ABSTRACT

ASSESSING TRAINER HAND FORCES FOR MANUAL BODY WEIGHT SUPPORTED WALKING

by
Manish Raval

Spinal cord injuries occur in approximately 12,000 to 15,000 people per year in the U.S. About 10,000 of these people are permanently paralyzed. Most spinal cord traumas occur in young, healthy individuals. Males between 15 and 35 years old are most commonly affected.

Recently new approaches to facilitate walking recovery for individuals after a spinal cord injury, have been directed towards a therapy known as Locomotor Training (LT) that implements repetitive stepping on a treadmill using body weight support. A major intent of LT research is to investigate the effect of an extended period of LT on bilateral muscle activation (EMG pattern, amplitude, and burst duration).

Currently, training is subjective and there is no way to evaluate if trainers are applying the appropriate force or not. Researchers have requested a method to measure the amount of force applied by the trainers. Researchers would use this information to assess the subject's progress over the course of training, to evaluate the consistency of training and to ensure trainers are properly trained.

A glove-like device was built to measure how much force the human trainers apply while performing LT for individuals with spinal cord injury (SCI) for the goal of quantifying force and assessing effectiveness. The development of the above mention device would be directly used by therapists to improve rehabilitation treatments. Measuring levels of assistance, rehab programs can identify how much improvement a

particular patient has achieved and at what rate. Rehabilitation programs would also be able to evaluate the performance of the trainers and observe just how effective they are.

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by
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ASSESSING TRAINER HAND FORCES FOR MANUAL BODY WEIGHT SUPPORTED WALKING

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To my beloved sis, Heena

My life

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CHAPTER 1

INTRODUCTION

1.1 Objective

The objective of this study is to design and develop a device which can be strapped on therapist's arm to measure the force applied. This will help to quantify the amount of force given at the legs of individuals with Spinal Cord Injury by therapist and to train and evaluate performance of novice therapist.

1.2 Background Information

Spinal Cord Injury (SCI) is injury to the spinal cord that results in a loss of function such as mobility or feeling. Most of the times this is caused due to trauma (car accident, gunshot, falls, etc.) or disease (polio, spina bifida, Friedreich's Ataxia, etc.). The spinal cord does not actually have to be cut in order for a loss of functioning to occur. In fact, even if it is slightly injured, there is loss of function. [10]

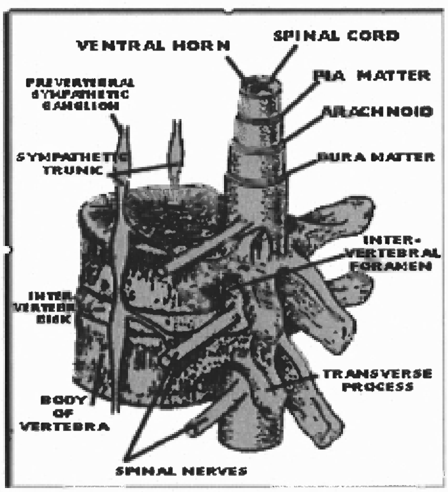


Figure 1.1 Anatomy of Spinal Cord.
http://www.spinalinjury.net/html/_spinal_cord_101.html

The spinal cord is about 18 inches long and extends from the base of the brain, down the middle of the back, to about the waist. The upper motor neurons (UMNs) are the nerves that lie within the spinal cord and their function is to carry the messages back and forth from the brain to the spinal nerves along the spinal tract. The lower motor neurons (LMNs) are the nerves that branch out from the spinal cord to other parts of the body. These nerves exit and enter at each vertebral level and communicate with specific areas of the body. There are two types of LMNs: sensory and motor. The sensory portions of the LMN carry messages about sensation from body parts and organs to the brain. The motor portions of the LMN send messages from the brain to the various body parts to initiate actions.

The spinal cord is surrounded by rings of bone called vertebra as seen in Figure 1.1 which constitute the spinal column (back bones). The vertebra are named according to their location and in general the higher the injury in the spinal cord, the more discomfort and dysfunction the patient has. As seen below in Figure 1.2, the eight vertebra in the neck are called the cervical vertebra. Cervical SCI's usually cause loss of function in the arms and legs, resulting in tetraplegia. Then have the twelve vertebra in the chest which are called the thoracic vertebra. Injuries in this region usually affect the chest and the legs and result in paraplegia. The vertebra in the lower back between the thoracic vertebra, where the ribs attach, and the pelvis (hip bone), are the Lumbar Vertebra. The sacral vertebra are from the pelvis to the end of the spinal column. Injuries to the five lumbar vertebra and similarly to the five sacral vertebra generally result in some loss of functioning in the hips and legs. [10]

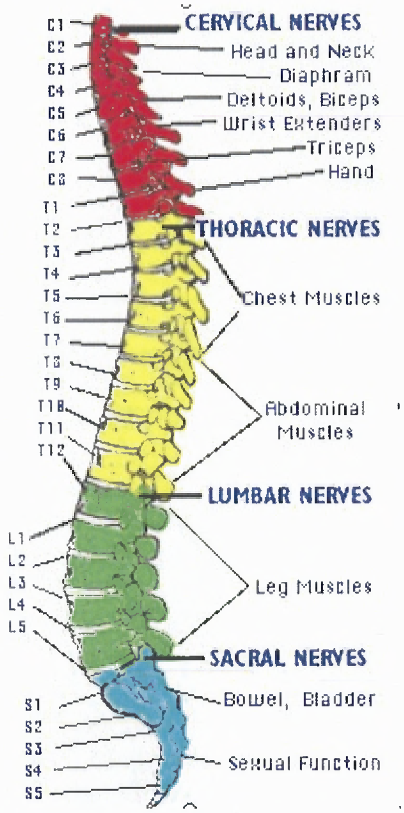


Figure 1.2 Positioning of Vertebrae.
http://www.spinalinjury.net/html/_spinal_cord_101.html

There are two types of SCI - complete and incomplete.

- A complete injury - no function below the level of the injury; no sensation and no voluntary movement. In this kind of injury, both sides of the body are equally affected.
- An incomplete injury - some functioning below the primary level of the injury. One may be able to move one limb more than another, may be able to feel parts of the body that cannot be moved, or may have more functioning on one side of the body than the other.

Besides a loss of sensation or motor functioning, SCI may cause other changes in individuals. It can cause dysfunctioning of the bowel and bladder and sexual dysfunctioning too. Very high injuries (C-1, C-2) can result in a loss of many involuntary functions including the ability to breathe. Some other effects of SCI may include low blood pressure, inability to regulate blood pressure effectively, reduced control of body temperature, inability to sweat below the level of injury, and chronic pain.

Approximately 450,000 people live with SCI in the US. There are about 10,000 new SCI's every year; the majority of them (82%) involve males between the ages of 16-30. These injuries result from motor vehicle accidents (36%), violence (28.9%), or falls (21.2%). Tetraplegia is slightly more common than paraplegia. [10]

There is no cure currently for SCI. There are several researchers attacking this problem, and there have been some advances in the labs like Human Performance Movement Analysis Lab at Kessler Research Center and Human Locomotion Research Center at University of California, Los Angeles. Many of the most exciting advances have resulted in a decrease in damage at the time of the injury, but have not cured it completely. Steroid drugs reduce swelling, which is a common cause of secondary damage at the time of injury. The experimental drug SygenÆ appears to reduce loss of function, although it's mechanism and working is not completely understood. [10]

When a SCI occurs, there is usually swelling of the spinal cord. After days or weeks, the swelling begins to go down and people may regain some functioning. With many injuries, the individual may recover some functioning as late as 18 months after the injury. In very rare cases, people with SCI will regain some functioning years after the injury. However, only a very small fraction of individuals sustaining SCIs recover all functioning.

There are many ways to help SCI patients recover. Locomotor Training (LT) using Body Weight Support (BWS) walking is one of the treatment procedure which is discussed next. BWS is where a spinal cord injured patient is supported using the harness and the therapist helps patient move his legs.

Figure 1.3 Locomotor Training using BWS.
http://www.harkema.ucla.edu/bws.html

Recently a therapy known as LT that implements repetitive stepping on a treadmill using body weight support is being used to help patients recover walking. The training optimizes afferent sensory information and facilitates activity-dependent changes in the spinal cord to control movement. The studies on LT using body weight support treadmill training in humans after SCI are based on extensive research related to animal studies.

A major intent of LT research is to investigate the effect of an extended period of locomotor training on bilateral muscle activation (EMG pattern, amplitude, and burst duration). It is hypothesized that with repetitive step training using body weight support (BWS) for an extended period of time, there would be an increase in EMG amplitudes and alteration in burst duration which were appropriate to the swing and stance phase of locomotion.

