces high resolution instant real-time response as the fingers are being articulated.

The next thing that has been done is signal conversion into digital domain. In order to do so, an ADC module is added in the signal processing algorithm. Since the microcontroller can only accept ADC values of length 10, two truncation constant for two finger channels are also supplied to the ADC module. Finally, the digital output is displayed in waveform as shown in the diagram below. Since a real-time response is being monitored, a while loop working within the DAW assistant which keeps on getting N number of analog data at F frequency sampling rate which are of course set by the user.

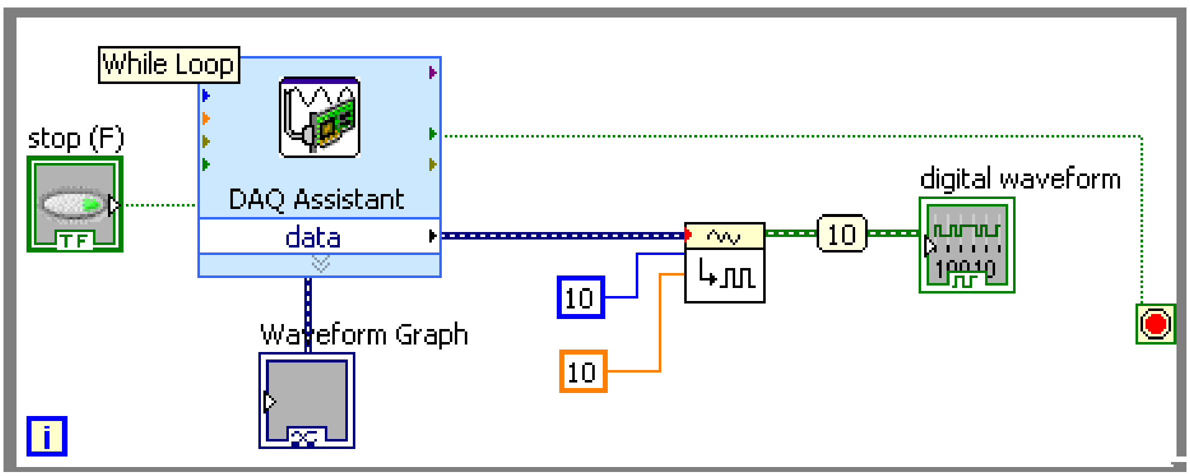


Figure 5.7: Analog to digital conversion scheme in LABVIEW

When this graphical program was run, an interesting finger movement was selected to be tested. The diagram in the next page demonstrates the behaviour of thumb adduction and abduction from the index finger. The highest peaks mean thumb is fully adducted and right beside index finger. The lowest peaks mean that the thumb is fully abducted away from the index. The middle small spikes represents the sudden force generated between the index and thumb when they are quickly being adducted and abducted.

