Grip Meter

Mid- Semester Report

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Table of Contents

1.0 Introduction

1.1 Background

A stroke is caused by the disruption of blood flow to part of the brain, ultimately resulting in a loss of brain function [1]. There are several types of strokes: ischemic and hemorrhagic. An ischemic stroke consists of a blood clot formation, either within the brain or somewhere else, which then travels to the brain. A hemorrhagic stroke occurs when a blood vessel within the brain bursts and leaks into other parts of the brain. Both types have serious consequences that can result in a plethora of different effects, depending on the location of the stroke. The sufferer of a stroke may have trouble hearing and seeing, whereas another person may not be able to move their left arm; it all depends on the individual [1]. Signs of stroke can include a constant headache, change in hearing or vision, numbness and tingling on one side of the body, as well as many others [1].

This project's focus is on strokes that have affected the hand musculature and neuronal control and the subsequent rehabilitation related to them. One of the most common forms of testing improvements in this area is by utilizing a hand dynamometer. A hand dynamometer measures the grip force applied to it with a spring, hydraulic instruments, pneumatic instruments, or a strain gauge [2]. These devices can be made out of many different materials and have a variety of ranges of the force they measure.

1.2 Problem Statement

In order to rehabilitate patients who have recently suffered strokes, hand dynamometers are used to measure the strength of their grip. The goal of this project is to design a dynamometer that is relatively inexpensive and that can accurately measure grip strengths of much weaker magnitude.

1.3 Current Designs

Pictured in Figure 1 are two examples of hand dynamometers. The patient reaches his or her hand across the two bars and squeezes on the one furthest from them. This displacement in the outer bar is then read by the gauge at the top as the grip strength of the individual. It is common for these dynamometers to keep a record of the maximum grip strength of the patient.

There are two major problems with this design. The first is cost. The two dynamometers shown below are priced at \$330 for Figure 1.1 and \$325 for Figure 1.2, and it is not uncommon to see such devices going for \$500 or more. The second is accuracy-specifically, the accuracy of reading smaller values (below 20 pounds). The devices on the market now have trouble reading smaller forces with the same degree of accuracy as higher forces- this, needless to say, is a dilemma for weaker patients, such as serious stroke victims and elderly patients, who cannot deliver as much force.

Figure 1. Two commonly used hand dynamometers. Figure 1.1 shows the Jamar model, while Figure 1.2 shows the Baseline model. The Baseline model is slightly less expensive than the Jamar model. Figures from http://www.thehumansolution.com/jahady.html.

1.4 Motivation

Stroke is a leading cause of long-term disability and is the third leading cause of death in the United States [3]. As such, it impacts many people's lives. For the patients who have had the function of their hands affected or their whole arm, it is important to have a consistent, accurate device to measure improvements in grip strength. In the Orthopedics and Rehabilitation Department of the University of Wisconsin hospital, Elizabeth Bourne and the staff who work with her currently use hand dynamometers to test the grip strength of their rehabilitating stroke patients. They, and potentially many other stroke rehabilitation facilities, have the need for an updated and improved device to effectively aid the aforementioned patients.

An additional incentive is cost. Most of the current designs that would fit our client's requirements are several hundred dollars up to over a thousand dollars. An economic, relatively cheap design of a hand dynamometer would greatly benefit hospitals and other institutions that are short on funds.

2.0 Design Specifications and Client Requirements

The client had a number of specific requirements for the project, which are described in full detail below.

The device must be capable of measuring forces from 0-20 lbs in at least 1 lb increments. The device must be fitted with an LCD screen that will read out the exact maximum grip strength of the patient. It also must be able to be recalibrated if necessary. Materials used in the designing of the device must not include latex or sponge-like foam. Some patients may have allergies to latex, while foam is difficult to clean and has limited durability.

In addition to the above, the client presented a list of priorities ranging from highest priority to lowest. These are reflected in the design matrices. Her priorities are described further in the design matrices section. They include, in order of importance, functionality, reliability, durability, portability, and safety. The client noted that the aesthetics of the device is not important, as long as it is fully functional.

3.0 Design Alternatives

Our design process consists of two separate concepts. One set of ideas is devised to determine the best way to measure the force generated by a patient's grip, while the second is based on the identification of the best grip apparatus. Three alternatives are evaluated under the force measurement category: spring, extensometer, and strain gauge. Under the grip apparatus category, two options are included: squeeze ball and 2-Bar. All designs are described in full detail below.

3.1 Force Measurement

The force measurement alternatives are focused on how to measure the force generated by a patient's grip.