Locomotor Training: As seen in Figure 1.3, three trainers are involved in the step training component of LT: one trainer at the hip/pelvis, and one trainer at each of the legs. During stance, assistance is given to aid in knee extension (not hyperextension) at the patella tendon (no 1 in Figure 1.4). During swing, assistance is given to promote knee flexion at the medial hamstring tendon (no 3 in Figure 1.4) at the distal tibial region to aid in toe clearance and unloading. The amount of assistance/force given would affect the muscle EMG activation pattern. It is important that we quantify the force given by the two leg trainers. This data is a valuable tool for assessing the subject's progress as a result of training.

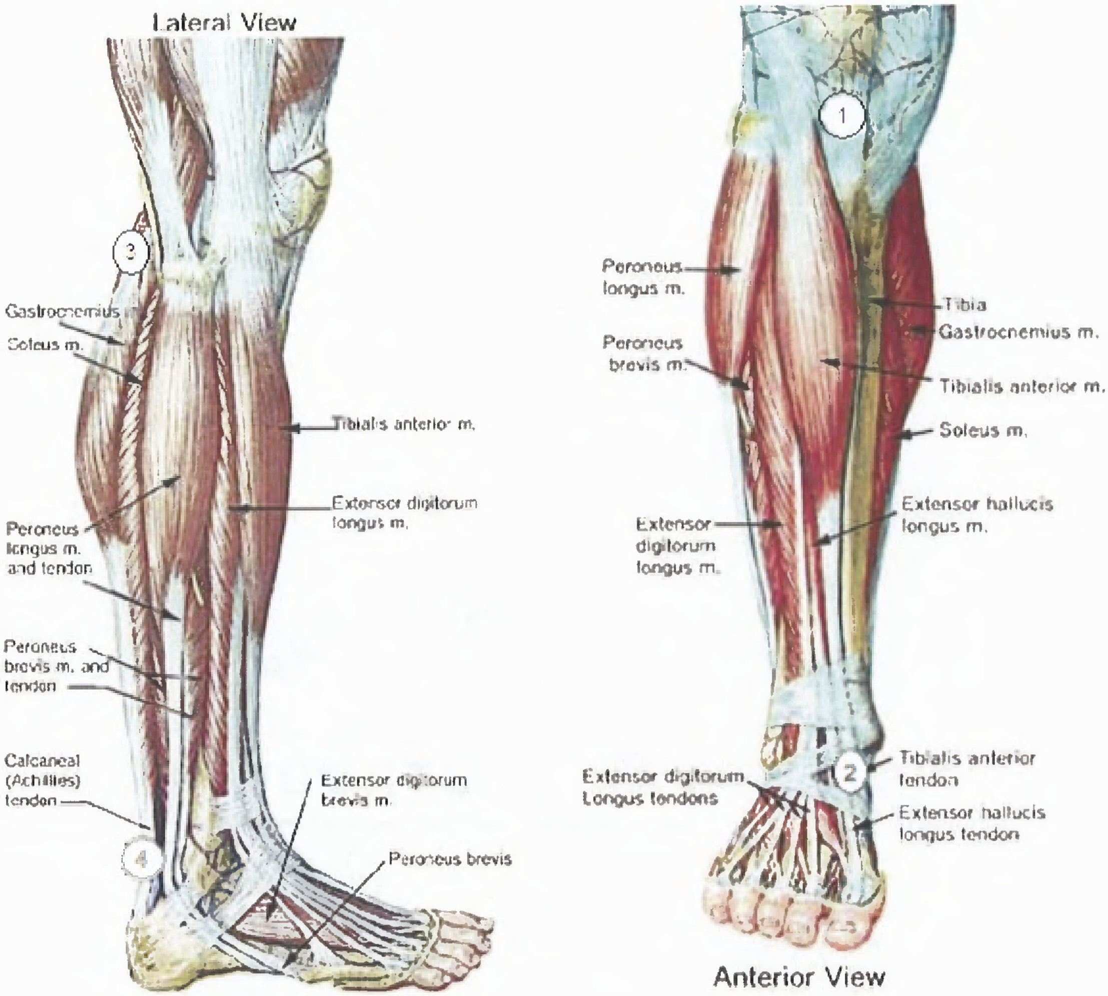


Figure 1.4 Leg muscles.
http://www.foottrainer.com/foot/

CHAPTER 2

SENSOR

2.1 Requirements

Requirements for the project were discussed with Dr. Gail Forrest and are listed below:

1. Device should measure force at hamstring tendon, patella tendon, tibialis anterior tendon and heel.
2. Force measurements should be accurate, reliable and reproducible.
3. Force should be measured at all point simultaneously.
4. Data should be collected continuously for each trial (~30 minutes).
5. Device should be compact, battery powered.
6. Device should not interfere the training procedure.
7. Data should be measured and stored continuously, with a sampling rate of 60Hz-100Hz.

2.2 Type of Sensor

First thing was to select the sensor type. Many sensors and their specifications were cross checked in order to select the final sensor. Few of them are listed below.

2.2.1 B201-L Sensor (Figure 2.1)

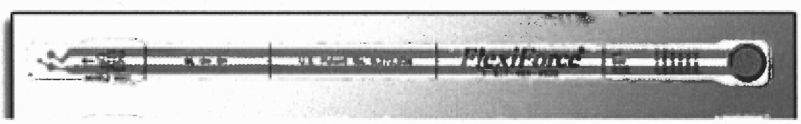


Figure 2.1 B201-L Sensor.
http://www.tekscan.com/flexiforce/flexiforce.html

This sensor manufactured by Tekscan Inc., Boston, MA has a force rating of 0-25lb and an adjustable gain feature. At low gain, the recommended maximum force of the B201-L sensor is 0-25 lb. At high gain, the recommended range is 0-1 lb and standard sensors are generally 9 inches long. This sensor is priced at $59.00 but it's not reliable and repeatable and hence had to be checked out as it was not meeting our important requirement. [11]

2.2.2 **Touch glove** (Figure 2.2)

Figure 2.2 Touch glove.
http://infusionsystems.com/catalog/product_info.php/products_id/45

This sensor manufactured by I-CubeX can be used to sense how much pressure is required to pick up a cup of coffee. The touch glove has a force range of 0-22lb. and the palm and finger sensors are also included. This sensor is priced at $321.70.

The touch glove is temperature sensitive; its sensors become less flexible in extreme cold and it is also not appropriate to use it in extreme heat. Applying more pressure on the sensors can damage the sensors. Also the touch glove is not waterproof and needs the I-CubeX Digitizer as shown in Figure 2.3 below which adds some extra cost. [12]

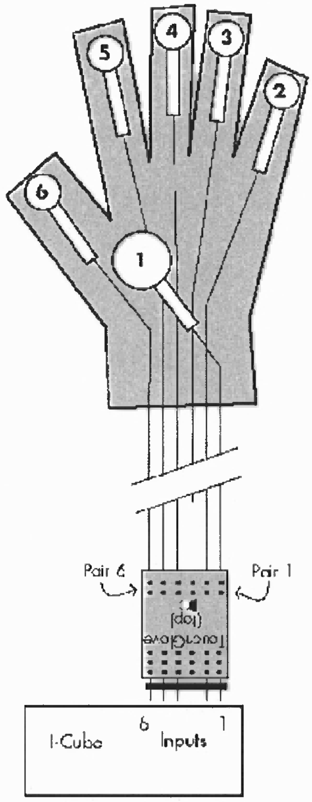
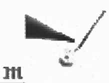


Figure 2.3 Touch glove with I-Cube X Digitizer.
http://infusionsystems.com/catalog/product_info.php/products_id/45

2.2.3 **XFL205R** - Subminiature - Diameter 0.2" [5 mm] (Figure 2.4)

e-mail:



tech@infusionsystems.com

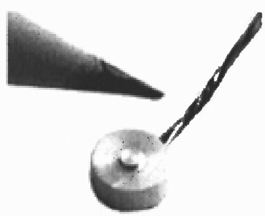


Figure 2.4 XFL205R.
http://www.fgpsensors.com

This sensor manufactured by FGP Sensors Inc., Epharata, PA has a force range of 0-20lb and a thickness and diameter of 2.5mm and 5mm, respectively. Also, this sensor can measure strain in static as well as dynamic conditions. It has a temperature compensated wheatstone bridge and is calibrated. The sensor is made of aluminum and has overload without damage which is equivalent to twice of its capacity range. But the sensor is expensive as it costs $495 each. [13]

2.2.4 XFL225D – Low Profile - Diameter 0.98" [25 mm] (Figure 2.5)

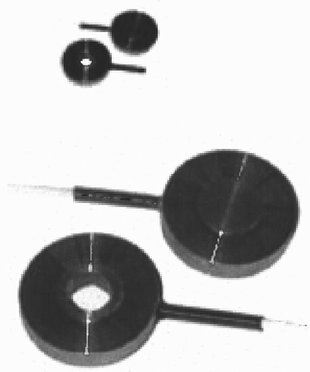


Figure 2.5 XFL225D.
http://www.fgpsensors.com

This sensor manufactured by FGP Sensors Inc., Epharata, PA has a force range of 0-20lb and 0-100lb. It has a diameter of 25mm and is very flat. All other features are similar to its subminiature counterpart. A more recent version called the XFL225D-Vi is also available which is more stable, accurate and has a high level analog output. This sensor is priced at $ 495. [13]

2.2.5 **XFL212R –** Low Profile – Diameter 0.5" [12.5 mm] (Figure 2.6)

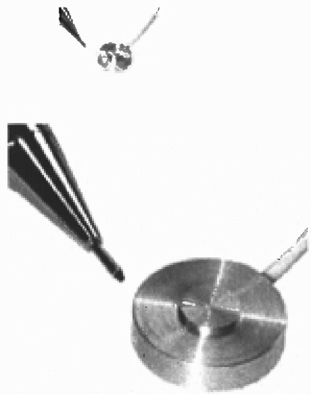


Figure 2.6 XFL212R.
http://www.fgpsensors.com

This sensor manufactured by FGP Sensors Inc., Epharata, PA has a force range of 0-100lb and all other features like its subminiature counterpart. But this sensor is a high performance sensor and is more stable and accurate. Also, it costs $415 for each piece. Hence XFL212R shown in Figure 2.7 below was selected and ordered. [13]

Figure 2.7 XFL212R.