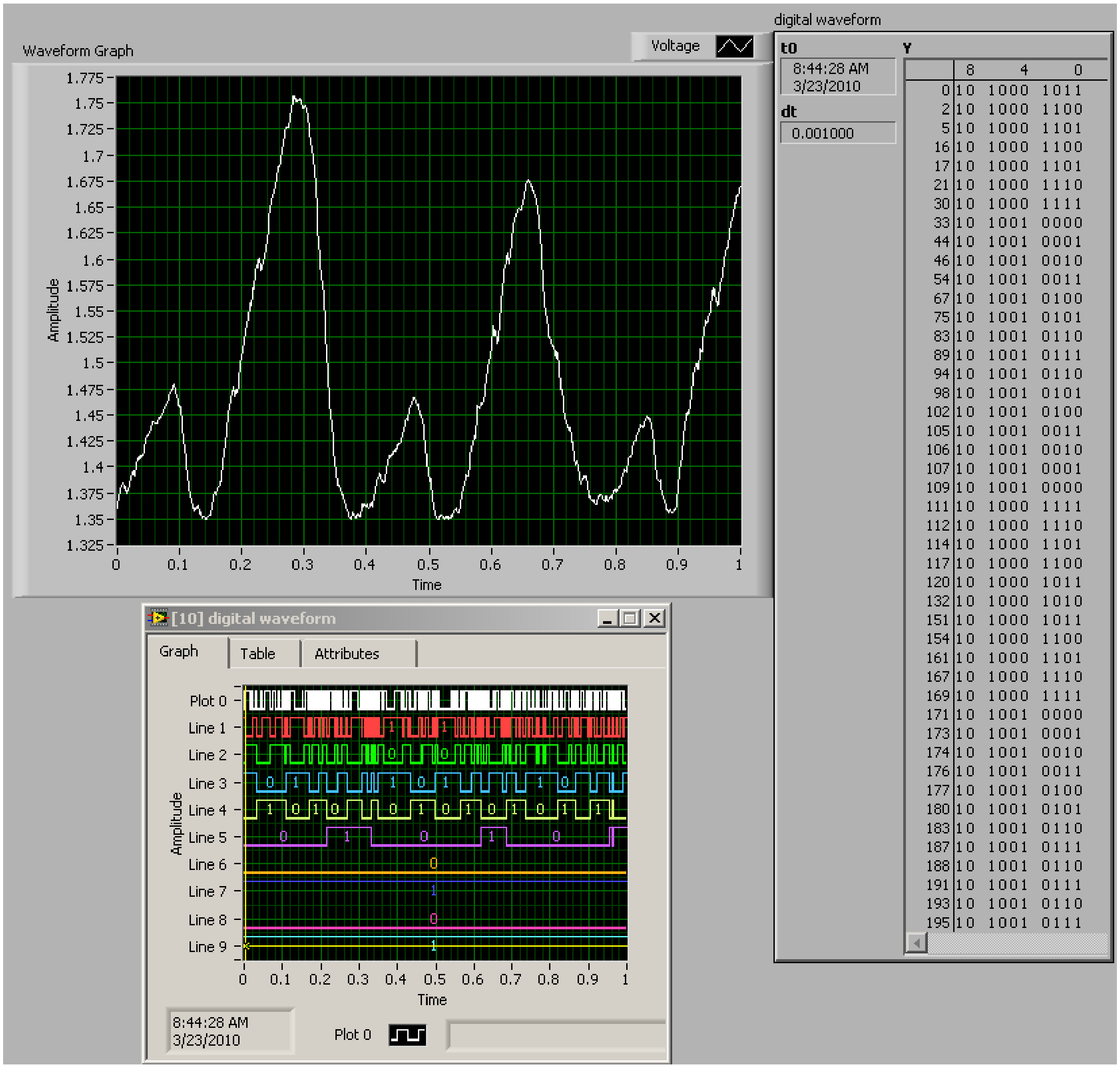


Figure 5.8: Real- time behaviour of the thumb adduction and abduction represented in analog waveform, digital waveform and digital bits of length 10.

5.2 Acquisition by Arduino IDE and Processing IDE

Using the Arduino IDE, same analog and digital data can be obtained but it will not be as detailed as the LABVIEW outputs. Both Arduino IDE and Processing IDE provide examples that can be slightly modified to obtain the real-time serial port output. To directly display the real time response of the sensor following program was uploaded to the microcontroller through the USB cable.

```
/*Analog serial reader
  Original program: by Tom Igoe
  Obtained from: Arduino builtin examples
  Language: Arduino/Wiring
  Modified by: Arefin Shamsil

  Program description: Reads 2 analog inputs and sends
  their values out.
*/
void setup() {
  // serial port initialization
  Serial.begin(9600);
}

void loop() {

    int thumb = analogRead(4); //define thumb input
    int index = analogRead(5); //define index input

    // print its value out as an ASCII numeric string
    Serial.print(thumb, DEC);
    // if this isn't the last sensor to read,
    // then print a comma after it
    Serial.print(",");
    Serial.print(index, DEC);

    Serial.println();
}
```

After running the program, the serial monitor shows continuous printout of two values as: 275, 0 . The reason it is continuous is because the values are being printed in loop. When then thumb is fully flexed, the first value increased up to 789. When index is fully flexed, the second value changes to 1023. These values are the decimal representation of the 10 bit digital data of the analog voltage obtained in real-time from the signal conversion circuit. Since the input range is only within 0V-5V and the microcontroller has 10 bit ADC capacity, there can only be 2^{10} = 1024 digital values from 0 to 1023. As a result, decimal voltage data such as 4.5098 as compared to 4.5 is not being sampled.

