Pinch Meter

Design of a Pinch Meter For Stroke Rehabilitation

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Fall 2011

Advisor: Professor John Webster

Client: Elizabeth Bourne

ABSTRACT

At the University of Wisconsin-Madison Hospital, Elizabeth Bourne, an occupational therapist, assists in the rehabilitation process of patients affected by the debilitating effects of strokes. Her objective is to use a measuring device to obtain a quantitative assessment on the progress of the patients' force application abilities of a finger pinch. Currently, pinch meters that are available cost approximately $300 and do not sense forces small enough to interpret the extreme level of disability of the targeted stroke patients. Our goal is to design a device that is capable of sensing pinch force in 0.2 kg increments to further assist Elizabeth Bourne in bettering the stroke patient rehabilitation procedure. Through our research, we have designed a device that utilizes a micro load cell that can produce the proper efficiency and accuracy.

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Background/Motivation

Every year approximately 800,000 people suffer from strokes in the United States (“Stroke” 2006). Three-quarters of these strokes occur in people over 65 years old. Strokes occur from blockages that prevent blood from reaching the brain. Following the stroke, mental and motor function may be impaired. The rehabilitation of stroke victims focuses on restoring fine motor control that may have been impaired (“Post-Stroke” 2008). Because of this, our mission is to design a device that measures the pinch force of stroke victims. This data can be used to measure the improvements in fine motor control.

Pinch force dynamometers are used in hospitals to measure the force generated from the fingers. There are two different tests used to evaluate the strength: a two-finger test (Figure 1) is conducted between the thumb and index finger and a three-finger test (Figure 2) is conducted between the thumb, index, and middle fingers (Bourne 2011).

Figure 1. Two-finger pinch

Figure 2. Three-finger pinch

Digital and analog pinch force dynamometers are commonly used. These devices are held by a rehabilitation therapist while the device is in use (Bourne 2011). The head of the meter, which contains a spring sensor in analog and an electronic force sensor in digital devices, is extended toward the patient. When the patient presses on the head, the force is displayed on the dynamometer.

Most of the products available today provide a readout up to 22.6 kg, with accuracy within 0.5 kg ("Pinch Gauge" 2008). However, most recovering stroke victims can only provide a force of 2.26 kg; thus, a more precise device is needed (Bourne 2011).

Problem Statement

Our Client, Elizabeth Bourne of UW-Hospital's Department of Rehabilitation, would like us to design a dynamometer to measure the finger force generated by recovering stroke victims. Current hand dynamometers are not precise enough to measure the reduced force of stroke victims. The device needs to be accurate, precise, and easy to use.

Competition

There are many accurate pinch gauges currently on the market. However, none of these dynamometers are specifically tailored to a recovering stroke patient's rehabilitation needs. The gauges that are currently sold use both hydraulics and spring designs. Some use scales to display the force (Figure 3), while others display the numbers on a digital LED monitor (Figure 4).

Figure 3. Jamar hydraulic pinch gauge.
www.pattersonmedical.com

Figure 4. A digital finger force dynamometer.
www.baselineproduct.net

They are able to measure up to 22.7 kg to 45.4 kg, and measure in increments of 0.91 kg (“Pinch Gauge” 2008). However, in order to accurately track the progress of the stroke victim’s rehabilitation process, smaller increments need to be measured. The diminished strength of the patient’s pinch causes the force of their pinch to be very small, usually less than 2.27 kg while the average pinch strength of a healthy individual is around 9.07 kg (Bourne 2011). This means that even the slightest increase in pinch strength is significant and should be recorded.

Another design aspect of competitor’s pinch gauges is that the sizes of the pinch pads are around 2.54 cm diameter. A larger pinch pad would be beneficial to a stroke patient since their motor skills are diminished, thus making it difficult to grab a small target.

The price of the competitions' designs may be their biggest downfalls, with costs averaging $300. As an extreme, HogganHealth's duel-design of a pinch and grip gauge costs $1395 (Figure 5). Our pinch meter design will face tough competition with accurate, aesthetically pleasing, and functional designs already on the market. However, the price needs to be more reasonable for our client.