2.3 Positioning of Sensor

As seen in Figure 1.4, the four locations i.e. patella tendon, tibialis anterior tendon, hamstring and heel are the ones where maximum force would be applied by the therapist. So it was important to make sure force sensors are placed such that we are able to cover these locations. Hence a glove-like device as shown in Figure 2.8 was developed that translated the voltage output of our sensors into force readings.

Figure 2.8 Glove with force sensor.

In all we would require two sensors on one hand. Sensor positions were selected by keeping in mind where maximum force would be applied while performing LT. The positions for right hand and left hand are shown in Figure 2.9 and Figure 2.10 respectively.

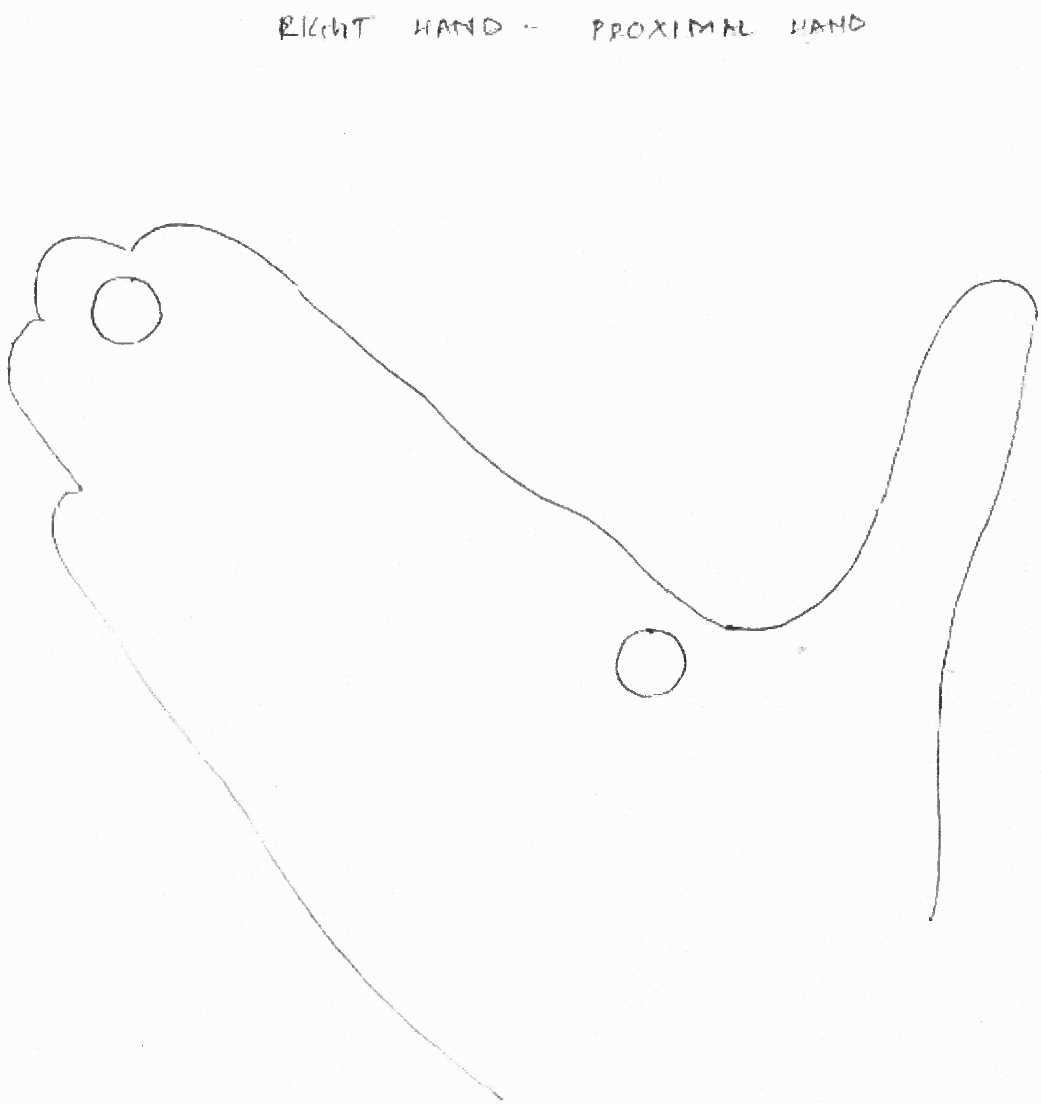


Figure 2.9 Positioning of sensor on right hand.

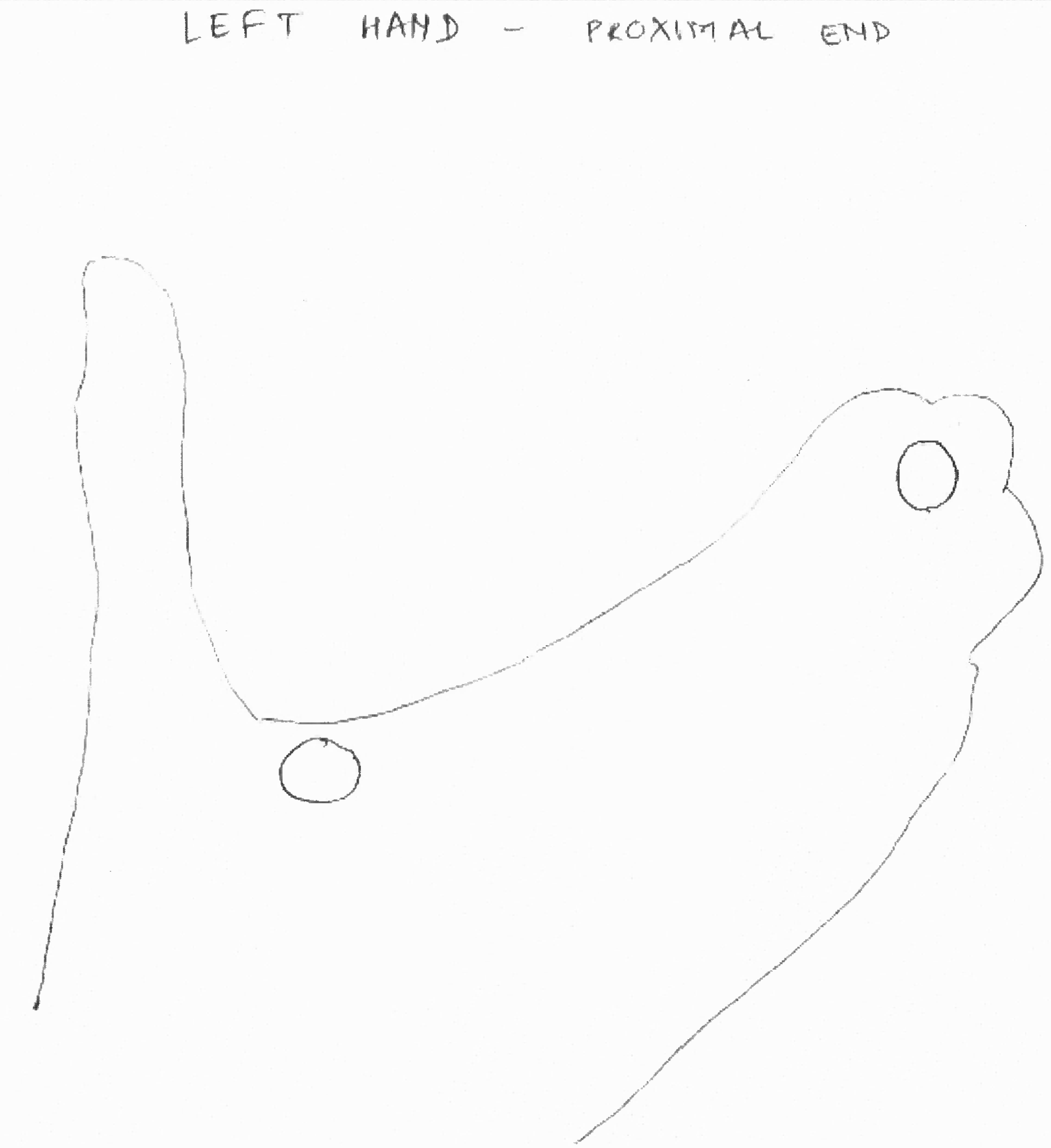


Figure 2.10 Positioning of sensor on left hand.