Using the serial port to graph program provided in the Processing IDE, real-time graphical output can be obtained. The other colleague in this capstone project has done so to display the real-time graphical representation of his IMU.

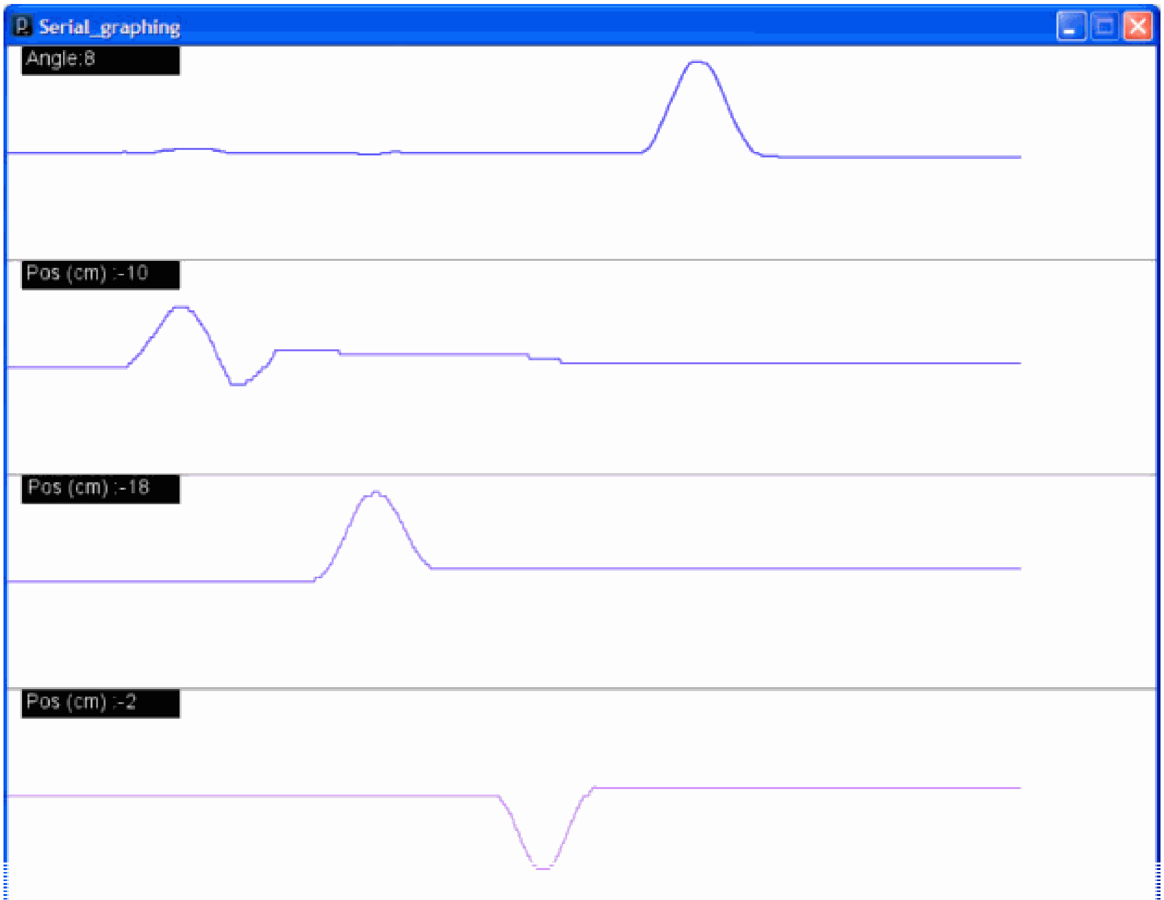


Figure 5.9: real-time serial graphing of IMU position data.