Design Criteria

There are specific requirements the pinch meter design must meet. Our client insisted that the device be portable. To achieve this, the product's weight cannot exceed 4.0 kg and the dimensions of the product cannot exceed 10 cm x 10 cm x 15 cm. Another important design aspect is that the product must not pose any safety risk to the patient or the therapist. Therefore, no exposed wires or sharp edges can be on the outer surface of the device. Additionally, the product cannot contain any latex because it is used in a hospital setting. The service life should be 2 to 5 years, with necessary battery changes every six months. The device must have digital output that displays force in pounds and respond to forces between 0.00 and 2.26 kg, increasing by 0.01 kg. Including all of the components and necessary cost of production, the device should cost under $100.

Materials

Table 1 outlines the materials that were used to create the final design. The total cost of the project was $100.10.

Table 1. Project materials and their costs.

Device	Cost
Micro Load Cell	$6.80
Mbed microcontroller (Trossen 2006)	$60.00
Circuit	$0.30
PVC junction box	$9
Amplifier	$0.30
LCD Screen (PG2011)	$14.00
Power Source (9V batteries)	$4.00
Battery Holder	$3.00
Steel for pinch pad	$0
Bread Board	$2.70
Total	$100.10

Ethical Considerations

There are several ethical concerns pertaining to the design of a pinch meter that is specifically tailored to a recovering stroke patient's needs. These include safety aspects as well as professional standards of ethics that must be upheld. Since there are pre-existing pinch gauge designs currently on the market, special care must be taken to not infringe upon any copyrights or patents of the current designs. In terms of safety, the device should not endanger or harm a patient in any way. This means that the design should be nontoxic and safe; it should have no sharp edges, exposed wires, or allergenic materials.

Design Alternatives

There are many different ways to approach designing a pinch meter. One way is through the modification of an existing device, which would essentially supply all of the necessary components needed to make the pinch meter. With all of the necessary parts, it becomes a matter of reprogramming it to match the client's needs. Another approach would be to create the meter completely from scratch. This would allow the freedom to design and specify the device's exact functions. It would also require extensive research into individual components. Both of these design approaches are feasible and each have various advantages and disadvantages.

Scale

One option was to disassemble a bathroom scale and modify its internal components to satisfy our needs. A scale uses a series of load cells and strain gauges to determine the force that is being applied. Load cells are comprised of an unsupported beam, much like a diving board (Webster 2011). When a person steps onto a scale, their weight acts on the load cell and causes it to bend. This movement of the load cells causes the strain gauges, which are attached to load cells, to bend as well. The resistance of the strain gauge changes with the bending of the metal and this causes a change in the output signal. The signal is then translated into the corresponding force and displayed on the screen.

Opening a bathroom scale and modifying its range of outputs is one possibility to make a pinch meter. The load cell would need to be small enough to match the clients design criteria and be portable. Another concern modifying the scale's program to calculate the force being applied. Bathroom scales work well for larger forces and may not be able to accurately identify the force for the range requested by the client. Another possible idea would be to use some parts of the bathroom scale, like the LCD screen and load cell, and implement them into a different microcontroller.

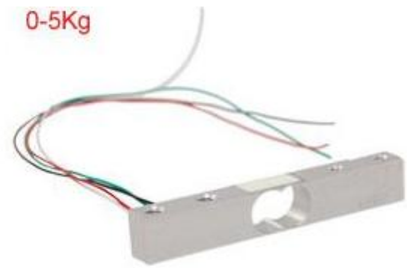
Assemble from Components

Creating the pinch meter from scratch requires analysis of individual components to make it work. In order to have a successful pinch meter, four important components need to be researched: a force sensor to translate the applied force to an analog signal, a microcontroller to take the analog signal from the sensor and convert it to a digital output, an LCD screen is needed to display the output from the microcontroller. Lastly, all of these components need to be enclosed in a housing unit.

Force Sensor

Many different force sensors were researched for this product. When using force sensors in a hospital setting, they need to be easily administered to the patient and be consistent so they can track a patient's progress. Force sensing resistors were initially looked into because of their cheap cost and ease of use. Unfortunately, its accuracy and long-term lifespan are poor (Webster 2011). Over time the internal resistance changes as force is applied to it resulting in unreliable data. Also, the resistance changes depending on the area on which force is applied.