2.4 Sensor Testing

Sensor was tested first for linearity and data is shown below in Table 2.1

Table 2.1 Test for linearity

X	y(obs) (mv)	y(pre) (mv)	Error = y(pre)-y(obs)	Sq of error	sqrt=error
0	-7.6	-7.3667	0.2333	0.054429	0.2333
2	-8.5	-8.4477	0.0523	0.002735	0.0523
4	-9.6	-9.5287	0.0713	0.005084	0.0713
6	-10.5	-10.6097	-0.1097	0.012034	0.1097
8	-11.2	-11.6907	-0.4907	0.240786	**0.4907**
10	-12.4	-12.7717	-0.3717	0.138161	0.3717
12	-14.2	-13.8527	0.3473	0.120617	0.3473
14	-15.2	-14.9337	0.2663	0.070916	0.2663

(Note: Tolerance - 3% of FSR)

Force transfer function of the above data was plotted and is shown below in Figure 2.11. The readings of the sensor were linear and maximum error is 0.4907

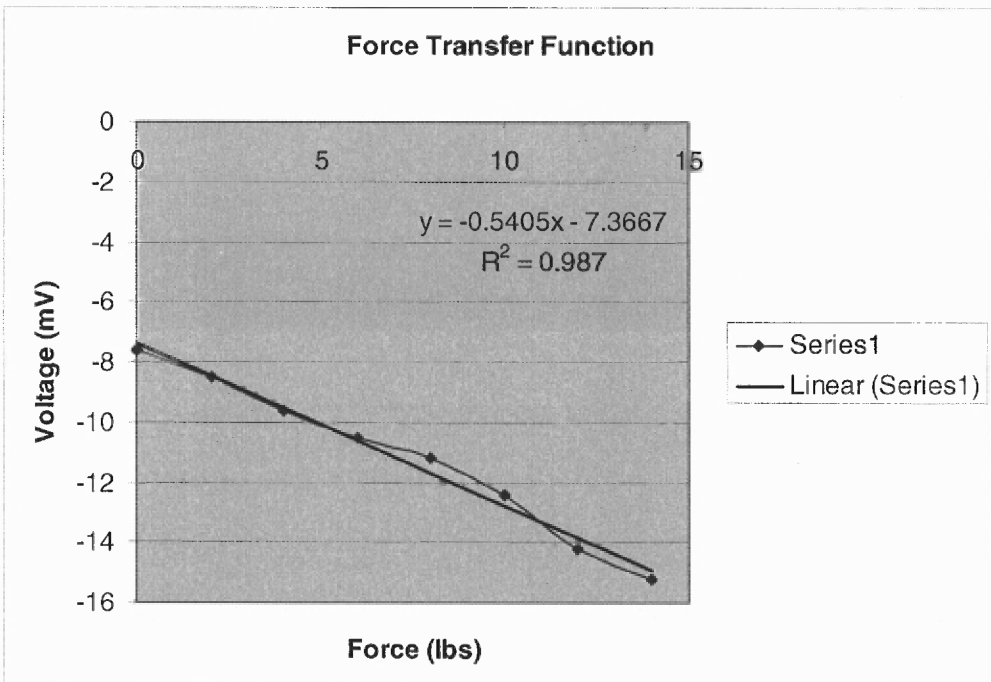


Figure 2.11 Force Transfer Function.

CHAPTER 3

DESIGN AND TESTING

3.1 Block Diagram

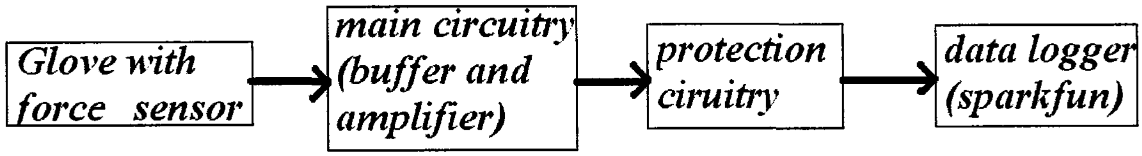


Figure 3.1 Block Diagram.

Explanation: Block diagram consists of Glove with force sensor which is connected to buffer and amplifier circuit. Buffer circuit is used to isolate sensor from rest of the circuit. The output voltage of the sensor is in millivolts. After the buffer circuit, the signal is amplified by a gain of 100. The differential output is connected to diode protection circuit which is in turn connected to data logger circuit where the data gets stored in the SD card.

3.2 Circuit Diagram

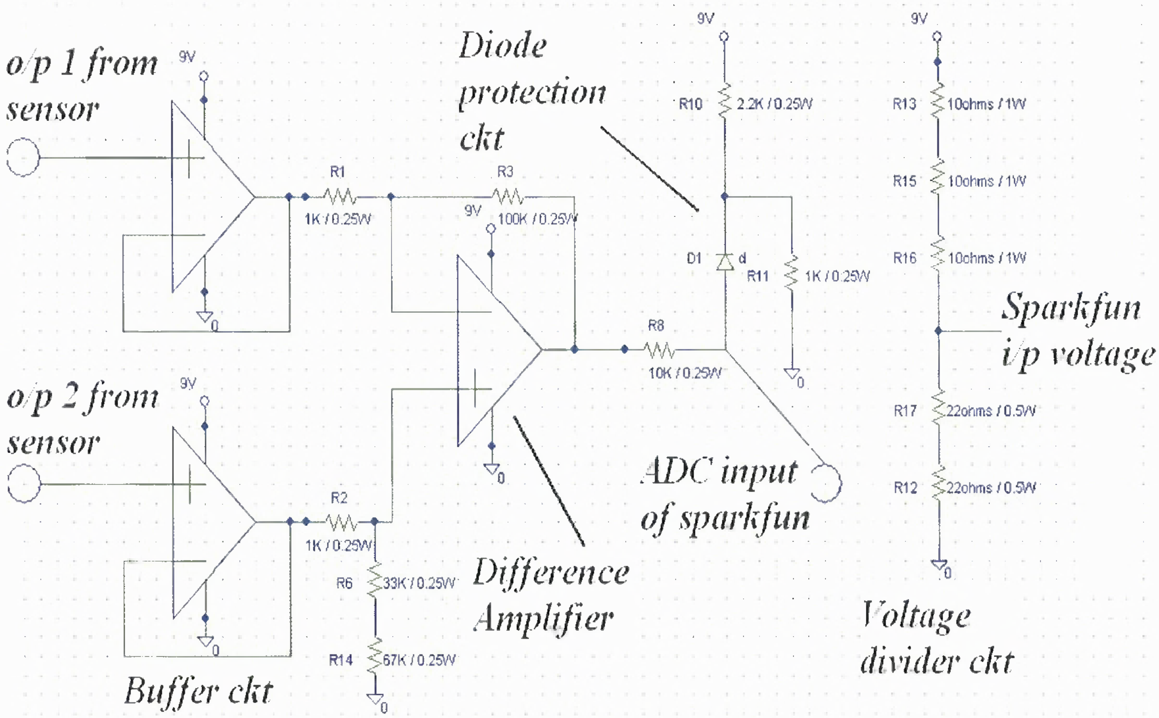


Figure 3.2 Circuit Diagram.

Explanation: IC LM324N is a quad op-amp which is used for buffer and amplification. A difference amplifier with a gain of 100 was designed as the output voltage of the sensor was in millivolts. Gain of 100 was selected in order to use the maximum resolution. With gain of 100 we can get 2.74V for 14lb of known force. While performing LT, therapist doesn't apply more than 10lb of force normally so 14lb would be within the required limits. Initially gain of 150 was selected but the obtained input voltage was going above our required ADC i/p voltage limit of 3.3V hence a gain of 100 was chosen.

Diode protection circuit is used to protect Sparkfun data logger. The output voltage from amplifier circuit is connected to data logger ADC input. The maximum voltage requirement for ADC i/p is 3.3V. So to make sure that output of the amplifier doesn't go beyond the threshold level, a diode protection circuit is connected in between the differential o/p and ADC input.

How diode protection circuit works: As seen in Figure 3.2, we have a potential divider of 2.89V on the cathode side of the diode because of R10 and R11 resistors. So whenever, the differential output voltage is from zero to 2.97V, the diode would get reverse biased and hence open. Thus the same voltage would be seen on the ADC input of sparkfun but when the differential voltage would go beyond 2.97V, the diode would get forward bias and hence short. Thus we would see 2.89V on the ADC input of sparkfun thus protecting the sparkfun board.