3.1.1 Spring

In the spring design, a patient pulls or pushes on a lever. This action causes a spring to extend. The displacement in the spring is used to calculate the force made by the patient. This design is similar to a spring scale and is simple to use.

3.1.2 Extensometer

An extensometer is a clip-like device. When the clips are pushed together, two bars are pushed apart. The distance between the two bars corresponds to a force. Extensometers measure small forces, are inexpensive, and very easy to use.

3.1.3 Strain Gauge

A strain gauge is a small, thin piece of metal foil. It is used to measure the strain in material it is adhered to by bending with the material. Because a strain gauge is so thin, it is correspondingly able to bend and form fit with the smallest strain applied to the material. Depending on the force of the strain, a voltage is created in the strain gauge. This voltage is electrically outputted to the user.

3.2 Grip Apparatus

The grip apparatus alternatives focus on the design of the grip a patient will employ when using the device.

3.2.1 Squeeze Ball

This design encloses the measurement apparatus in a ball. A patient squeezes the bar, like a stress ball. The force of the squeeze is then measured.

3.2.2 2-Bar

This design is similar to the current device. A patient pulls two bars together. One bar is curved to place the patient's hand in the same spot for every use.

4.0 Design Matrices

We generated two design matrices to evaluate the main design factors, force measurement and grip apparatus, separately. The matrices have identical categories. Category weights are assigned and distributed by our client according to her preference and opinions regarding the degrees of importance of the different categories.

The following categories were identified: functionality, reliability, durability, portability, and safety. Our client chose functionality and reliability as the most important part of the designs. It is important that the device be consistent and function accurately every time. The next most important category was durability. The device needs to be able to withstand cleaning after each use since it is to be used in a hospital. The device also needs to be portable. The least important category was safety. Although safety is an important component of any design, the safety of this project is very limited in scope. The design is only dangerous if the device contains latex, as some patients could be allergic. It should also be noted that appearance and aesthetics of the design is not important to the client.

4.1 Force Measurement Design Matrix

After rating each mechanism in each category a final score was tabulated. As shown in Table 1, the strain gauge was chosen for the force measurement. Functionality and reliability were the main factors that separated strain gauge from spring and extensometer. This was because a strain gauge already generates an electrical output of the force generated. In the spring and extensometer designs, we would have to generate this output ourselves, which could pose a problem and increase the difficulty of the design.

Table 1: Force Measurement Design Matrix. Design matrix comparing the possible alternatives of the measurement of force. Categories were selected and weighted by client.

	Spring	Extensometer	Strain Gauge
Functionality (30)	23	23	30
Reliability (30)	23	23	30
Durability (20)	18	5	15
Portability (15)	15	15	15
Safety (5)	5	5	5
Total (100)	84	71	95

4.2 Grip Apparatus Design Matrix

The grip apparatus was put through the same matrix, with the same categories. As shown in Table 2, the 2-bar design outperformed the squeeze ball. Again, functionality and reliability were the deciding factors. In the squeeze ball design, a ball of the proper hand dimensions for max grip is not big enough to encompass the whole hand. If the ball's size is increased, the palm of the hand is not used in the grip, which is not what our client wants. The 2-Bar design incorporates the whole hand in concert with the proper grip of a hand.

Table 2: Grip Apparatus Design Matrix. Design matrix comparing the possible alternatives of the different grip designs. Categories were selected and weighted by client.

	Squeeze Ball	2-Bar
Functionality (30)	20	30
Reliability (30)	20	30
Durability (20)	16	18
Portability (15)	15	15
Safety (5)	5	5
Total (100)	76	98

5.0 Final Design

The chosen final design combines the traditional, two bar grip of existing dynamometers with the efficiency and accuracy of strain gauges. The grip force can then be measured and output as an electrical signal. This eliminates the need to convert from a mechanical spring force or distance measurement to an electrical signal. The signal will be output to an external instrumentation unit that will house all of the electrical components including the LCD screen, battery, circuit elements, and buttons. The grip and instrumentation unit will be connected by a flexible, non-latex rubber wire cover. The entire product will have all electrical components sealed off so that it can be sanitized when needed.

5.1 Grip Apparatus

Existing dynamometer grip styles are ergonomic and allow for an accurate measurement of the users grip. The two bar system is the basis for this design. One bar is a straight, even surface, giving a solid platform for palm placement. The second bar is a straight section, with angled ends. This angling naturally forces the users hand towards the center of the device, ensuring accuracy and precision for every reading. The two bars would be connected at the top by a thin, durable metal bar onto which the strain gauges would be mounted.