On the other hand, digital representation of the finger articulation can be displayed though LED brightness lever. This functionality has been programmed in the microcontroller to accomplish the result. The program is shown in the next page. This program basically reads in the analog value, converts to digital bits and then maps the values within 0 -255 which essentially a digital value but output as analog output. This basically limits the current level supplied to the LED and thus controlling the brightness of the LEDs in real-time. Therefore, when the fingers are fully flexed, the brightness should be very high and when the fingers are flat, the LEDs should be dim.

```
int indexPin = 5; // index sensor analog input
int thumbPin = 4; // bend sensor analog input

 int indexValue = 0;    // value read from the index analog sensor
 int thumbValue = 0;    // value read from the thumb analog sensor

 int indexLed = 3; // PWM pin for digital output
 int thumbLed = 5; // PMW pin for digital thumb output
 void setup() {
   // initialize serial communications at 9600 bps:
   Serial.begin(9600);
   // declare the led pin as an output:
   pinMode(indexLed, OUTPUT);
   pinMode(thumbLed, OUTPUT);
 }

 void loop() {
   indexValue = analogRead(indexPin); // read the index values
   thumbValue = analogRead(thumbPin); // read the thumb values

   int indexbrightness = map(indexValue, 0, 1023, 0, 255);
   int thumbbrightness = map(thumbValue, 270, 765, 0, 255);
   // set the indexLED brightness with the result
   analogWrite(indexLed, indexbrightness);
   // set the thumbLED brightness with the result
   analogWrite(thumbLed, thumbbrightness);
   // print the analog value of index finger
   Serial.print(indexValue,DEC);
   Serial.print(",");
  Serial.print(thumbValue,DEC);
     Serial.println();
   delay(10); // wait 10 milliseconds before the next loop
}
```

LEDs were connected as following:

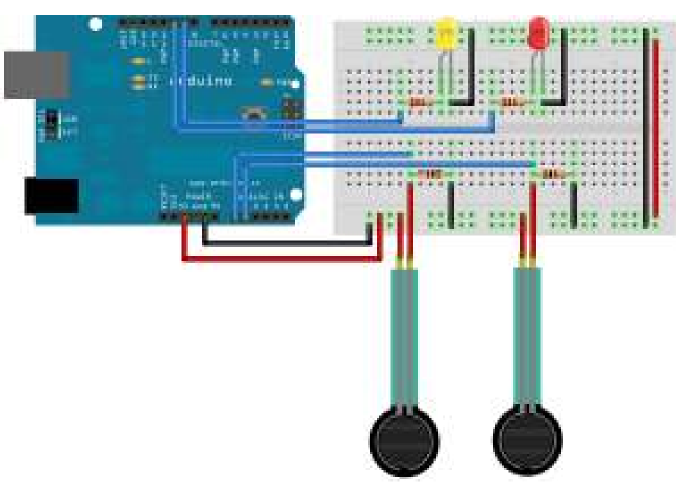


Figure 5.10: LED circuit connections. Courtesy of ITP Physical Computing website. http://itp.nyu.edu/physcomp/Labs/AnalogIn

The above circuit has been implement using 556 Ώ resistors for current limiting. One of the LED series circuit is for thumb and the other for index.