Supply voltage for sparkfun is achieved by having voltage divider which reduces 9V battery voltage to 5.35V which is within the specified supply voltage range for sparkfun datalogger. The ADC input is connected to diode protection o/p circuitry.

3.3 Sparkfun Datalogger

Figure 3.3 Logomatic V1.0.
http://www.sparkfun.com

The Logomatic's list of features is lengthy:

- 3 modes of operation: Auto UART, Character-triggered UART, ADC
- Configurable baud rates in UART modes of 1200, 2400, 4800, 9600, 19200, 38400, 57600 and 115200 baud
- Triggered UART mode has a configurable frame length of up to 510 characters (including trigger character)
- Triggered UART frames are delimited with carriage return and line feed characters for easy reading
- 10 ADC channels, all selectable as on or off
- ADC logging in ASCII or binary format
- ASCII logging delimited by tabs between measurements, delimited between frames by carriage return and line feed characters
- Variable frequency for ADC mode
- Frequency "safeties" to ensure that the file doesn't try to overwrite itself, maximum of 1500Hz for one channel and 150Hz for all ten channels (ASCII logging mode)
- For the brave of heart, you can turn the safety off! [14]

The basic layout of the Logomatic V1.0 looks like this:

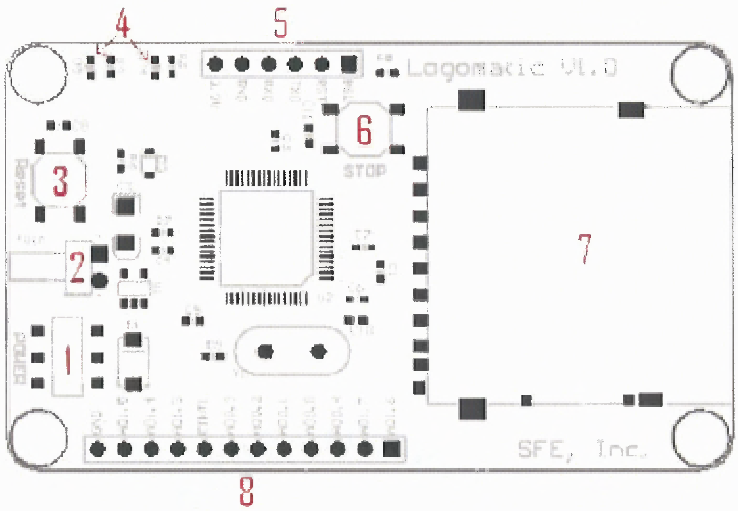


Figure 3.4 Basic layout.
http://www.sparkfun.com

1. Power switch
2. Right-angle + Vin jack
3. Reset button
4. Status LEDs
5. UART0 / programming port
6. Stop logging button
7. Push-push SD card socket
8. ADC ports

The Logomatic has an LDO 3.3V regulator and a reverse current protection Schottky diode. The maximum power dissipation of the voltage regulator is about 450mW, and the maximum current draw of the Logomatic is about 80mA (worst case). Neglecting the voltage drop on the Schottky diode, the maximum voltage the Logomatic could run with is (450mW) / (80mA) + 3.3V = 8.925V, but this will be very close to putting the voltage regulator into thermal shutdown. For best operation, the supply voltage should be kept between 3.6V and about 7.5V. [14]

Theory of Operation – The Logomatic saves data to an SD card in a two-stage process. Data is first saved to one of two 512-byte data buffers. As each buffer is filled, it is logged to the SD card and logging continues on the other buffer.

The limiting factor on the speed of the Logomatic is the write process to the SD card. The longest write cycle is approximately 42.5mS, which means that the shortest time allowed to log data to one of the buffers is also 42.5mS. If logging occurs faster than this, the buffers that's currently being written to the SD card will be overwritten by new input during the write process to the SD.

In ADC mode, safety margins are imposed to alleviate buffer overwriting. Sample rates are capped depending on how many channels you have active, though this is only imposed when logging in ASCII format. The frequency caps are:

1 channel active, 1500Hz maximum

2 channels active, 750Hz maximum

3 channels active, 500Hz maximum

4 channels active, 375Hz maximum

5 channels active, 300Hz maximum

6 channels active, 250Hz maximum

7 channels active, 214Hz maximum

8 channels active, 187Hz maximum

9 channels active, 166Hz maximum

10 channels active, 150Hz maximum

The frequency caps are not imposed in binary ADC logging mode. Faster sample rates can be realized in binary mode, from a 43% increase for 10 channels to 57% increase for one channel, but you will be required to write your own application that can interpret the resulting file. To get the faster data rates, just change the "Safety On" option from "Y" to "N" and set the "Frequency" number to whatever you want. The parser that reads the configuration file reads up to 4 digits, so you can set it as high as 9999Hz (though it will likely stop running at that speed). [14]

First Power-up and the Configuration File – Before you power up your Logomatic for the first time, put your SD card into your card reader and format it in FAT16. Then install the card into your Logomatic and turn it on. The LEDs will blank reassuringly and then go quiet. Turn off your Logomatic, pull out the SD card and put it back in your reader. You will now find 2 files on your card, LOGCON.TXT and LOG0.TXT. The first is the configuration file, the second is the first logged file (empty).

Open up the configuration file and you will see this:

MODE = 0

ASCII = N

Baud = 4

Frequency = 100

Trigger Character = $

Text Frame = 100

AD1.5 = N

AD1.4 = N

AD1.3 = N

AD0.3 = N

AD0.2 = N

AD0.1 = N

AD1.2 = N

AD0.4 = N

AD1.7 = N

AD1.6 = N

Safety On = Y

Mode – There are 3 mode settings. "0" for automatic UART logging, "1" for triggered UART logging and "2" for ADC logging. Mode 0 logs everything that comes in on UART0, provided that it's the right UART format (8 data bits, one stop bit, no parity, data rate of your choosing). Mode 1 logs a specified number of characters ("Text Frame = 100" in this case will result in 99 characters logged after the trigger) after a specified character ("Trigger = $" in this case). Mode 2 logs ADC measurements according to which are selected as active at whatever frequency is specified ("Frequency = 100" in this case). [14]

ASCII – The "ASCII" field only applies to ADC mode (mode 2). It specifies whether the unit will log in ASCII format ("ASCII = Y") or binary format ("ASCII = N").

Baud – The "Baud" field sets the baud rate for the UART logging modes. The available rates are as follows:

"1" = 1200

"2" = 2400

"3" = 4800

"4" = 9600

"5" = 19200

"6" = 38400

"7" = 57600

"8" = 15200

Frequency – The "Frequency" field only applies to ADC logging mode and is responsible for setting the sampling rate of the Logomatic. The number shown (100 in this case) is in hertz and can be set from 1 to 9999. However, if the frequency safeties are active, the maximum values will be imposed as indicated in an earlier section. [14]

Trigger Character – The "Trigger Character" field only applies to the triggered UART mode (mode 1). This is the character that the device waits for to begin logging a specified number of characters.

Text Frame – The "Text Frame" field specifies the number of characters to be logged with the trigger character when the Logomatic is running in mode 1. The reader should be aware that the first character in the logged text frame will be the trigger character, so if you wish to log 100 characters after the trigger you should set the text frame to 101.

Operational ADC Lines – The next ten lines in the configuration file indicate which ADC lines are to be read by the Logomatic. They can each be turned on by changing the "N" to a "Y". These values have no affect when in one of the two UART modes. For ease of use, they are listed in the configuration file in the same sequence that they're seen on the Logomatic PCB.

Safety On – The last field in the configuration file is the "Safety On" field. This sets the frequency caps for ADC mode on with a "Y" or off with an "N". The values for those caps are mentioned in an earlier section.

Output Formats – The formats of the text files produced by the Logomatic will be a little different in each mode. For mode 0 (automatic UART), any ascii characters that come in on the UART will be sent to the SD card. Nothing is omitted and nothing is added. For mode 1 (triggered UART), anything after and including the trigger character will be logged, including white space characters, up to the end of the specified data frame. Each data frame is delimited with a carriage return and a line feed character to make it easier to distinguish between the frames.

In ASCII ADC mode (mode 2, ASCII = Y), each single measurement is between 1 and 4 characters in length depending on how many digits are required, followed by a tab (ASCII 9) for delimiting. At the end of each measurement frame, that is, one time through the list of selected active ADC lines, carriage return and a line feed characters are placed for further delimiting. The sequence of measurements displayed in the file from left to right are exactly the sequence of channels selected in the configuration file from top to bottom.

