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Design andConstruction of a simple force sensing system – FELIESS

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Abstract— Manual force application to different parts of the human body is an essential part of physical therapy practice and ranges in intensity from gentle superficial touch to high intensity thrust manipulations. Objective of the study was to design and construct a small, low cost force sensing system for therapists to gain real time feedback of manually applied forces. The device was calibrated and evaluated within and outside the laboratory setting for the followings: (1) test of validity (2) test of reliability (3) test of practicability. The accuracy of the preliminary design in terms of the coefficient of correlation between he applied force and the resultant force as shown by the device comes out to be 0.99 with a standard deviation of ±5grams and 95% confidence interval of ±0.14 grams about the mean. FELIESS (Force evaluation, Listing and integration- electronic and software system) is a simple force sensing system with acceptable validity and reliability that can be used as a means to provide real time force feedback.

Index Terms—Biofeedback, Equipment Design, Force, Musculoskeletal Manipulation

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1 INTRODUCTION

Manual force application to different parts of the human body is an essential part of physical therapy practice and ranges in intensity from gentle superficial touch to high intensity thrust manipulations. Practitioners develop the decision that what kind of situation requires what kind and intensity of force over years of practice and experience. However this skill when transferred to students in a classroom or clinical setting lacks the transfer of knowledge with respect to intensity of force application that they are expected to develop out of experience themselves. A similar situation arises in the reproducibility of results of literature involving manual force application. For example a particular study might claim that a certain mobilization has significant effects, however when the same is attempted by a reader in order to gain similar effects the question arises as to how much force has to be applied. Author's indicate indirect parameters such as the 'end feel' or ' till you achieve a block', however these are difficult to appreciate by students or even some therapists, as indicated by a study that shows that manual force application can differ as much as 500% among practitioners.[1, 2] Several sophisticated equipment have been developed in this regard however most lack practical clinical use for either being too large and wired, expensive or simply compromising on the 'feel' of the tissue being worked on. Some have developed machinery that measure forces indirectly like sensor fitted mobilization couches, however in such designs it becomes difficult to differentiate between the forces actually part of the mobilization and the artifacts.[3, 4, 5] Here an attempt is made to design and construct a simple force-sensing device that is small, wireless, cost effective and can be easily modified according to individual needs as force application in physical therapy takes multiple dimensions. It must be kept in mind that even though we make this humble effort to develop a device to gain a feedback of the manually applied force, we in no way underestimate the importance and usefulness of classically used indirect indicators like the patient's facial grimace indicating pain, the skin's blanching reaction indicating the level of vascular reaction, patient's feedback indicating whether something is more or less, the therapist's experience developed over years of practice etc. The device is intended to provide real time feedback of forces as an additional parameter over and above the parameters already prescribed for what he/she is doing, for the therapist to gain meaningful insight into his work which can be at the stage of diagnosis, treatment, prognosis or simply increasing the safety of his treatment method which involves manual force application. As you shall read in the following pages the simplicity and modifiability of the design renders it the much needed versatility and readers are free to let their imagination run wild and explore the various possibilities where such a system can help enhance their practice or assist in their work.

2 MATERIALS AND METHODS

2.1 Device construction

The device consists of three units:

- Sensing Unit (Force Sensing Resistor-FSR)
- Processing Unit (Micro-controller)

- Display Unit (LCD Screen)
- Power source

Sensing Unit: FSR402

This is a force sensitive resistor (FSR) [6] with a round 0.5" diameter, sensing area. This FSR will vary its resistance

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depending on how much force is applied on the sensing area. The higher the force, lower is the resistance. When no pressure is applied to the FSR, its resistance would be larger than 1 MΩ. This FSR cansense applied force anywhere in the range of 10g – 10kg. It is interfaced to the processing unit(micro-controller) through ADC (analogue to digital convertor). Its Nominal thickness is 0.018” [0.46 mm]. It has a Semi conductive Layer of 0.005”, a Spacer Adhesive of 0.006”, an Acrylic Conductive Layer of 0.005” and Rear Adhesive of 0.002”.

Processing Unit: AVR – Atmega32

Atmega32 is an AVR 8-bit micro-controller by Atmel. AVR is one of the most powerful 8bit-controller. They are a unique combination of performance, power efficiency and design flexibility. It can give performance up-to 16MIPS (million instructions per second). Sensor and the LCD are interfaced to the micro-controller through ADC and SPI interface respectively.

