Pinch Meter

Design of a Pinch Meter For Stroke Rehabilitation

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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 are exceptionally expensive 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 small increments of pinch forces applied to further assist Elizabeth Bourne in bettering the stroke patient rehabilitation procedure. Through our research, we were able to analyze methods of force measurement and compile the necessary components into our design to create a device with efficiency and accuracy.

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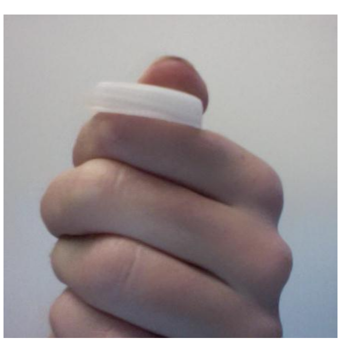
Background/Motivation

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).



. Two-finger

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 22.6kg, with accuracy within .5 kg ("Pinch Gauge" 2008). However, most recovering stroke victims can only provide a force of 2.26kg; 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 patients 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 22.68kg to 45.36kg, and measure in increments of .91kg ("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 2.27kg while the average pinch strength of a healthy individual is around 9.07kg (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 2.54cm 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.

Figure 5. Hoggan Health's Pinch and Grip Meter Design (www.hogganhealth.com)

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 4kg and the dimensions of the product cannot exceed 10 cm x 10 cm x 15cm. 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 2.26kg, increasing by .01kg. Including all of the components and necessary cost of production, the device should cost under $100.

Materials

Most of the materials currently being used were given for free. However the following table 1 outlines what the materials would cost.

Table 1. Project materials and their costs .

Device	**Cost**
Piezoresistive sensor (Thelen, 2011)	**$ 30.00**
Mbed microcontroller (Trossen 2006)	**$ 60.00**
Circuit (differential amplifier)	**$ 0**
3D Housing (plastic)	**$ 0**
Amplifier	**$ 0.30**
LCD Screen (liquid crystal display) (PG 2011)	**$ 7.00**
Power Source (batteries)	**$ 1.00**
Total Cost	**$98.30**

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 preexisting 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. However, since the device is not specifically doing anything to the patient, and instead the patient is doing something to it, no IRB approval is needed prior to production and clinical trials (Bourne 2011).

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 idea 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 resistive capability 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. Unfortunately, these are very expensive. In addition, load cells need to be attached to a fixed object. This fixed attachment might be hard to achieve with a portable handheld device.

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.

Figure 6. FX1901 piezoresistive sensor. (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 run through the UW and therefore, free to students. However, once the model is printed, alterations cannot be made without doing manual work on it.

The second consideration was buying a PVC box in any hardware store. This will cost slightly more than the 3D model, but we will also have the ability of choosing whatever style and size box the store has in stock to fit our needs.

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. This is very important to the design as indicated by the scaling factor of one. 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 .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 .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 .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	.75	3	3
Functionality	1	2	5
Availability	.5	5	5
Total		12.75	18.75

Table 3. Design matrix of force sensors.

Force Sensors				
	Weight	Force Resistive Sensor	Load Cell	Piezoresistive Sensor
Reliability	1	1	5	5
Cost	1	5	1	3
Ease of Use	.5	4	3	4
Accessibility	.5	5	2	5
Total		10.5	9.5	12.5

Table 4. Design matrix of housing options.

Housing Options				
	Weight	3D Printer	Computer	PVC Box
Reliability	1	4	5	5
Cost	1	5	5	3
Ease of Assembly	.5	5	3	2
Functionality	1	4	2	2
Availability	.5	4	1	5
Total		17.5	14	13.5

<u>Final Design</u>

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 Dr. Thelen's suggestion for the force sensor and the mbed microcontroller will lead to the best results.