In binary ADC mode (mode 2, ASCII = N), each measurement is two bytes in length (MSB, LSB), and they will occur in the same sequence as the ASCII logs with respect to the configuration file. There are no delimiters between measurements, but measurement frames are delimited by the characters "$$". [14]

Operation – Turn on your Logomatic without the SD card in place. You'll see the status LED's blink rather quickly during initialization, then they will go into a slow and steady sort of blinking. Familiarize yourself with that particular blinking. It's what the Logomatic will do whenever it is stopped. In this case it's stopped because it doesn't see the SD card. It will also do this if the card had been formatted in FAT32 instead of FAT16, or if the STOP button has been pushed.

Now that you know how the Logomatic works and what all of the settings do, it's time to power it up. Set your configuration however you like, plug your SD card into the Logomatic and turn it on. The two status LED's will blink at you rather quickly during the initialization, then the unit will go to work with the settings you chose. The only further indication of operation that you will see is when one of the two data buffers logs to the SD card, STAT0 for buffer #1 and STAT1 for buffer #2. These will be very quick "blips" because the LED's are only on during the write process, between 20 and 40mS.

When you are done logging, press the STOP button before shutting off the unit. Why a stop button? The Logomatic is interrupt driven. Pressing the STOP button disables the interrupts, logs the remainder of whichever buffer hasn't been written yet and updates the FAT. This ensures that you get ALL of your data and prevents leaving the file in an unfinished and corrupt state. Not pressing he STOP button prior to shutting down can leave you with a corrupted text file.

The Logomatic will create up to 256 log files in text format, numbering from LOG0.txt to LOG255.txt. The most recent log file will be the one with the highest number. [14]

Initially everything was tested on bread board as shown in Figure 3.5 before hand soldering it on blank PCB as shown in Figure 3.6.

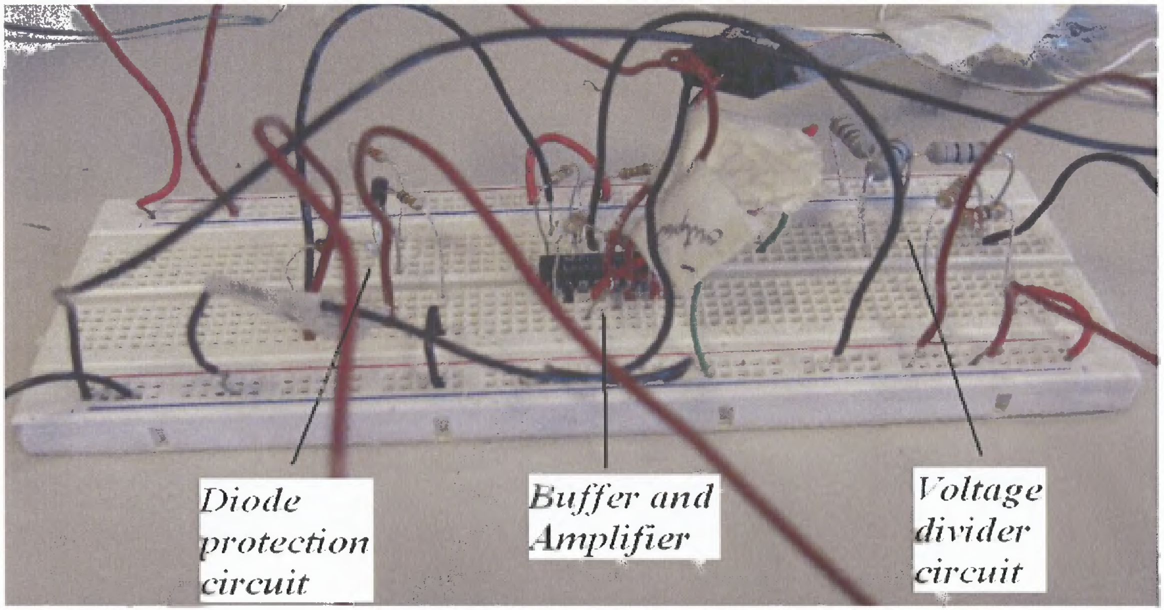


Figure 3.5 Bread board testing.

The problem while testing on bread board was that the voltage divider for sparkfun was not getting enough power and hence resistors were short circuiting. Thus the voltage divider had to be re-designed with keeping power requirements in mind. Initially all resistors were 1/4W but afterwards some resistors had to be selected from 1/2W and some from 1W to meet the power requirements as seen in Figure 3.2.

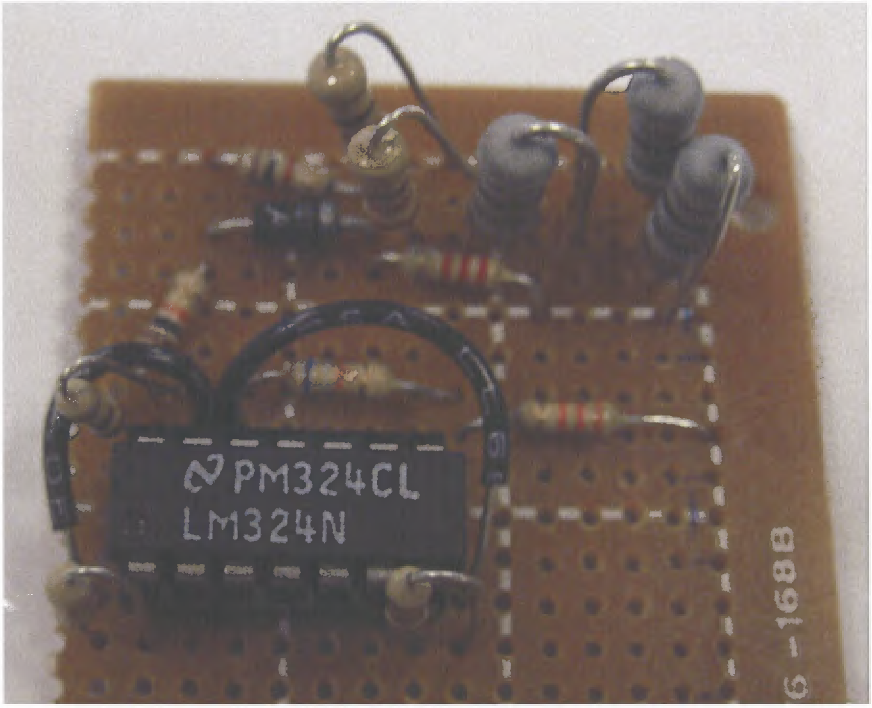


Figure 3.6 PCB Mounting.

Finally device prototype as shown in Figure 3.7 was built and tested. A 9V battery was used to power up the Op-amp. The force sensor was excited with same 9V battery.

Figure 3.7 Device prototype.

CHAPTER 4

RESULTS AND CONCLUSION

4.1 Results

Known force was given from 0lb to 14lb and corresponding output voltages were measured. Table 4.1 shows relation between applied known force and output voltage. Observed voltage is the one measured using multimeter, differential voltage is the one measured directly from sensor and calculated voltage is differential voltage multiplied by a factor of 100. As seen below, voltage value increases with increase in force value.

Table 4.1 Force vs. Voltage

Force (lb)	Differential Voltage(mV)	Calculated Voltage(mV)	Observed Voltage(mV)
0	6.5	650	140
2	14.6	1460	864
4	16.8	1680	1543
6	17.6	1760	1680
8	21	2100	1970
10	22	2200	2160
12	24.1	2410	2420
14	27.4	2740	2550

Note - Gain of 100

An experiment was conducted where in a known force was varied from zero lb to 15lb and the corresponding voltage values were recorded (Figure 4.1).

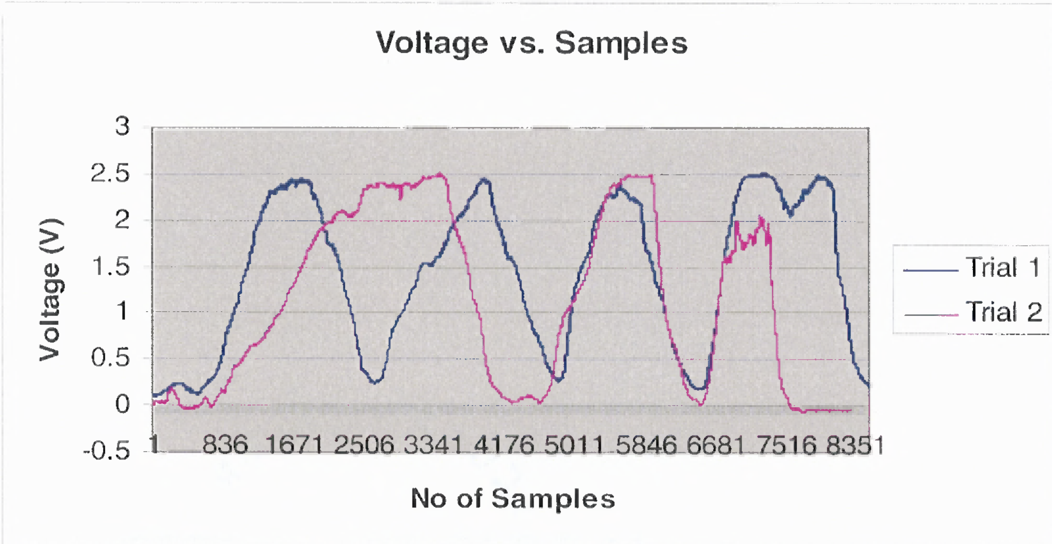


Figure 4.1 Voltage vs. Samples.