5.2 Strain gauge

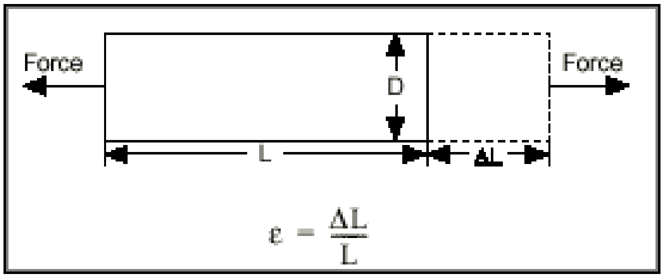

Figure 3: Definition of Strain (http://zone.ni.com/devzone/cda/tut/p/id/3642)

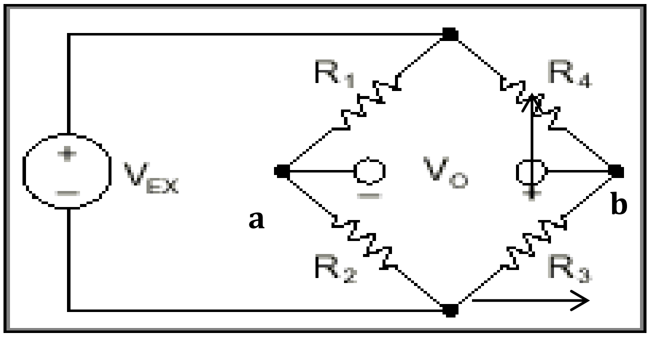

Figure 4: Wheatstone Bridge (http://zone.ni.com/devzone/cda/tut/p/id/10636)

Strain gauges are a multi-functional class of sensors that convert physical phenomena, such as tension, compression, or pressure, into readable electrical signals. As seen in Figure 3, strain (ε) is classified as the change in length (ΔL) divided by unstressed length (L) of an object. Different materials exhibit different strain characteristics, so it is important to choose the proper strain gauge to get an accurate reading. Strain gauges have two main properties: material they are made of and Gauge Factor (κ). As the strain in an object changes, the resistance of the attached strain gauge changes as well; this is measured as a change in output voltage. The change in voltage is measured using a special circuit known as a Wheatstone bridge (Figure 4). A specific type of Wheatstone bridge configuration is known as a half-bridge circuit. Resistors R_3 and R_4 are variable resistors, in this case strain gauges. R_1 and R_2 are known values. The resistance changes independently between the two branches of the circuit, and as a result, the output voltage (V_o) changes. To accurately measure strain while accounting for the induced bending moment, R_4 is bonded to the top surface of the metal connector and R_3 is bonded to the bottom surface.

5.2.1 Derivation of Strain (ε)

Change in resistance (ΔR) divided by the original resistance (R) is linearly related to strain by the gauge factor:

$$(1) \quad \frac{\Delta R}{\mathrm{R}} = \kappa * \varepsilon$$

Substituting in for ε and rearranging:

$$(2) \quad \kappa = \frac{\frac{\Delta R}{\mathrm{R}}}{\frac{\Delta \mathrm{L}}{\mathrm{L}}}$$

$$(3) \quad \Delta R = \kappa * \varepsilon * R$$

Using circuit analysis techniques, the voltage at nodes a (V_a) and b (V_b) can be found, as well as $V_{o.}$

$$(4) \quad Va = \frac{R2}{R1+R2} * Vin$$

$$(5) \quad Vb = \frac{R3}{R3+R4} * Vin$$

$$(6) \quad Vo = Vb - Va$$

In the half-bridge circuit, R_4 is assumed to be in tension, while R_3 is assumed to be in compression. R is taken as the pre-strain resistance of both strain gauges. $R_2 = R_1$ is assumed also. This gives:

$$(7) \quad R4 = R + \Delta R$$

$$(8) \quad R3 = R - \Delta R$$

Plugging V_a, V_b, $R_{4,}$ and R_3 into equation (6), dividing both sides by $V_{in,}$ and understanding V_b = ½ :

$$(9) \quad \frac{Vo}{Vin} = \frac{R-\Delta R}{(R - \Delta R)+(R + \Delta R)} - \frac{1}{2}$$

Substitute ΔR from equation (3) into equation (9):

$$(10) \quad \frac{Vo}{Vin} = \frac{R - R*\kappa*\varepsilon}{(R - R*\kappa*\varepsilon) + (R + R*\kappa*\varepsilon)} - \frac{1}{2}$$

