Hand Exerciser

Brian Ginter, Team Leader
Patrick Kurkiewicz, BWIG
Matt Hoffman, BSAC
David Leinweber, Communications

BME 201
Department of Biomedical Engineering
University of Wisconsin-Madison
March 11, 2008

Client: Dr. Alexander Yevzlin

Advisor: Professor John Webster Ph. D

Abstract

Everyday, people all over go through a process called dialysis, or filtering of the blood. This involves attaching two blood vessels in the arm to form a fistula. After dialysis is performed, there are sometimes issues regarding the fistula. In order to help the fistula mature, an ordinary stress ball is used to exercise the hand and promote blood flow. Our client has presented us with the task of creating a device to record data regarding a person's post surgery exercise regiment. He will then use that data to determine what is the ideal plan for a post dialysis patient.

Table of Contents **Page**

Abstract	**2**
Table of Contents	**3**
Problem Statement	**4**
Background Information	**4**
Current Devices	**5**
Design Constraints	**5**
Design 1	**6**
Design 2	**7**
Design 3	**8**
Design Matrix	**9**
Future Work	**12**
References	**12**
Appendix A: Project Design Specifications	**13**

Problem Statement

Our client Dr. Alex Yevzlin has proposed to us the assignment of making a stress ball like device capable of recording and transmitting data. The device will record how hard a patient squeezes, how long they squeeze for, and how many times they squeeze per day. This will be used so that Dr. Yevzlin can more accurately determine the ideal exercise regiment for post surgery patients. The device will be contained in an ordinary stress ball capable of exercising the hand after surgery. The device should be as low cost and user friendly as possible.

Background

Dr. Yevzlin works extensively in the field of dialysis. Dialysis is the process of filtering the blood, similar to what the kidneys do. When the kidneys no longer function properly, dialysis must be used to "clean" the blood of toxins. The process is accomplished by passing the blood across a semi permeable membrane. In order for this to work the blood must be flowing at high enough rates to pass the membrane.

Veins in the arm are incapable of supporting flow rates that high, so a surgeon must instead attach a vein to an artery in the arm to create an AV Fistula. This point of attachment ensures that flow rates stay high enough to ensure dialysis works properly. Two needles are then inserted into the fistula, one to remove unfiltered blood and another to recycle filtered blood back into the body.

After dialysis, issues often arise with the fistula. Sometimes the fistula will not take and blood flow to the hand can be cut off. To combat this, patients are asked to squeeze a stress ball as much as possible in the weeks after surgery. This helps the fistula to mature and helps to promote blood flow to the rest of the hand. While many times, the squeezing alone is enough to mature the fistula, little is known about the ideal conditions for maturation. Our client Dr. Yevzlin would like to commission a study to determine just that.

Current Devices

The only applicable device currently used is an ordinary stress ball. This is sufficient to exercise the hand but offers nothing to determine the ideal regiment for post surgery exercise. Our device will obviously incorporate a stress ball with internal workings added later. Other than that, current devices have little application to our device.

Design Constraints

Our design must follow the constraints given by our client, Doctor Yevzlin, who wanted a device that is self-contained, portable and durable. He stated the device must be durable enough to allow it to withstand 30-60 minutes of squeezing from the user each day, but soft enough so that an elderly person is able to squeeze it comfortably. Ideally, the device would cost around $10 to manufacture, although a microcomputer kit necessary to make the unit self-contained costs $150 alone. Dr. Yevzlin also requires that the material the unit is composed of should be safe for human use and should feel smooth and comfortable in the user's hand. He also required that the aesthetics of the device be user friendly and non-intimidating.