As seen above in Figure 4.1, voltage value increases with increase in frequency and vice versa. Readings were accurate when compared with multimeter readings and was able to get same peak voltage of 2.5V for seven times, four times in trial 1 and three times in trial 2. Hence force measurements were reliable.

One more experiment was conducted wherein known force was varied from 0-13lb for five different trials and there force values were measured to check the reproducibility.

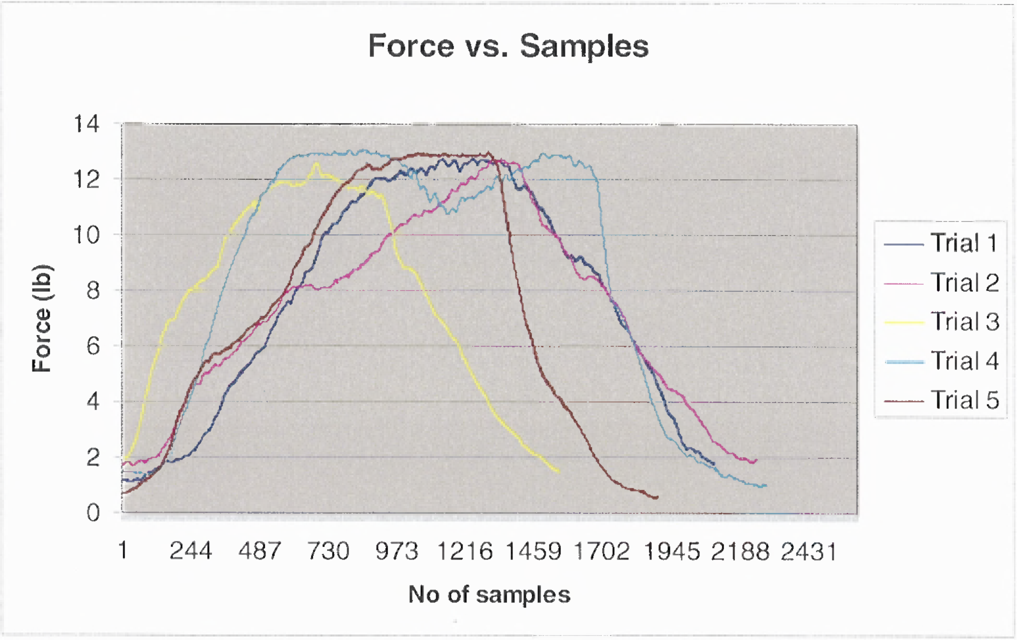


Figure 4.2 Force vs. Samples.

As seen above in Figure 4.2, for each trial force value increased from 0lb to 13lb and back and hence force measurements were reproducible.

Data was measured and stored continuously at 375Hz which is within the requirement of 60-100Hz. Battery life of 9V alkaline battery was ~8.5hrs (565mAhr rating) so data can be easily recorded for each trial which usually lasts 30 minutes. Memory card can record hours of data. Expandable upto 10 sensors (we would require four per therapist). Sensors are embedded in glove in such a way that all four areas of interest would be covered. Device is compact, battery powered and would not interfere the training procedure. From Figure 4.1 and Figure 4.2, force measurements are accurate, reliable and reproducible.

4.2 CONCLUSION

Thus we have a device which can accurately and reliably quantify the force applied by the therapist during Locomotor training of SCI patients.

CHAPTER 5

FUTURE WORK

Testing was done using one sensor, so next step would be to built and test for four sensors as normally we require four sensors for one therapist. Secondly, mannequin testing has to be done. Now as we know the force measurements are accurate. We can apply unknown force on mannequin and find out the force that would be required to move mannequin, say for different angles from 0-80 degrees in step of 20 degrees.

Figure 5.1 Mannequin testing.

APPENDIX

SPARKFUN DATALOGGER

Data Set

187	160	223	366	479	668	824	859	966	962	992	736	269	185
187	161	223	366	479	670	825	859	967	963	991	736	271	183
186	161	222	367	481	670	825	860	966	964	994	735	267	184
191	160	224	367	480	670	825	861	967	964	992	735	267	186
192	162	224	366	480	669	826	861	967	964	992	735	265	186
193	161	224	366	482	671	826	862	968	966	994	734	264	185
194	161	224	367	483	671	826	862	967	966	991	734	262	184
193	162	223	368	483	672	826	862	968	966	991	734	266	186
195	162	224	369	482	672	826	866	970	964	990	731	259	186
195	162	225	368	482	673	825	865	970	964	990	731	260	186
199	163	223	370	483	673	825	865	970	964	990	730	258	186
198	163	223	369	483	673	826	867	970	963	991	728	256	186
199	163	224	370	483	674	827	866	970	962	990	729	256	187
200	164	221	368	484	674	826	866	968	962	991	728	255	187
202	162	219	371	483	675	827	864	970	962	990	725	254	187
202	164	220	372	483	675	827	865	970	960	992	726	251	188
204	163	218	373	485	678	828	865	969	960	991	723	251	187
205	163	219	373	486	678	829	865	967	958	991	720	249	186
208	163	218	374	488	679	828	864	966	958	994	723	250	186
208	164	216	374	487	679	827	863	966	954	994	721	248	185
210	163	216	375	486	681	828	863	966	954	994	720	246	186
210	162	217	376	489	682	827	863	967	951	994	719	247	186
210	162	215	376	489	685	829	864	968	951	995	718	247	187
212	163	214	377	490	686	829	865	970	951	995	715	246	187
214	162	214	379	489	686	827	866	968	949	995	715	244	186
214	161	215	379	489	686	827	866	967	950	995	715	244	186
216	162	213	379	490	688	827	867	967	950	997	713	243	186
218	161	214	378	490	689	826	867	967	950	996	712	243	187
218	160	214	379	492	691	826	870	966	950	995	709	243	187
219	162	214	380	492	693	826	871	966	954	996	706	242	190
221	162	214	381	494	694	826	871	967	950	996	706	243	
222	159	212	379	491	692	827	872	966	950	996	703	243	
222	160	214	379	493	695	827	874	966	951	997	703	244	
223	159	214	379	494	696	826	875	964	951	997	700	243	
223	158	216	379	494	698	826	875	964	951	995	699	244	
222	159	214	379	494	696	827	877	963	951	995	698	243	
225	158	216	381	494	698	828	878	963	955	995	696	242	
226	158	216	380	495	697	827	879	963	952	995	695	242	
226	162	216	378	497	697	828	882	963	954	995	693	242	
226	158	217	379	495	696	830	882	963	952	995	692	242	
227	158	218	381	496	696	832	884	962	952	995	691	240	
226	158	216	381	497	698	832	883	962	954	996	693	238	

227	157	219	382	495	698	832	886	962	956	996	690	239
227	160	219	381	496	697	834	887	962	956	998	691	238
223	159	219	382	497	701	835	888	962	958	998	689	238
225	158	223	382	498	702	836	888	961	958	998	688	237
224	159	222	383	498	702	837	888	961	958	999	687	236
226	160	223	382	499	703	838	889	962	960	999	687	235
226	161	223	383	498	704	840	891	962	959	1000	683	234
227	162	223	383	499	704	840	889	960	959	1000	682	234
227	160	226	383	499	707	841	889	960	960	1000	679	233
227	160	226	383	498	707	843	891	960	960	1000	680	232
226	161	226	385	499	709	842	891	960	960	1000	678	230
228	161	227	383	499	710	842	889	960	961	1003	677	231
229	158	230	385	501	711	843	890	960	960	1002	674	229
228	161	230	384	502	712	842	891	959	959	1000	673	230
230	163	230	384	501	715	842	892	960	959	1000	670	229
230	162	232	386	502	715	843	894	960	958	999	670	226
230	163	234	385	502	717	843	894	960	958	1000	667	227
230	163	234	385	502	719	843	894	960	958	999	666	228
231	163	236	386	503	719	842	894	959	958	996	663	228
230	163	239	385	502	719	842	898	958	955	995	662	228
230	163	240	386	504	721	843	898	958	957	995	660	227
231	163	241	384	506	722	842	899	958	956	994	659	227
230	162	243	386	505	722	843	902	956	955	995	657	227
230	163	245	387	506	723	843	903	958	955	994	656	227
231	163	246	385	507	723	843	904	958	955	994	654	227
229	164	248	385	506	723	843	907	956	955	994	654	227
227	163	250	386	506	723	843	908	955	955	992	653	226
226	167	250	386	507	723	845	912	955	956	991	651	226
227	165	251	385	508	724	845	911	956	958	991	654	226
226	166	254	386	507	727	848	914	956	957	992	648	226
225	166	255	386	509	727	847	915	956	958	993	647	226
223	166	255	386	511	726	848	915	956	958	994	645	226
225	166	258	384	510	727	850	917	957	959	994	642	226
223	167	258	385	512	727	849	921	955	960	994	641	223
221	166	259	386	510	727	849	921	957	958	994	641	224
222	169	258	384	511	727	850	921	956	960	994	639	225
219	170	260	385	512	728	850	926	958	961	994	638	226
221	169	259	385	513	729	851	923	957	961	995	635	223
219	167	260	386	513	728	850	925	958	962	995	634	223
218	170	261	385	515	729	852	926	955	962	995	632	222
218	170	262	386	515	729	855	926	955	963	996	630	224
217	170	261	385	515	728	854	927	955	963	995	627	221
216	171	262	385	517	731	852	927	954	964	995	626	222
215	171	262	386	518	731	853	928	954	964	995	624	219
217	172	261	388	517	731	854	930	955	967	994	622	219
215	173	261	385	515	731	854	928	954	966	995	619	220
214	174	260	384	518	732	854	931	954	966	994	616	219
214	173	259	383	518	733	857	930	954	967	994	614	219
215	173	262	386	519	734	855	930	954	966	993	611	219
215	173	259	384	522	735	857	930	955	966	992	610	220