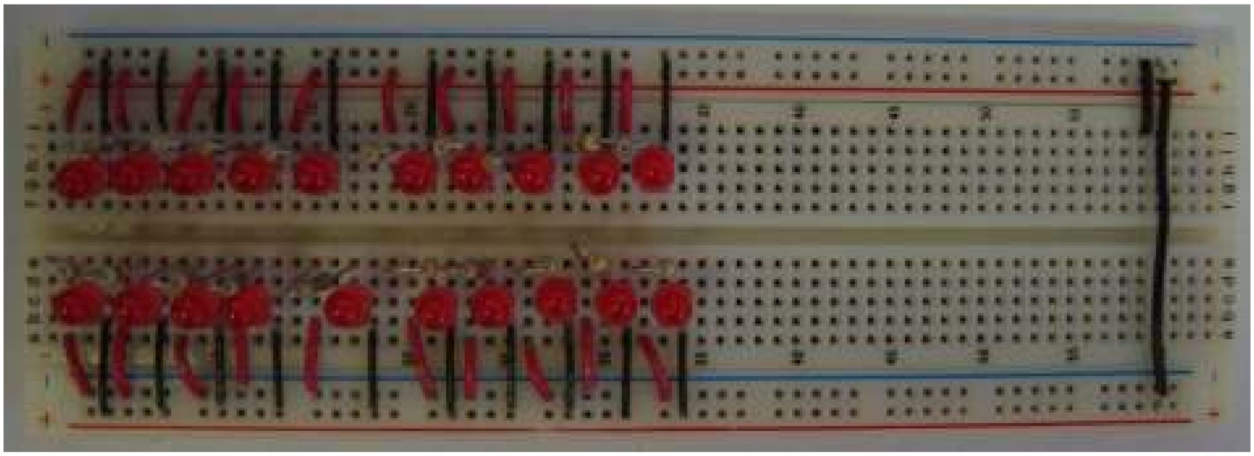


Figure 5.11: LED circuit implementation

When this circuit is connected to the signal conversion circuit via microcontroller as the interface, the following outputs were obtained.

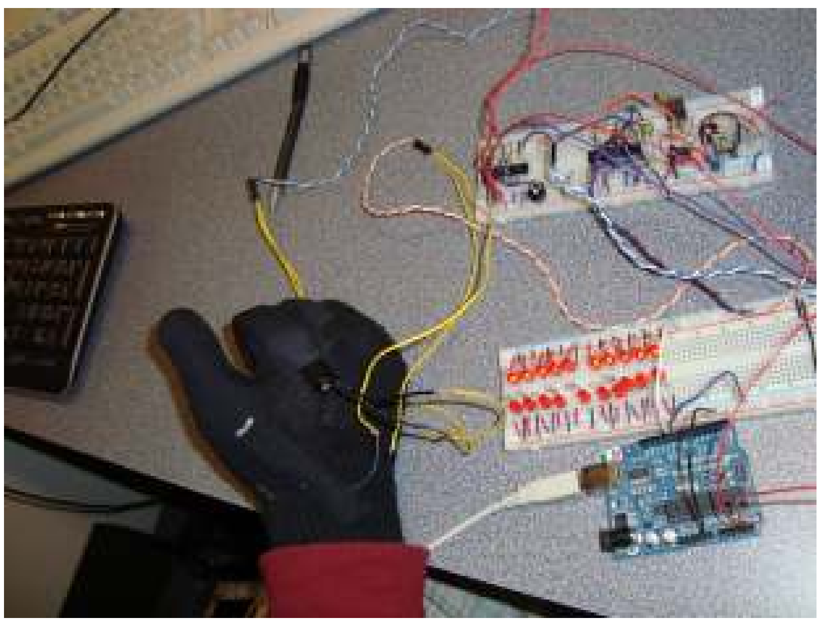


Figure 5.12: LED output when index finger is fully bent

The above picture demonstrates that when the index finger is fully bent one set of LEDS (that connected to index) fully lights up.