Design 1: Piezoelectric

Overview:

The piezoelectric design is composed of placing three piezoelectric sensors in the center of the stress ball. The three sensors must be placed orthogonal to each other. The reason for doing this is so that the device is able to sense pressure from any direction.. When experiencing external pressure, the piezoelectric sensor gives a voltage signal. This small voltage must be amplified by an Op Amp and processed by an analog to digital converter. This amplified digital signal could be transmitted to a computer, which is able to process the information and display it in graphical form. The program will operate by starting to record data after a set threshold is broken. After this threshold is broken, the program will record the number of peaks and height of the peaks of the graphs drawn by the program. By recording the height and number of the peaks the user would be able to see the record of many times they squeezed and how hard they squeezed.

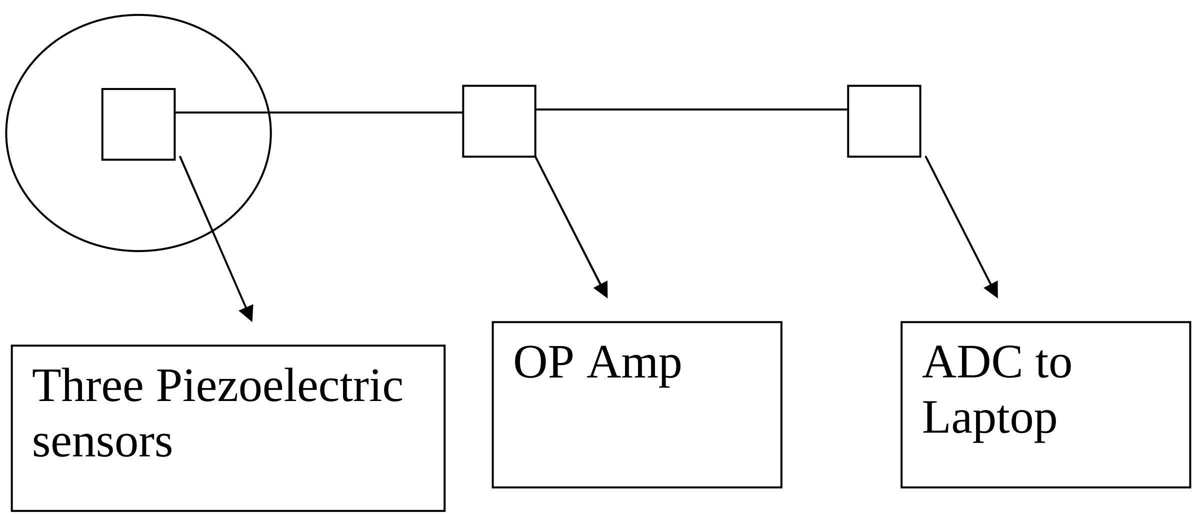


Figure 1: Piezoelectric sensors

Advantages:

The piezoelectric sensors are inexpensive, which is important for our client who wants manufacturing costs per unit to be less than $10. The sensor's price can be as low as $1.85 if buying in bulk (Jameco.com). The piezoelectric sensors also have linearity and are accurate, which benefits our client. The sensors are very durable and our able to withstand strong loadings and are unaffected by electromagnetic fields which could be present in the environment (piezocryst.com). The linearity of the sensors allows accurate readings at varying pressures because the voltage output and the pressure have a linear relation to each other.

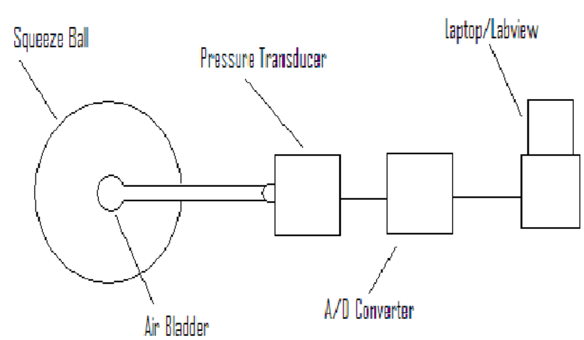
Cons:

Having three sensors, of dimensions 0.30 by 0.54 inches, inside the ball takes up a lot of room, which could pose a problem when trying to make the unit self-contained. (Jameco.com) Hand positioning from the user might also cause problems with directionality, which have not yet been tested by our team.