214	175	259	386	522	735	854	932	955	967	990	608	220
213	176	258	385	521	734	855	932	956	967	990	604	218
212	176	259	385	522	735	855	933	955	967	987	603	219
211	176	258	386	523	735	855	933	955	967	987	601	218
211	179	258	386	523	736	855	934	955	966	986	598	219
210	179	257	386	525	737	858	933	955	965	986	595	218
208	179	258	386	526	736	857	935	955	966	985	594	216
210	182	257	387	526	737	856	936	955	966	985	591	218
210	181	256	386	526	737	855	936	956	967	985	589	217
207	182	258	387	528	736	855	938	958	965	984	588	218
208	182	257	387	528	736	855	939	958	966	983	586	216
207	183	255	387	528	737	856	940	959	966	984	585	217
207	183	255	390	529	737	855	942	960	965	983	582	217
205	186	256	390	530	737	856	946	960	964	983	582	216
205	185	257	388	530	738	854	946	962	963	984	579	218
205	186	256	389	531	738	856	944	962	963	984	578	217
205	186	257	389	531	739	855	947	963	964	983	576	216
204	189	258	388	533	739	856	946	962	963	983	574	215
203	189	258	390	534	740	857	947	962	963	983	573	215
203	190	259	390	534	741	858	947	963	965	983	571	216
202	190	259	391	534	740	858	947	962	965	982	570	215
202	189	261	392	536	742	858	947	963	966	982	569	216
202	192	262	391	536	742	859	945	964	966	982	569	214
202	194	264	390	538	743	859	946	963	967	980	567	215
202	192	265	391	539	744	860	945	963	966	981	565	214
200	192	266	391	539	744	861	943	963	967	979	563	214
200	192	267	391	539	746	860	944	962	968	978	563	213
200	192	267	390	542	745	859	944	962	967	978	563	214
200	191	270	391	540	746	861	944	962	970	977	562	213
199	190	271	391	542	746	859	944	960	970	975	560	211
198	191	274	391	543	748	860	944	958	971	975	561	213
195	191	274	392	543	750	861	943	959	972	971	559	211
195	192	275	391	542	750	859	944	959	971	971	557	213
195	190	275	392	543	750	859	945	958	972	970	557	211
194	190	275	392	543	751	859	944	958	974	968	555	209
192	190	275	392	545	752	860	945	958	974	967	555	209
192	191	275	391	544	753	860	946	960	975	967	553	208
190	190	278	393	545	755	859	946	956	975	966	552	208
188	190	278	393	546	758	859	946	960	976	965	551	208
186	190	279	391	548	757	858	946	960	976	966	550	208
186	190	280	393	548	758	859	947	960	975	963	549	206
186	191	282	394	550	759	860	948	960	975	963	549	206
183	192	283	394	551	760	862	948	960	976	965	547	206
183	192	283	394	549	759	862	949	960	976	963	546	206
181	192	288	393	552	760	862	950	960	978	960	544	206
181	192	288	394	553	762	862	951	962	978	961	545	205
179	193	287	395	554	763	862	951	963	978	963	544	203
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178	195	293	395	557	763	864	951	966	978	960	541	203
178	195	294	397	558	763	862	955	963	976	958	541	203

177	195	294	397	559	762	864	955	964	975	960	539	202
176	194	295	398	560	763	863	956	964	975	958	539	202
176	194	297	398	561	765	863	958	963	976	958	538	202
174	192	297	398	563	765	863	958	963	974	956	538	200
174	192	299	399	563	767	863	959	963	976	954	538	200
175	193	299	400	565	764	866	958	963	977	951	537	199
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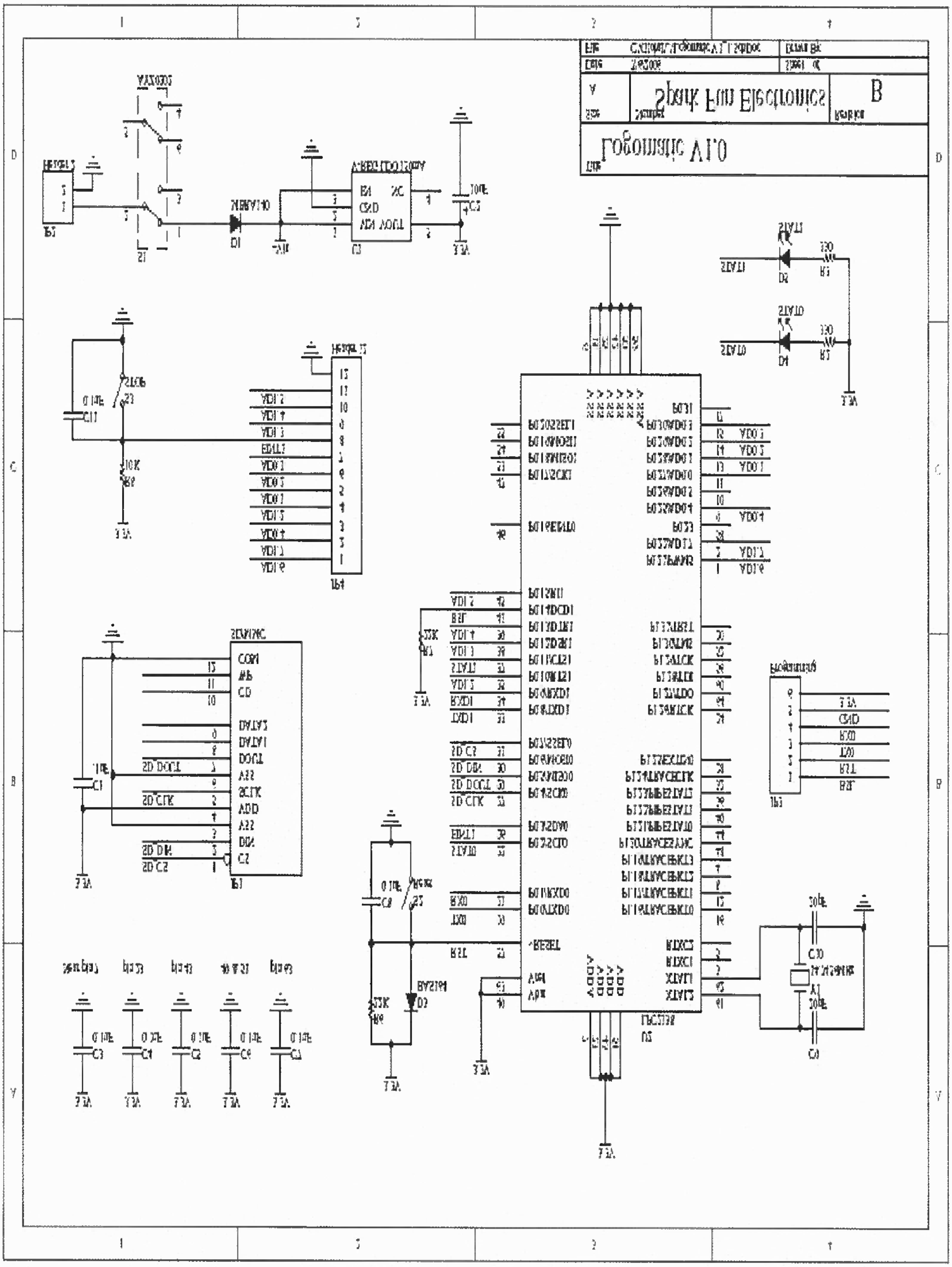

Figure 1 Logomatic V1.0.

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