Load cells were another alternative researched for the force sensor. Load cells, as described earlier, bend when force is applied, changing their resistance. Load cells are reliable and maintain their accuracy over time. The cost of load cells is variable, but the price may be as low as $7 (Sourcing Map 2011). In addition, load cells need to be attached to a fixed object. Most load cells come as a unit that contains the resistor portion and an attachment base (Figure 5).



(Figure 5). Load Cell which contains a resistor and attachment base (Sourcing Map 2011).

After talking with Dr. Thelen, a professor in biomechanics, it was suggested that a force sensor would be ideal for this project, specifically the FX1901 from Measurement Specialties (Figure 6). It takes advantage of piezoresistive silicon that varies the voltage output of the sensor as force is applied (Measurement 2011). These offer reliability, fast response time, and low cost. A drawback of piezoresistive force sensor is the shape. The sensors often have designs that are meant to have force applied to one very specific point. This design leads to a problem of distributing the entire force of the pinch over one point, which may be difficult to achieve with a large pinch pad.

Figure 6. FX1901 piezoresistive sensor, which contains a pinch pad in the center of the device. (http://www.meas-spec.com/force-sensors/force-sensor-elements.aspx)

Microcontroller

The microcontroller is control center of the pinch meter. The analog data from the sensor enters one of its pins and is converted to a digital signal. This is then entered into a calibration curve that will calculate the force being applied corresponding to the voltage input. The digital force quantity is then transmitted to an LCD display.

The first microcontroller investigated was the Arduino Uno ATmega328. Arduino is designed for artists or designers, and accessible for people with little to no programming experience. It uses its own programming language called Arduino programming language.

Pete Klomberg suggested the mbed microcontroller. These are more universal microcontrollers used for rapid prototyping. The mbed uses C++ as its programming language. This language is used widely and is easier with existing programming experience. This device is also available for immediate use.

To create a pinch meter from scratch there needs to be an LCD screen to display the resulting force and units. Any small and compact display would work well. It needs to be able to handle the mbed's output signal. Such a model would be a HD44780 lcd screen.

Housing

Within the Pinch Meter design, a housing container must be developed that will protect and enclose the circuit system components. Ideally we would like to have something that can open and close so that work can be done inside of it if needed. We also want the housing to be space efficient and small enough to be portable and hand-held. Three options were considered in this analysis.

The first is a design made in the 3D Printer located on UW Campus. To create this, a model must be made in Solid Works of the appropriate shaped housing container and sent to the 3D printer that will, in turn, print a plastic 3D model of the design. The printer is quite costly, approximately $2/cm^3. Additionally, once the model is printed, alterations cannot be made without doing manual work on it.

The second consideration was buying a PVC junction box in any hardware store. PVC junction boxes are designed for outdoor use and, therefore, have a very durable design. Modification of the junction box would be necessary to incorporate our electronic components.

The third design considered was a direct USB attachment from the force sensor and circuit to a computer. This would be very easy and cheap to create as we will not need an LCD screen to display the reading. The monitor on the computer will be used instead. We would also not have to buy or design any housing device. This design is disadvantageous, however, because the device would not be portable as the client desires and we also do not know of the availability of computers within the work environments.

Design Matrices

Design matrices were used to evaluate the design alternatives. The first design matrix compares different ideas for the circuit design. The second design matrix compares different housing options. Lastly the third design matrix compares the possible force sensor options. For all of these matrices the score can be between 1 and 5, with 5 being the best. All the matrices have a scaling factor that describes the importance of the category. The scaling is between 0 and 1, with 1 being the most important. The five categories compared were reliability, cost, ease of use, functionality, and accessibility.

The first category compared for all of the matrices was reliability. This means that the design will last for an extended period of time with very consistent data. Reliabilty was given a scoring factor of 1. This is important because our device needs to be able to last between 2-5 years, as the client specified. The device needs to be reliable so that comparing equal forces at different times has the same results.

Cost was the second category and was scaled at a factor of 1 for all matrices. This is an important factor because the final device needs to be under $100. In order to be competitive with other devices the cost of this design needs to be cheap. This will allow for this product to be successful and achieve the client’s goals.