Display Unit: Nokia LCD

A Nokia phone LCD is used to display the output of the sensor. It uses the PCD8544 controller. The PCD8544 is a low power CMOS (complimentary metal oxide semiconductor) LCD controller/driver, designed to drive a graphic display of 48 rows and 84 columns. All necessary functions for the display are provided in a single chip, including on-chip generation of LCD supply and bias voltages, resulting in a minimum of external components and low power consumption. This LCD is interfaced to the micro-controller through Serial Bus interface.

Power source

Currently we used a simple 9volt DC battery however more sleek and light weight options are available

2.2Device Schematic

Device schematic is represented in the ***appendix A*** to have an outlook of detailed circuitry for construction of the device.

2.3 Device working

FSR is tied to a measuring resistor in voltage divider configuration, for a simple force-to-voltage conversion. The output is described by the following equation:

$VOUT = (V+) / [1 + R_{FSR}/R_M]$.

In the shown configuration, the output voltage increases with increasing force. The measuring resistor, R_M, is chosen to maximize the desired force sensitivity range and to limit current. The current through the FSR should be limited to less than 1 mA/square cm of applied force. Op-amp used in the circuit is LM358which is the suggested op-amp for single supply use in the FSR datasheet.

The output of the op-amp goes to the ADC input pin of the micro-controller. Micro-controller converts the input analog voltage to a digital value, which can be understood by the controller.

2.4Device calibration

For different values of the applied force, a graph is drawn between voltage and force. By using this graph, we have made a look-up table of digital voltage and corresponding force values, which is further used in the system to show the output force value on the LCD screen.

2.5Device testing

The device is tested under different force conditions. Different weight ranges from 10g – 2.5Kg is tested with the sensor and a graph is drawn between the force and the output voltage as shown in ***figure 1***. Another graph between the applied force and the force displayed on the LCD is also plotted outside the laboratory setting with the sensor placed over apadded treatment plinth and the weights placed directly over the sensor’s active area as shown in ***figure 2***.

2.6Test of validity

The device readings are taken at rest when no external weight is applied on it, which it showed as zero. There is no observable interference or alteration in value due to light, sound or vibration at rest or during measurement. Validity is also rendered due to the fact that change in output is only obtained when there is change in the distance between the different layers composed in the sensor.

2.7Test of reliability

The device is tested both in the laboratory and clinical setting to get real time values. For clinical testing the device is placed over a padded treatment plinth and external weights between 500 to 2500 grams are applied on the sensor’s active surface perpendicularly and five repeated measures are taken.

2.8Test of practicality

For the device to be of practical value it must 1) be a valid and reliable measure of force 2) should provide real time feedback 3) should not interfere with any other parameter of value to the therapist 4) must be easy to use, store and retrieve 6) must be modifiable as per need 5) must be cost effective and 6) must have a wide range of application

3 Results

The coefficient of Correlation between the applied force and output voltage was 0.96. Since the lookup table formed is an inversion of the voltage values obtained while testing, error reduce to minimal under laboratory conditions approaching almost zero and nearly complete repeatability, whatever minute error obtained can be mainly attributed to the errors encountered in analogue to digital conversion. On analyzing the forces applied on the sensor directly outside the laboratory setting a standard deviation of ±5 grams was obtained with a resolution of 8 grams at 10 Hertz. The coefficient of correlation between the applied force and the resultant force value is 0.99 and 95% confidence interval is ±0.14 grams about the mean. The differences in results obtained can mainly be attributed to the various equipment and human factors. The manufacturer describes various mechanical distortions that can possibly affect the output like kinking and bending of the sensor tail, bending of the active area of the sensor and application over curved surfaces that may cause preloading of the sensor and alter the output. As a remedy a small piece of two-way adhesive tape maybe used to more evenly distribute the forces however we did not use the same as we felt it might compromise on the feel on the tissue beneath the sensor surface. The error thus encountered due to it was too small and barely distinguishable by humans. The error may also be due to the change in angles at which the external force was applied with respect to the sensor surface given that it was done without any external angle measurement and the plinth was padded, however attempts were made to keep the external weight perpendicular and motionless.

The device provides a valid and reliable real time feedback of the externally applied forces. The device is small measuring 5.8X4.5X2.0 cm and light in weight, weighing approximately 110 grams minus the batteries, thus providing for optimal and hindrance free usage. The parts can be easily dismantled for storage as shown in ***image 1***. FSR are purposely used here for theirs thin design. The device can be easily modified to incorporate many other features that may be of significance to potential users, as discussed later. It has a wide range of application where the maximum external force and the sensing area can be altered as per need. The overall cost of the device comes out to be around 20 USD for a single piece here in India, but we are hopeful that bulk ordering which significantly slashes prices in the world of electronics can bring down the cost to between 10 -15 USD, which makes it cost effective as compared to other options in its category.