Design 2: Air Bladder

The second design that we considered involves the use of an air bladder. An air bladder is a thin, hollow piece of flexible plastic with a hollow marble-sized bulb on one end. The bulb end of the bladder would be inserted into the center of a squeeze ball with the tube end sticking out. The tube would be attached to a pressure transducer whose output voltage is a function of measured pressure. After

Figure 2



converting this analog voltage signal to a digital signal, we would compile and track the data with a laptop (and Labview) as in Design 1. A sketch of this system is shown in Figure 2.

The pressure transducer we selected for this system is light (50 grams) and compact. While we are not attempting to build a self contained model this semester, this particular pressure transducer would likely be feasible if/when we try to take that step.

There are several positive aspects to this design. The first and foremost is that it would provide accurate and reliable results. Because it is the same shape as the squeeze ball, the bladder would experience a consistent pressure increase regardless of which direction the patient squeezed it from. The pressure transducer has a response time of <5 ms, so it would be able to detect the change in pressure over time of an individual squeeze. The circuitry involved in this design would be very simple, as it doesn't require any additional circuit elements or complicated wiring.

This design also has a few drawbacks related to the pressure transducer. Even our compact and lightweight transducer is too large to fit inside of a squeeze ball, so any eventual self contained device would need a different shape or design. The transducer costs $60 – far above the $10 "ideal" that Dr. Yevzlin proposed. Also, testing needs to be done on the air bladder to insure that its capable of handling the pressure associated with a strong squeeze.

Design 3: Inductors

The third design considered involved the use of adjustable core inductors, and the

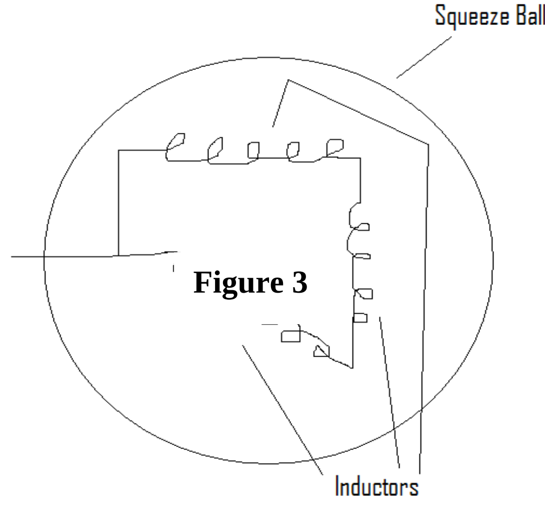


Figure 3

fact that the inductance of an inductor is a function of its length (among many other factors). In theory, it would be possible to arrange a system of inductors within a squeeze ball such that the length of the inductors would change with each squeeze, therefore changing the inductance. Additional circuitry could be designed to detect this change in inductance, and ultimately convert to a change in pressure.

This design does have one very good feature: inductors are inexpensive, and the entire design has the potential to be very cheap. Other than that, this design isn't a feasible solution to our problem, as it requires much more knowledge of circuitry and design than we possess. Designing a way to orient the inductors so that the directionality of the squeeze doesn't matter would be extremely hard, and likely impossible in one semester's time. While inductors work well in theory, they are difficult to actually implement into a circuit – especially when considering the size constraint presented by the squeeze ball. Reliably calculating the pressure applied to the ball from a change in inductance would be very hard. Overall, this design is a much less realistic possibility than the 2 designs mentioned previously.

Design Matrix

The three possible designs were rated in six different weighted categories: cost, accuracy, durability, ease of construction, ease of use, and size (below). These characteristics were weighted based on client demands. Dr.