Ease of assembly is a category that ranks the projects on how much labor is involved in production of the device. Given the limited amount of time, this is an important category because this helps determine the amount of time that will be needed to produce the design. This is also an indicator of how difficult the design will be. The circuit matrix this was given a scaling factor of 0.75. Since creating a circuit may be a timely process, this value was given because creating a circuit may be timely process. For the other two matrices it was given a factor of only 0.5 because they do not require extensive assembly.

Functionality is the fourth category, which is the components' ability to accomplish needed task. Functionality was given a scaling factor of one, but was excluded from the force sensor matrix because they all have the ability to measure force.

The last category is accessibility. This category represents how fast we can get the components implemented into our design. A few of the design ideas could be used immediately. In addition, testing on the component could be done to determine if it would work before purchasing anything. This was only given a scaling factor of 0.5. This factor was determined because having a component that fits the project perfectly is worth the wait.

Table 2. Design matrix for circuit designs.

Circuit Designs			
	Weight	Modified Scale	From Components
Reliability	1	4	4
Cost	1	2	5
Ease of Assembly	0.75	3	3
Functionality	1	2	5
Availability	0.5	5	5
Total		12.75	18.75

Table 3. Design matrix of force sensors.

Force Sensors				
	Weight	Force Sensitive Resistor	Load Cell	Piezoresistive Sensor
Reliability	1	1	5	5
Cost	1	5	5	3
Ease of Use	0.5	4	4	4
Accessibility	0.5	5	3	5
Total		10.5	13.5	12.5

Table 4. Design matrix of housing options.

Housing Options				
	Weight	3D Printer	Computer	PVC Box
Reliablitly	1	4	5	5
Cost	1	1	4	4
Ease of Assembly	0.5	5	2	2
Functionality	1	4	2	4
Availability	0.5	3	5	5
Total		13	15	16.5

Final Design

After analyzing the different options to produce this pinch meter, it was determined that assembly by components was the best option. This will give the product all of the functions needed. It was determined that using an inexpensive load cell and the mbed microcontroller with a custom housing unit, will lead to the best results.

The CZL635 micro load cell from Phidgets.com is a cheap and accurate sensor to measure the pinch. This sensor has a range of 0-5 kg, which is equal to about 11 pounds. This exceeds our clients criteria, and still provides accurate readings. The outgoing voltage decreases as force is applied to the load cell. The load cell is attached to a bent piece of metal that allows the strain gauges to be bent as force is applied (Figure 7). This sensor's zero force output is about 90 mV, but this needs to be amplified.

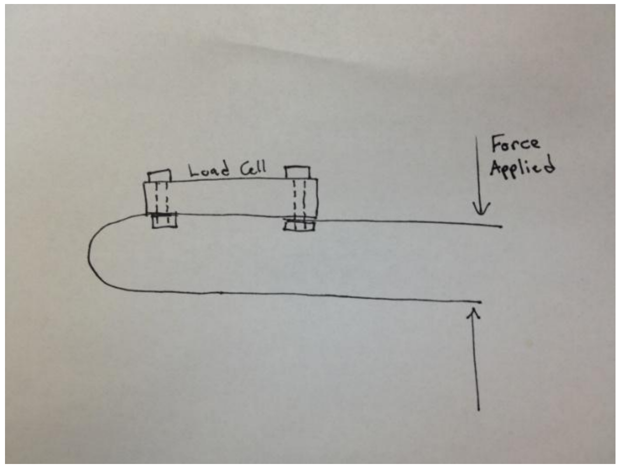


Figure 7. Drawing of micro load cell attached to metal pinch pad.

A differential amplifier is being used to amplify the signal. The resistance from each of the input wires is 1 kohms, and act as the two input resistors. The next pair of resistors are chosen in relationship to the input resistance to accomplish the desired amplification. A differential amplifier was chosen because of the multiple outputs from the voltage sensor. The operational amplifier for the voltage differential amplifier is the MCP6002. This op amp has low impedance and requires low power requirements. This amplifies the 90 mV signal from the sensor to about 3.3 V (Figure 8).