4 Discussion

As proved by the above results the device makes a simple force sensing system with acceptable validity and reliability that can be used as a means to provide real time force feedback. The device is small and can be easily incorporated in the palm of the hand and uses an interfaced LCD that eliminates the need for an external display unit to show the result. The current frequency of signal uptake was chosen as it was the optimal speed and allowed the user to clearly read the digits as they altered, however this can be easily changed and modified depending upon the need, for example while testing forces applied during oscillations, a higher frequency maybe desirable. The overall resolution can also be improved by altering the system code. The device can be used over a large range of forces, which is mainly a function of the sensor used. Various other sensors of different force ranges and sizes are available that can be used with the same circuit requiring changes only in the coding. The sensor used here can be used up to 10kgs. There are several other modifications that may be of significance to users and can be easily incorporated into the design. Firstly is the option of multiple channels, thus multiple sensors can be used. Secondly the option of data storage in a Micro SD card that can be discretely affixed and can store data that can be retrieved later via a data card reader. Thirdly the SWTICH, we realized that during use there may be times when a certain data needs to be stored while at times storage is not required, thus we developed the SWITCH that helps control the amount and type of data that actually requires storage, with a subsidiary inbuilt clock to monitor time of application as well. Finally we designed a simple wrist strap, so that it can be worn as like a wristwatch to increase the usability of the device.

Kilogram vs. Newton vs. Pascal

In the various studies published previously on the topic, various units of measurement of output have been used.[7,8] However the question arises which one is the most appropriate. According to laws of physics kg is the measure of mass, Newton the measure of force and Pascal the measure of pressure. Kg however is also used as a term to denote the weight of an object that would be the mass into the acceleration due to gravity, also called kg force. We realized that since the device may have varied uses it is more appropriate for the user to decide which parameter best represents what he wishes to study. Here the nature of the FSR must also be kept in mind. As discussed in the result kinking and bending of the sensor can cause preloading of the sensor and thus produce altered values, similarly if the entire force is concentrated on a smaller part of the active area of the sensor the resistance will still alter. Thus when differentiating between pressure and force, the use of a puck, like thick two way tape or rubber bumpers evenly distributes the force in the entire active surface area of the sensor in addition to the fact that the external force must be applied entirely through that bumper so that no forces are lost. The conversion is simple and according to the equation: 1kgF = 9.8 N. Conversion into Pascal requires division of the force in Newton by the area in meter square: Pressure= Force/Area. This is important as some users maybe using larger sensors but may be applying the force to a smaller area of the sensor. We are also looking at the possibility of incorporating a software system that detects the actual surface area over which the force is applied.

5 Clinical Message

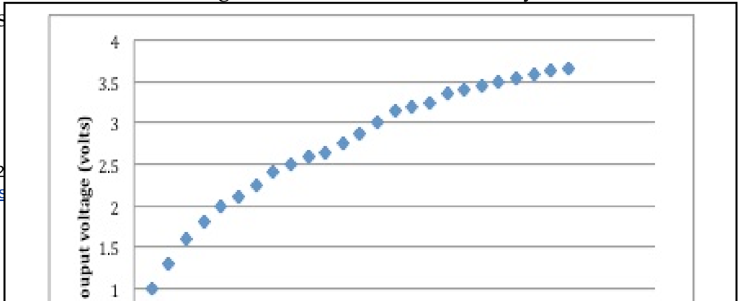
Findings: The device design tries to incorporate all major features that may be of use to researchers and clinicians.

Implications: The multi dimensional use and cost effectiveness of the device can make it a standard tool in practice.

Caution: Calibration of the device at regular intervals is suggested to identify any small internal damage during use.

6 Conclusion

The design and construction of a simple force sensing system is described here that tries to incorporate all the major features that may be of value for therapist, students etc who require any sort of feedback of forces in their work. All efforts are made to make it modifiable such that the unique demands of their work are met effectively. Special emphasis has been made on controlling the cost to make it easily accessible for s