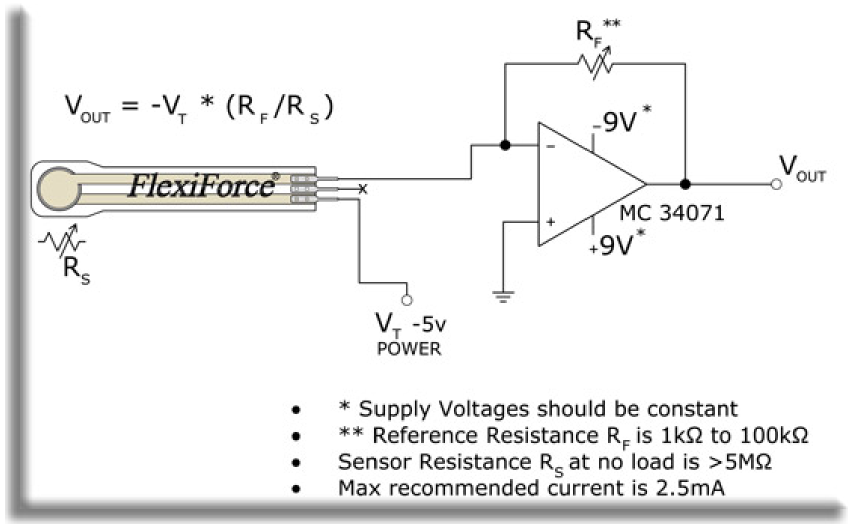
	Design 1 (Piezo)	Design 2 (Pressure)	Design 3 (Wire)
Cost (.20)	7	6	8
Accuracy (.05)	7	8	2
Durability (.20)	6	6	3
Ease of construction (.05)	8	7	6
Ease of Use (.25)	6	8	5
Size (.25)	6	5	6
Total	6.35	6.4	5.35

Alex Yevzlin requested that the device be self contained and cost under $10. While fulfilling both of these requirements seems impossible considering the cost of the parts needed, (microcomputers are over $100, according to Professor John Webster from UW-Madison) these properties are the most important to Dr. Yevzlin. This is why ease of use, size, and cost are all weighted heavily in the matrix. The reason that the device must be durable (.20) is that patients will be using a stress ball for long periods of time between hospital visits as their fistula matures. Ease of construction is not too important as long as something that works can be eventually built. The project will just have to be continued next semester if it ends up being too complex. Accuracy is also not of critical importance because all that is needed to be known about the patients' squeezes on the stress ball is the frequency and relative intensity. Because it is unlikely that the patient can consciously correct squeezes by fractions of a percent, the device will not have to have that level of precision.

The main reason that the air bladder design had the highest total in the matrix (6.4) is that there is not a directionality problem with having a pressure bulb in the middle of the silicon ball. It is also the most user friendly design because the patient can hold the ball at any orientation while squeezing. The only worries with this design are whether the IOPI bulb can withstand pressures upwards of 50 PSI and the cost of the pressure transducer. If three piezoelectric sensors were placed in the ball, the patient may have to orient the ball in a particular way while squeezing to ensure accurate readings. The inductive wire design posed a similar problem. It got the lowest score (5.35) because it has an additional complication that is not present in the other designs: durability. Inductors within the ball would have to remain at the same orientation and not deform in order to ensure accurate readings. In addition to this, the springs would have to be prevented from coming into contact with themselves or each other. All devices have a low score in the size category because none of them can operate as a closed system (a computer with LabView is needed at this point).

Circuitry

The circuitry of the force sensor design as well as the pressure sensor design relies on the same principles as in the figure seen below. When force is applied to a piezo force sensor, the resistance changes linearly and causes an increase in voltage. This can then be run through an op amp to get the correct intensity, which is connected to an analog to digital converter. LabView will be programmed to analyze this voltage in a useful way. The voltage pressure transducer works in a similar fashion only the amplifier is built into it. Otherwise, it gives a linear voltage output based on the amount of pressure exerted just like the piezo force sensor. The circuitry associated with Design 3 would be very complicated and difficult to implement, and it is for that reason that we haven't pursued that option..