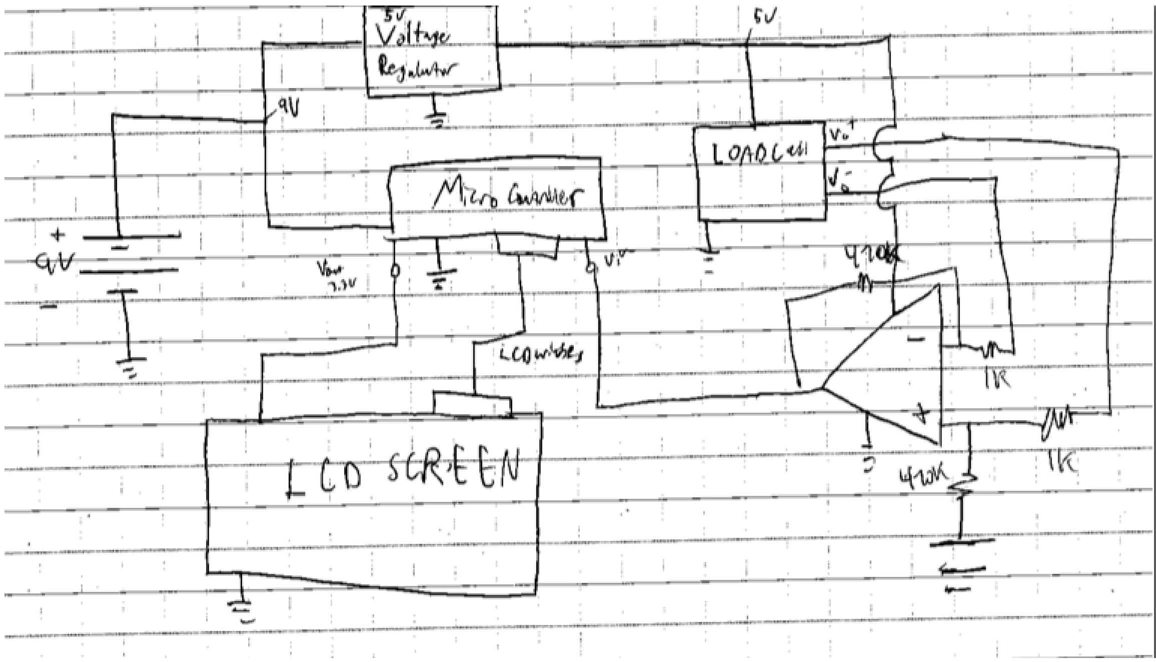


Figure 8. Flow diagram of circuit including differential amplifier, voltage regulator, LCD screen, microcontroller, and load cell.

The 3.3 V signal will enter the mbed microcontroller. The mbed microcontroller was deemed the best option because of its affordable price, immediate availability, and primarily because of its programming language and online support. The mbed microcontroller uses C++ programming language. When the signal enters the microcontroller it needs to be programmed to convert the voltage to a unit of pounds, as the client requested. To achieve this the mbed samples the input pin 10 times per second. It keeps track of the lowest voltage that enters the pin over a five second period, which corresponds to the maximum force applied. Once this period is over the minimum voltage is converted to pounds.

To accomplish this, the sensor was calibrated by hanging known weights from the sensor. From this testing, an equation was determined. This equation converts the voltage to a force and then the force output is displayed on an LCD screen. The LCD screen has specific programming code within C++ that will display the force output (code in Appendix). Each time a new trial is to be run, the device must be turned off and then on.

In addition, all of these electronic devices need a supply voltage from a battery. The sensor needs 5 V, the op amp needs 5 V, the microcontroller needs 9-5 V and the LCD screen needs 3.3 V. A 9 V battery will power all of these devices. The microcontroller is directly powered by the battery. The op amp and sensor are powered through a 5 V voltage regulator. The voltage regulator takes the voltage from the battery and constantly outputs 5 V. The LCD screen is powered by the microcontroller.

All of these components need to be incorporated into a housing unit. An ideal container has been drawn in Solidworks (Figure 9).This final housing unit was unobtainable with the time constraints of the semester. As an alternative a 4"x 4" x 4" PVC box was modified to place the components inside. The necessary holes were drilled, and the components were secured to the inside with screws and glue.