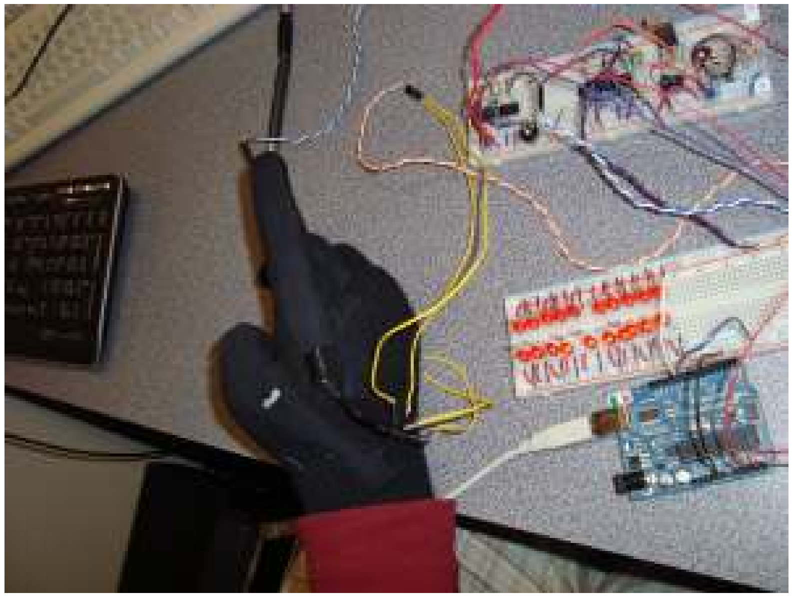


Figure 5.13: LED output when thumb in fully bent

Similarly, when the thumb is fully flexed, the other set of LEDs connected to thumb fully bright up. These results demonstrates the capturing of finger articulations.

Chapter 6: Conclusion and Recommendation

6.1 Conclusion

The object of the project was to design a circuit that would generate real time response as the flex sensors are moved. With appropriate design methods and research, the objectives has been obtained.

6.2 Recommendation

In this project, the data glove was also connected to a mouse circuit and interfaced with the Arduino microcontroller. The end result was that by bending the fingers, the mouse buttons can be controlled. This is just one of the many dynamic uses of this device. With more time and proper management, this project can be taken much further and an example would be remotely controlling the computer without even touch the monitor mouse or keyboard. It can only be imagined, what good it can do for the paralyzed people who cannot walk. This device would then be able to give these individuals ability to use computers with simple hand and finger movements.

Moreover, Data glove can put promising results in the field of medicine. It can be used for monitoring hand function for rehabilitation purposes, it can be used in telerobotic surgery and not to mention high quality virtual interactive gaming.

Therefore, it is a highly recommended research topic for the obtainment of many well and advanced outcomes.

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Ji-Hwan Kim 1, *Student Member, IEEE,* Nguyen Duc Thang2
, Tae-Seong Kim1, *Member, IEEE*
lDepartment of Biomedical Engineering, 2 Department of Computer Engineering,
Kyung Hee University, 1 Seocheon-dong, Giheung-gu, Yongin-si, 446-701 Gyeonggi-do, Korea
E-mail: kjh_bme@khu.ac.kr.thangth2082@yahoo.com.tskim@khu.ac.kr
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Yunli Lee1, Seungki Min1, HwangKyu Yang2, and Keechul Jung1*
1HCI Lab, School of Media, College of Information Technology, Soongsil University,
156-743, Seoul, South Korea.
{yunli, dfmin, kcjung}@ssu.ac.kr
2Department of Computer Information Engineering, Dongseo University,
617-716, Busan, South Korea
hkyang88@dongseo.ac.kr

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Stephen Mascaro and H. Harry Asada
d' Arbeloff Laboratory for Information Systems and Technology
Department of Mechanical Ehgineering
Massachusetts Institute of Technology
Cambridge, MA 02139, e-mail: asada@mit.edu, smascaro@mit.edu
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Xiaoling Lv , Minglu Zhang , Feng Cui , Xiaoli Zhang
（*School of Mechanical Engineering*，*Hebei University of Technology*，*Tianjin 300130, China*）

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Alejandro Garcia Blanco, Gildardo Jiménez, Pedro Ochoa Moreno

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Vitae

Name: Arefin Shamsil

Place of Birth: Dhaka, Bangladesh

Year of Birth 1988

Secondary School: W.F. Herman Secondary School, Windsor Ontario, Canada

Awards: Achieved Queen Elizabeth II and Laundry Yves memorial Scholarships and three consecutive Millennium Excellence bursaries

Obtained award for winning Ontario province Chemistry Contest directed by Waterloo University

Dean's List 2005, Windsor Ontario