Future Work

Now that the last of the parts have just come in, the next step is to talk to Dr. Yevzlin before construction is begun. Ideally, additional funds will be donated to the project so that it may eventually be self contained. Now, the goal is to build a proof of concept and run it off of LabView. The first design that will be built is the air bladder design. If this works well, there is no need to try any of the other designs. If the pressure design is unsuitable for the intended application, the force design will be attempted next. Other potential problems will be weeded out through experimental processes, and the design will be modified over and over until a final prototype is built. In upcoming semesters the design can be can be modified to be self contained.

References

"Piezoelectric Sensors." Piezocryst Advanced Sensorics GmbH. 5 Mar. 2008. <http://www.piezocryst.com/piezoelectric_sensors.php>. More Details

"Piezo Buzzer." Jameco Electronics. 5 Mar. 2008. <http://www.jameco.com/webapp/wcs/stores/servlet/ProductDisplay>. More Details

Appendix A: PDS

Team
Brian Ginter (Team Leader)
Patrick Kurkiewicz (BWIG)
David Leinweber (Communicator)
Matt Hoffman (BSAC)

Function

Develop a stress ball type hand exerciser capable of recording and transmitting data to be used in medical studies. The stress ball should be low cost and capable of exercising a hand post surgery.

Client Requirements

The device must be able to measure:

- Pressure (PSI) per squeeze
- Repetition of squeezes per time period
- Duration of time spent squeezing

Physical and Operational Characteristics

a. *Performance requirements*: The device will need to withstand 30 minutes to 60 minutes of squeezing every day. The device also needs to also be able to record pressure, number of, and duration of the squeezes, and be able to output the information.

b. *Safety:* The device should not be used in excess and the patient should follow their doctor's guidelines.

c. *Accuracy and Reliability*: The device should be within + or – 5% in order to give accurate enough readings for a doctor to see if the patient is showing improvement and completing exercises.

d. Life in Service: The device needs to be able to withstand 30-60 minutes of squeezing a day.

e. *Shelf Life*: N/A

f: *Operating Environment:* Needs to be able to withstand repeated loads and be able to withstand idle times of up to 24 hours.

g. *Ergonomics*: The device should feel comfortable in a person's hand while he or she is squeezing the device.

h. *Size:* The device should be portable.

i: *Weight:* Device should be of reasonable weight so that a person in questionable

j. *Materials:* All materials must be safe and non hazardous.

k. *Aesthetics, Appearance, and Finish:* The device will have to have a smooth surface that is comfortable to grip. The color of the device should also be black.

Production Characteristics

a. Ideally Dr. Yevzlin would like to make a ball that can be given to all fistula patients to monitor their usage. This would mean production in the thousands.
b. The target product cost including the cost of the ball and sensors is $100. While the ball does not need to be particularly affordable, the cost must be kept under control so that insurance companies agree to cover it. There aren't any products created specifically for this purpose, but there are contraptions that monitor and record pressure priced as low as $50 and as high as $1000.

Miscellaneous

a. *Standards and Specifications:* The FDA requires that all medical devices that fall under "electronic devices which emit radiation" be regulated. Electromedical devices and ranging/detection equipment fall under these requirements, and therefore our product may require FDA approval.
b. *Customer:* Our customer has indicated a preference for a self-contained device similar in appearance to the current squeeze-ball.
c. *Patient-related concerns*: We want patients to be able to use our device without focusing all of their attention on it. (i.e. a patient should be able to use our product while watching TV). It is unlikely that a patient would stick to a hand exerciser regimen that required them to set aside substantial time for its use.
d. *Competition*: A Google search for "instrumented hand exerciser" yielded a few interesting items. There are currently a few glove-shaped systems, used for physical therapy by post-stroke patients. No handheld products were found, and none for speeding the maturation of a fistula.