Figure 9. Image of an ideal housing produced using Solidworks.

Testing

Once a force sensor was constructed and working, the pinch meter needed to be calibrated to relate voltage and force applied. To do this, seven known weights were hung off the pinch meter at the same location. Each weight was tested three times and the voltage of each trial was recorded. Using an average value of the 3 trials, a plot (Figure 10) was created. From this, the equation that relates voltage to force applied was derived with an R value of 1. Also, it was found that the device has an accuracy of ±0.02 lbs.

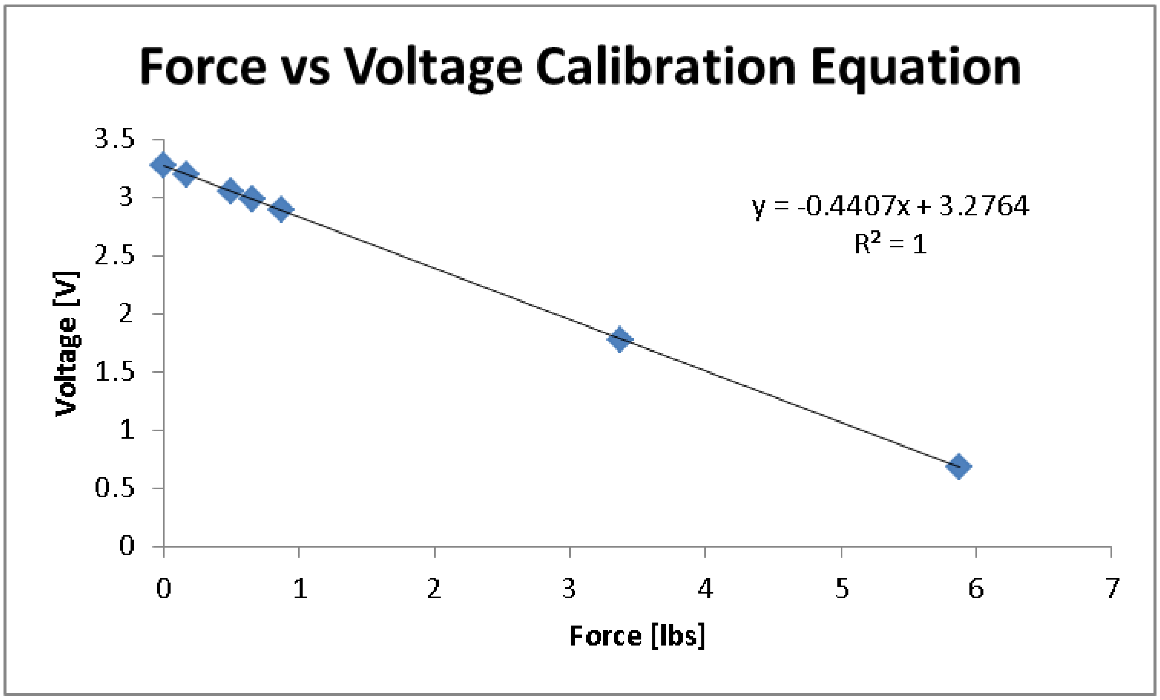


Figure 10: Calibration curve determined by averaging 3 trials at 7 different known weights.

Another test that was conducted determined the percent error of the force applied different locations on the pinch pad. To do this, a known weight was hung from 6 different locations on the pinch pad. Compared to the voltage output of the known weight hung from the center of the device, the output at the various locations varied only slightly. The device's percent error at different points on the pinch pad of the sensor was calculated to be 0.3%. Both the device accuracy and the percent error were well within the design criteria range.

Future Work

After completing our prototype, four activities must be completed. The first is testing the device in clinical trials. As of now, we have tested our device using known weights in order to achieve proper calibration, and we have tested the error of the device by applying known loads to different locations on the pinch pad. However, we have yet to test our device on rehabilitation patients. We must get an IRB to test our device in the clinical setting. In the clinical setting, our device should be compared to the rehabilitation centers current pinch force dynamometer.