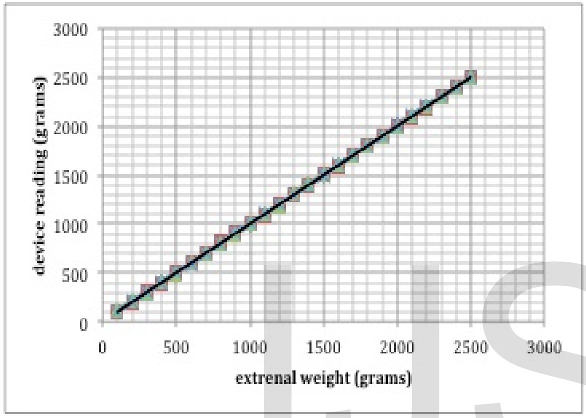


Fig. 2. Plot of external weight in grams versus device readings in grams

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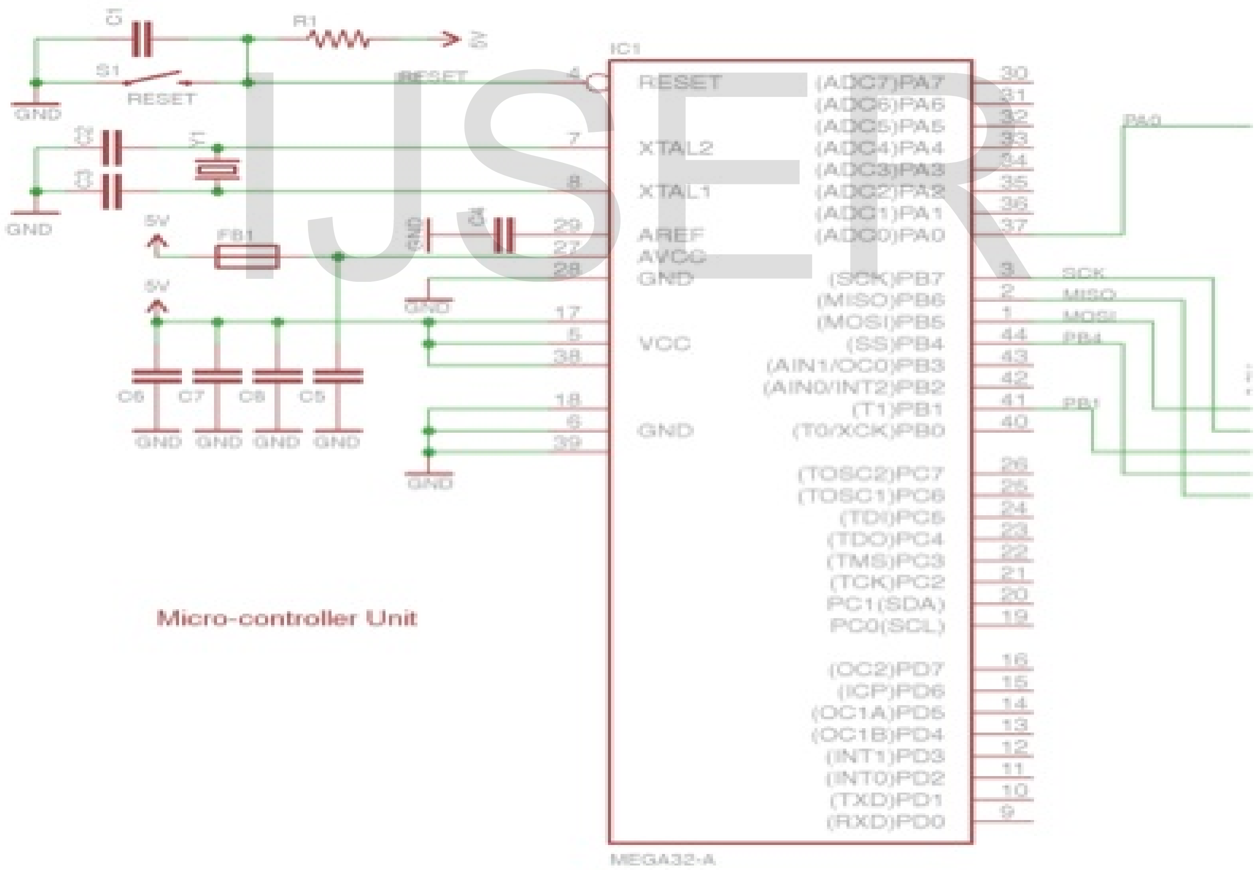
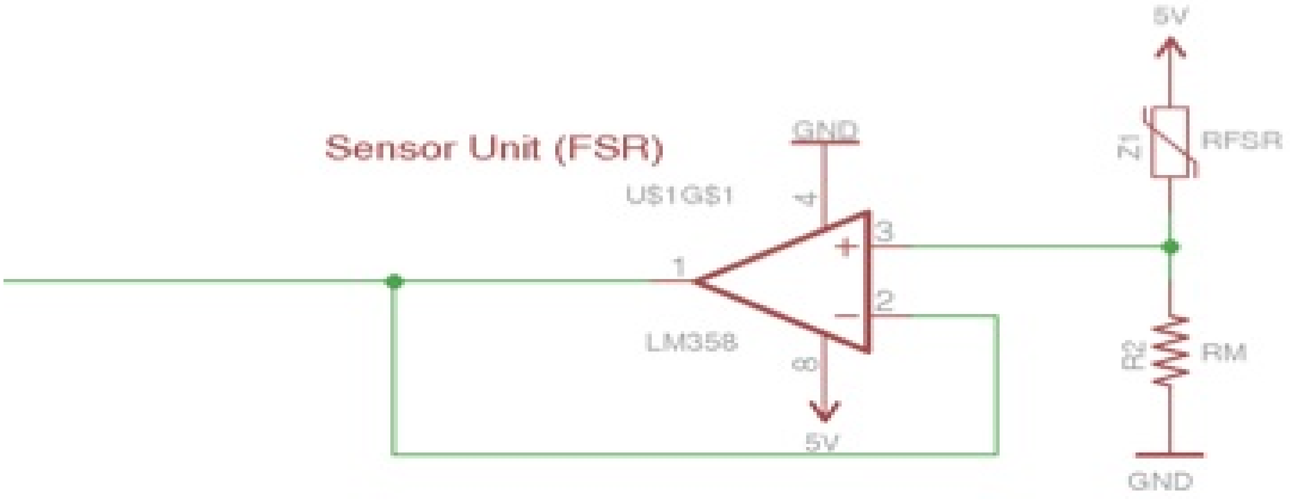
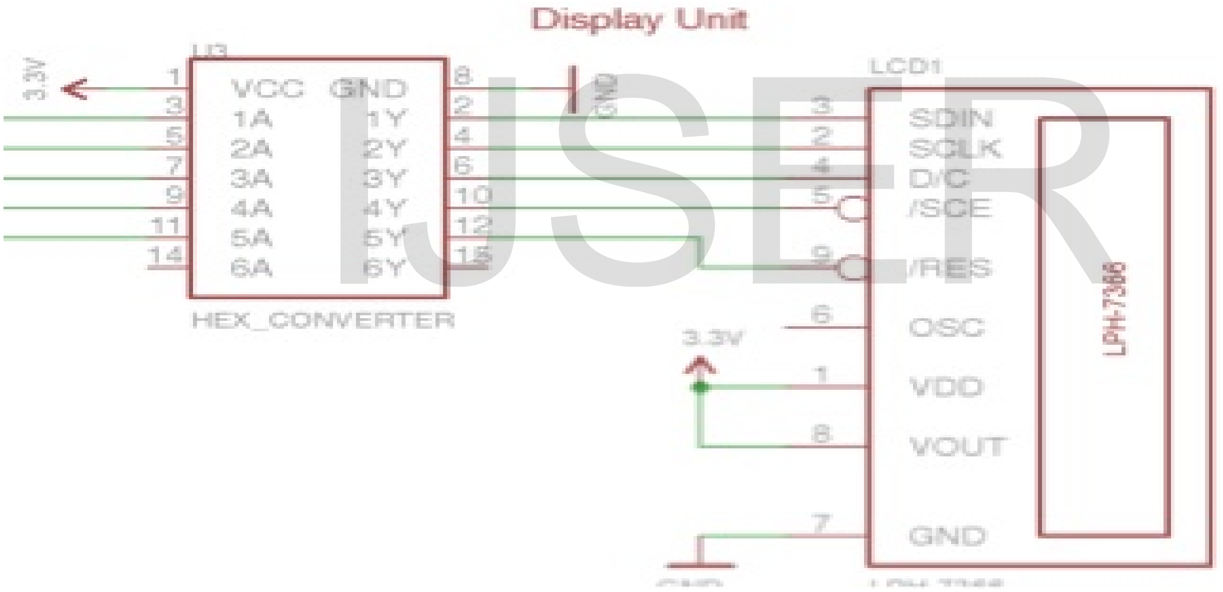
Image 1- dismantled system showing the component parts (top) battery connector (middle row L to R) sensor device batteries

Appendix A

DEVICE SCHEMATIC




Sensor Unit (FSR)
GND
U$1G$1
4
3
+
1
2
−
LM358
8
5V
5V
Z1
RFSR
R2
RM
GND


Display Unit
U3
3.3V
1
3
5
7
9
11
14
VCC
1A
2A
3A
4A
5A
6A
GND
1Y
2Y
3Y
4Y
5Y
6Y
8
2
4
6
10
12
15
GND
HEX_CONVERTER
LCD1
3
2
4
5
9
6
1
8
7
SDIN
SCLK
D/C
/SCE
/RES
OSC
VDD
VOUT
GND
LPH-7366
3.3V