Simplification of equation (10) gives an equation with the only unknown being strain (ε):

$$(11) \quad \frac{Vo}{Vin} = \frac{-\kappa*\varepsilon}{2}$$

5.2.2 Derivation of Force Treating the Metal Connector as a Spring

The force of a spring can be found using the simple equation:

$$(12) \qquad F = C * \Delta x$$

C is the spring constant for the metal connector (it is normally represented as K or K_s in practice but to avoid confusion with the gauge factor it has been labeled C). Δx is the displacement of the spring from the unloaded position. C, for a rigid body, can be modeled by:

$$(13) \qquad C = \frac{A*E}{Ls}$$

Where A is the cross-sectional area of the connector, E is a known material constant, and L_s is the length of the connector (Prof. Witt, Robert. Engineering Mechanics and Astronautics, UW –Madison). Once C is determined, equation (12) may be rearranged:

$$(14) \qquad \Delta x = \frac{F}{C}$$

Noticing that Δx = ΔL, since the bonded strain gauge is displaced along the connector, equation (14) may be substituted into the definition of strain:

$$(15) \qquad \varepsilon = \frac{\frac{F}{c}}{L} = \frac{F}{C*L}$$

Equation (15) may then be substituted into equation (11):

$$(16) \qquad \frac{Vo}{Vin} = \frac{-\kappa * \frac{F}{C*L}}{2}$$

Solving for F produces:

$$(17) \qquad F = -\frac{2*Vo*C*L}{\kappa*Vin}$$

This equation finds the force of the grip acting on the strain gauge, with the bending moment theoretically being accounted for by the circuitry.

5.3 Instrumentation Unit

The instrumentation unit is connected to the grip apparatus by a long flexible rubber wire cover as mentioned above. It is the center for all electrical components. Four lead wires (two for each strain gauge) are run from the housing to the grip through the wire cover. The rest of the half-bridge circuit is found inside of the unit. This external entity will hold the visible LED screen, power switch, battery, instrumentation amplifier, filter circuitry, buttons, and the microcontroller. It will be a sealed unit, allowing for proper sanitation.

5.4 Microcontroller

The brain of the instrumentation unit is the microcontroller. For this application, an mbed NXP LPC1768 with an ARM Cortex-M3 Core processor will be used [4]. This microcontroller allows sensitive, machine-level control, while providing a user-friendly online compiler complete with a wide variety of predefined libraries. C++ is the language utilized by the mbed software.

Since multiple different classes will be utilized to complete the wide variety of tasks, a new GripMeter class is in development that will control these components. The LCD screen, button response system, and analog voltage sensor readings will all be encapsulated by this class.

6.0 Future Work

The biggest focus will be placed on choosing and finalizing the grip apparatus' and the instrumentation shell's materials. This includes the two metal bars, specific strain gauges, plastic casing, and non-latex rubber wire cover. These parts require time consuming fabrication and need to be addressed first.

The design of the circuit is another important focus for the project. Almost all of the human interface components (such as buttons, LCD screen, and power switch) have been chosen, however the internal circuit still needs to be designed. The Wheatstone bridge will require an instrumentation amplifier to provide a more accurate reading. A basic high-frequency filter will be necessary to help eliminate signal noise and increase program speed. The circuit needs to be designed to deliver enough power to each component reliably, taking into account non-ideal components. Once the design is complete, the parts will need to be ordered.

Upon arrival of the grip apparatus materials, a long fabrication and assembly process will begin. Strain gauges are difficult to install, and great care must be taken during this phase of the project. The instrumentation housing can also be fabricated, however the microcontroller will need to be accessed during testing, so it will be the last part to be fully assembled.

During this whole process the software will be in development. Debugging and tuning of the program will be a large part of testing. In depth testing of the product will be necessary to ensure accuracy and precision through multiple uses. The zeroing capability will be tested, as well as the effect moderate temperature and humidity changes have on the readings.

7.0 References

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[2] Innes, Ev. "Handgrip Strength Testing: A Review of the Literature." Australian Occupational Therapy Journal 46.3 (1999): 120-40. Print.

[3] "Stroke Fact Sheet." Centers for Disease Control and Prevention. CDC, 29 Apr. 2011. Web. 20 Oct. 2011. <http://www.cdc.gov/dhdsp/data_statistics/fact_sheets/fs_stroke.htm>.