Secondly, we should attempt to construct a housing for our device that is more aesthetically pleasing and more ergonomic. Our current housing serves its purpose to protect the sensitive electronics from damage, but the cube shape of the device makes it slightly difficult to hold.

Thirdly, the microcontroller draws a large current from the battery which limits the battery life of the device. A microchip can be created which would reduce the current of the device, increasing the battery life. This would also decrease the size of the electronic components within the device.

Finally, the team should be prepared to perform regular maintenance on the device to ensure that it functions correctly throughout its life. This maintenance may include, but is not limited to, retesting the calibration curve after several months of service, changing batteries, and assuring that the electronic components are secure within the housing.

Conclusion

There is a need for a more sensitive and affordable device to measure the force applied from a finger pinch of patients that suffer stroke repercussions. Our client requests a device that will provide small-increment measurements of force applications that will further improve the stroke rehabilitation process. The team has created a prototype that can accurately and reliably measure the pinch force of a stroke patient.

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Appendix A
Project Design Specifications
#42 – Pinch Meter Device
Team: Catharine Moran, Andrew Pierce, Myranda Schmitt, Michael Stitgen
Client: Elizabeth Bourne
Advisor: Professor John Webster

Function:

Our mission is to redesign a pinch meter device to be more precise, patient friendly, and practical for recovering stroke victims. Pinch meter devices are used to measure the hand strength of stroke patients which is an indication of their recovery progress.

Client Requirements:

- Ergonomical
- Effective
- Portable

Design Requirements:

1) Physical and Operational Characteristics
    a. Performance Requirements
        i. Handheld
        ii. Durable
        iii. Portable
        iv. Larger pinch pad compared to current device
        v. Battery Powered
    b. Safety
        i. No exposed wires
        ii. Comfortable pinch pad
        iii. No sharp edges
    c. Accuracy and Reliability
        i. Measures range 0-2.27 kg
        ii. Measures in 0.09 kg increments
    d. Life in Service
        i. 2-5 years
    e. Shelf Life
        i. Batteries must be replaced twice a year
    f. Operating Environment
        i. Rehabilitation Center's rooms
    g. Ergonomics
        i. Comfortable to pinch
        ii. Able to be held by technician
    h. Size

            i. Less than 10 cm x 10 cm x 15 cm
    i. Weight
        i. Less than 2.27 kg
    j. Materials
        i. No latex
        ii. Easily cleaned
        iii. Long lasting
    k. Aesthetics
        i. Pleasing to the eye
        ii. Smooth pinch pad
2) Production Characteristics
    a. Quantity
        i. One model
    b. Target Production Cost
        i. Under $100
3) Miscellaneous
    a. Standards and Specifications
        i. Must be tested to ensure patient comfort and product performance
    b. Customer
        i. Rehabilitation Centers
    c. Patient-related concerns
        i. Ease of use
    d. Competition
        i. Fabrication Enterprises
        ii. Hoggan Health Industries
        iii. Jamar

Code for mbed microcontroller

```
#include "mbed.h"
#include "TextLCD.h"
AnalogIn ain(p16);

TextLCD lcd(p23, p24, p25, p26, p27, p28); // rs, e, d4-d7

float forceConv(float mV){
   float force = ((-2.2691*(mV))+7.4345);
   return force;
   }

float round(float p){
   float f;
   int i;
   f = p * 100.0;
   i = f + .5;
   f = (float)i/100.0;
```

```
    return f;
    }

int main() {
        float percent;
        float voltage;

        lcd.printf("Apply Pressure \nin 3 Seconds");
        wait(3);
        lcd.cls();
        wait(.5);

        float minV = 3.3;

        for(int i= 0; i<50; i=i+1){ // can add a count down if statements
            lcd.cls();
            percent = ain.read();
            voltage = percent*3.3+.02;

            if(voltage < minV){
                minV = voltage;
            }

            char vOut[4]; //originally 16
            sprintf(vOut, "%f", voltage);
            lcd.printf("%s", vOut);
            wait(.1);
        }

       float pounds = forceConv(minV);
       float roundPounds = round(pounds);

        lcd.cls();
        char MaxC[4];
        sprintf(MaxC, "%f", roundPounds);

        lcd.printf("Maximum Force: \n%s lbs.", MaxC);
    }
```