Final Report

Muscle Recorder

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Abstract:

The Biomedical Engineering (BME) Department of the University of Connecticut has requested a Muscle Recorder to be used in the program’s BME Measurements course. The device will allow the students to understand the mechanics of muscle contraction. It will record the Force-Velocity relationship as well as the Length-Tension relationship for a variety of muscles at different stimuli percentages. The Force-Velocity relationship should be able to record both the muscle’s lengthening (concentric contraction) as well as the shortening (eccentric contraction). Muscle Mechanics is the study of the energy and forces involved in muscle movements. Most devices used in other laboratories measure only the shortening of the muscle; therefore, this device is unique for it measures the lengthening of the muscle as well. The sponsor for our project Dr. Enderle, requested the building of this device as an incentive to encourage and promote BME students in the laboratory to improve their knowledge in muscle mechanics in conjunction with a computer software that will greatly help with the set up, recording and output of the experiment.

The entire device consists of a plastic enclosure containing a force sensor, weights, a lever arm, a saline reservoir and a saline pump. The muscle is attached to the lever by a fishing line; a tray that holds the weights is attached to the lever as well. In the back of the enclosure, there is the PCB board that houses the Hall Effect Sensor and voltage regulators. The bottom contains a saline reservoir, a pump and a vinyl tube pipe that sprays the muscle specimen with saline solution. With the help of National Instruments (NI) and the LabVIEW® software working together, the muscle will be stimulated through a pair of electrodes attached to the muscle, and the graphs showing the Force-Velocity (for both shortening and lengthening) and Length-Tension Relationships would be acquired and displayed after several trials for the experiment.

The muscle recorder is unique in the sense that the LabVIEW® software will control be providing the stimulation to the muscle instead of having an actual muscle stimulator; it will be timing the saline solution and, as stated before, it will also display the Force-Velocity for the lengthening of the muscle. Safety and environmental constraints are considered since this device uses an animal muscle in order to satisfy the requirements.
1. Introduction:

1.1 Background:

Dr. John D. Enderle is the Program Director & Professor for Biomedical Engineering at the University of Connecticut. He has been looking to incorporate a muscle response experiment in the Biomeasurements laboratory, a class designed for Biomedical Engineering undergraduates. Currently, undergraduate students in the Biomedical Engineering program perform experiments on frog muscles in the Physiology and Neurobiology class required by the program. Dr. Enderle would like to include a muscle experiment in the Biomeasurements Laboratory to ensure that the undergraduate students gain a deeper understanding of muscle performance by analyzing muscle responses using a LabVIEW® program.

1.2 Purpose of the project:

The University of Connecticut’s BME Dept. has requested a muscle recorder for use in the program’s Biomedical Engineering Measurements course. The device will allow the students to understand the mechanics of muscle contraction by recording the force-velocity and length-tension relationships for a variety of muscles. Moreover, the students will learn how the LabVIEW® program operates in conjunction with the experiment. There are some basic requirements that the muscle recorder should adhere to. The primary requirement for the device is to record the length-tension and force-velocity relationships for a variety of muscles. The muscle recorder should measure the tension and length of the muscle at various stimulation levels. The peak velocity will also be measured at different stimulation levels in addition to different loads for both shortening and lengthening of the muscles. A program should be written using the LabVIEW software in order to automate the recorder and display information from the data. The muscles primarily used will be skeletal muscles ranging from 5mm to 25cm in length. The device must be user friendly, portable, durable and safe; it should also be able to withstand load.

1.3 Previous Work Done by Others:

There are some products that stimulate muscles for different reasons. Some are used in laboratories in animal muscle in order to study reactions and cures, and some others are used in hospitals in order to help people that suffer from some disorders by stimulating some parts of muscles. A product
that produces the same type of results that our muscle recorder produces was not found. None of these products seem to use the LabVIEW® software to either stimulate the muscle or provide the relationships of the desired measurements.

**1.3.1 Products**

**ELECTRONIC MUSCLE/NEUROMUSCULAR STIMULATORS:** The Electronic Muscle/Neuromuscular Stimulators are used in diagnosis, evaluation and treatment of muscle dysfunction caused by peripheral and C.N.S. (Central Nervous System) disorder. They are also used for preventing or retarding disuse atrophy, relaxing muscle spasms and muscle re-education. The stimulators feature user replaceable electrodes and wires that are either water soaked or conductive rubber electrodes. Additional features include ring current adjustment, active probe positioning, on-off control and easy operation with hemiplegics. The unit may be operated with one hand. It weighs 8 ounces, and it is available to physicians and registered physical therapists only. [1].