[4]"The Strain Gauge" Omega: One Stop Shop. Transactions: Volume 3. Web. 14 Oct. 2011 <http://www.omega.ca/literature/transactions/volume3/strain.html>

[5] "mbed Microcontroller" mbed.org, 19 Sept. 2011 <http://mbed.org/handbook/mbed-Microcontroller>

8.0 Appendix

8.1 PDS

Product Design Specification

Problem Statement

Stroke is one of the leading causes of adult disability in the United States. It is caused by the disturbance of blood supply to the brain leading to loss in brain functions. Stroke can lead a person to occupational disability, wherein the person is unable to perform the functions required to complete their daily functional tasks satisfactorily. In the Orthopedics and Rehabilitation Department at the UW hospitals nurses and doctors treat patients with physical, occupational and speech therapy. They assess the recovery of upper extremity function in stroke patients with occupational disability, using a grip meter or dynamometer. The grip meter measures the grip strength of an individual.

Current grip meters available in the market are expensive and do not allow measurement of forces due to grip from 0 to 20 lb with 1 lb increment, limiting the ability to measure small changes in very weak patients.

The project consists of designing an ergonomically suitable grip meter that will allow measurement of 1 lb force with a range from 0 to 20 lb and necessary calibration before use. The grip meter should also provide a digital readout of the force on an LCD screen.

Client Requirements:

- Must have at least 1 lb increments
- Must have a max grip read out on a LCD screen
- Must at least measure from 0 to 20 lbs
- Must have the ability to be recalibrated if necessary
- Must have no latex

Design Requirements:

1. Physical and Operational Characteristics

a. Performance Requirements

The grip meter must be able to display the max grip on an LCD screen. The device must be portable and hand-held.

b. Safety

The device must not contain any latex, as it is to be used in a hospital setting.

c. Accuracy and Reliability

Our design must at least have 1 lb increments and be able to read from a range of 0 to 20 lbs. It also must be able to be recalibrated to make sure it remains accurate in the future.

d. Life in Service / Shelf Life

The device is believed to be used around 5 to 10 times a month. The shelf life will depend on the circuits remaining intact and the strain gauge remaining plastic.

e. Operating Environment:

Our device would be used in a hospital setting, but could be used in any environment.

f. Ergonomics:

The device must be extremely user friendly. Anyone should easily be able to use the device.

g. Size:

The device should not be too cumbersome and not exceed a maximum length of one foot.

h. Weight:

The device must be lightweight so a patient recovering from a stroke will be able to lift and hold onto it.

i. Materials:

Exact materials are still being looked into to determine the most cost effective design.

j. Aesthetics, Appearance, and Finish:

Materials for the outside appearance are still being looked into and it should be noted that the appearance of the device is not important to the client.

2. Production Characteristics

a. Quantity: 1 deliverable.
b. Target Product Cost: Yet to be determined.

3. Miscellaneous

a. Standards and Specifications: N/A
b. Customer/Patient related concerns: N/A
c. Competition: There are other grip meters currently on the market. The ones typically used in a rehabilitation setting can cost around $500.

8.2 Preliminary Design Models

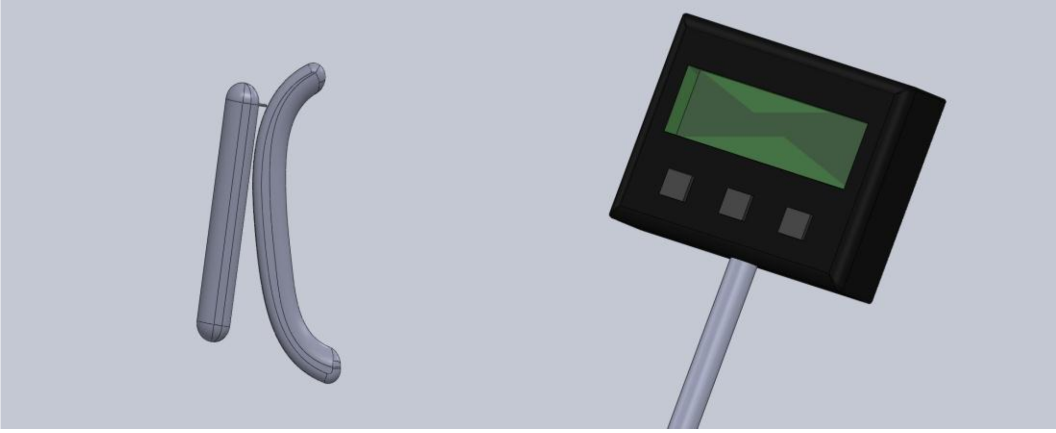

Figure 5: Initial grip and instrumentation design (Peter Guerin)