The force sensor FX1901 is cheap and provides a good platform to take measurements. This force sensor allows for the patients to apply pressure directly to the sensor. This sensor's zero force output is 20mV, but this needs to be amplified. A series of voltage followers and a differential amplifier is being used to accomplish this. The voltage followers allow the differential amplifier to ignore the resistance before the voltage followers. The input resistance can then be chosen freely to acquire the desired gain of the circuit. A differential amplifier was chosen because of the multiple voltage sensor outputs. The operational amplifier for the voltage followers and the differential operational amplifier is the MCP6002. This amplifies the 20mV signal from the sensor to about 3V.

The 3V 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. 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 accomplish this, the sensor needs to be calibrated, from this an equation needs to be determined. This equation will convert the voltage to a force and then force output will be displayed on a LCD screen. The LCD screen has specific programming code within C++ that will display the force output.

In addition, all of these electronic devices need a supply voltage from a battery. The sensor needs 5V, the op amps need 6V, the microcontroller needs 9V and the LCD screen needs 5V. A 9V battery will power all of these devices.

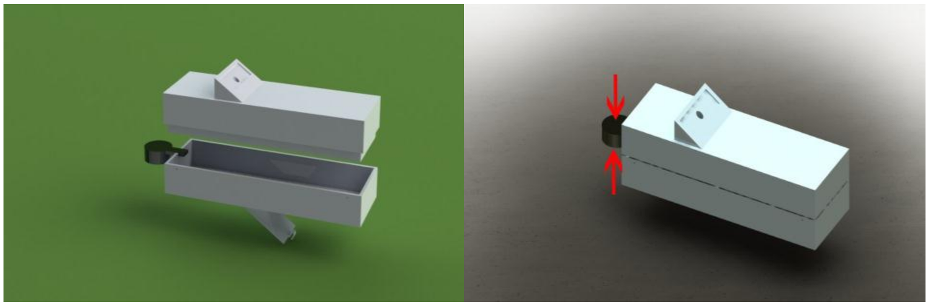


Figure 7. Images of the final housing design including the force sensor.

All of these components need to be incorporated into a housing unit(Figure 7). Drawings have been made in Solidworks to make models of ideal containers. Throughout the semester the models will change until the final sizes have been determined. When a final model is determined, it will be printed for free using a 3D printer.

Future Work

After making the decision that our design will include a piezoresistive force sensor, a 3D model print for the housing, a circuit built from individual components, and an MBed microcontroller, we need to acquire these materials via an online catalog. We are borrowing a force sensor right now for preliminary tests and analysis, so we need to have our own to actually start construction. Once the materials are obtained, the force sensor and circuit must be tested and calibrated. There are a number of ways to calibrate the system. A simple formula is usually used to convert the measured mv/V output from the load cell to the measured force:

We can use a postal scale to formulate the calibration curve by using known weights.

The most important part of our future work is the assembly of the device. Since we are borrowing right now, we will have to start assembly as soon as we obtain our materials. We will also need to test the device in its accuracy, capacity, sensitivity, and durability. To test its capacity, we will need to apply known forces and test the sensors ability to read the weight. We will most likely already have an idea of the capacity as it is typically displayed on the product so the testing may need to be simply a fine-tuned addition to the known capacity. In the sensitivity category, our device needs to be able to measure in increments of .09kg, so we will have to use a force of that quantity and make sure it reads accurately, gradually adding more increments of the same weight. For durability testing, we will need to be sure that all the wires and components stay intact and in the correct position even through moderately harsh environments (in case of accidental drops or bumping).

We will also need to write the program for the mbed microcontroller. This program will be written in C++ language. The program will incorporate our calibration curve to display the forces on our LCD display.

The final testing of our device will be completed in the clinical trials. In this testing, actual stroke patients will use the device to be sure that it is functioning properly and appropriately according to our client's requirements

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. A prototype will be fabricated for the client and tested in clinical trials with the stroke patients.

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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 0-2.27kg
        ii. Measures in 0.09kg 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 10cm x 10cm x 15cm
        i. Weight
                i. Less than 2.27kg
        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