**HIGH VOLTAGE ELECTRONIC GALVANIC STIMULATOR (MODEL EGS100-2S):** The High Voltage Electronic Galvanic Stimulator, model EGS100-2S, generates pulses from 1 to 120 per second at a voltage ranging from 0 to 500 volts to stimulate nerves, joints, and muscles in water. Features include 2 active, moistened 2 x 2 inch or 4 x 4 inch pads, one 8 x 10 inch dispersive pad, a hand applicator attachment, and a pulse rate and voltage intensity controls. POWER: Plug in AC current. Available in 220 volts, 50 or 60 cycles for foreign countries. DIMENSIONS: 16.75 x 11 3/8 x 8 5/8 inches. WEIGHT: 15.5 pounds. Manufacturer states this product is Underwriters' Laboratory (UL) and CSA listed. This device is restricted to sale by or on the order of a licensed physician or other practitioner by the law of the state in which the practitioner practices to use or order the use of the device. [2]

**1.3.2 Patent Search Results**

When searching in a patent database, no results for the term “muscle recorder” were found. Then a search under “muscle stimulation” and “electrical muscle stimulation” was conducted in [http://patents.cos.com/cgi-bin/result](http://patents.cos.com/cgi-bin/result) and [www.uspto.gov/patft/index.html](http://www.uspto.gov/patft/index.html), and the following related patents were found.
U.S Patent 4,595,010 by Radke, et al. An **electrical muscle stimulator** that simultaneously supplies a pulse (i.e., 270, 271) to each electrode (5, 6) having first and second phases (272, 273; 274, 275) which are a mirror image to the pulse supplied to the other electrode. A control is connected to unbalance either or both the width and amplitude of the first and second phases of each pulse to selectively provide an unbalanced stimulation to one or more muscles through the electrodes (5, 6). The stimulator provides a precise control which is readily adjustable for a large number of operating sequences.

U.S Patent 06865423 by Oldham, et al. An **electrical muscle stimulator** relies upon the application to the muscles of a patient of a stimulating signal which comprises a series of regularly spaced bursts of pulses. Each burst includes a first component as a first continuous train of regularly spaced pulses and a second component as a series of regularly spaced second trains of regularly spaced pulses. The second component is combined with the first component and the spacing between successive pulses in the second pulse trains is less than the spacing between successive pulses in the first pulse train. A third component as a series of regularly spaced third trains of regularly spaced pulses may be combined with the first and second components, the spacing between successive pulses in the third pulse train being less than the spacing between successive pulses in the second pulse trains.

U.S Patent 20050096711 by Adib, et al. A **muscle stimulator** uses methods and apparatus for stimulating the masticatory, shoulder, or back, and facial muscles. This is achieved by way of placing four output electrodes and at least one common electrode in the vicinity of the head, neck, and shoulder or back of a subject. In particular, two output electrodes are placed adjacent to the ears of the subject and two output electrodes are placed along the upper back of the subject. The at least one common transmitting electrode is placed on the back of the neck of the subject, generally just below the hairline. Stimulation of muscles/nerves in the vicinity of each output electrode is achieved substantially simultaneously by way of the current produced by the output electrodes.

U.S Patent 20070032750 by Oster, et al. A **Muscle Strength Assessment System** that determines patient's muscle strength of a lever arm comprising a leg, ankle, and foot. A value indicative of the strength is determined based on at least one eccentric
and concentric pressure values associated with the lever arm, as well as at least one weight based. The values may be entered remotely or locally to a computer that outputs the value indicative of the strength.

U.S Patent 20060105357 by Benesch, et al. **Tissue Sensor.** Described are assemblies for screening a compound for bioactivity, the assemblies comprising a tissue and a sensor. A change in a biological parameter is measured by the sensor, such that a change in a parameter occurring when the tissue is contacted with a candidate compound is detected by the sensor. Assemblies provided herein include single sensor/tissue assemblies and arrays of such assemblies, including plates comprising tissues in combination with one or more sensors. Also provided are methods of screening a compound using tissue/sensor tissue assemblies as described.

1.4: Map for the rest of the report:

In the remainder of the report, the first three design alternatives will be outlined; then, the optimal design will be discussed. After that, a description of the actual prototype is included. The prototype is also compared to the previous designs. In the project design, an explanation for selecting the prototype is included based on specifications and the realistic constraints for this specific device. The realistic constraints, covering economic, environmental, ethical, health and safety, manufacturability, and sustainability issues, will then be discussed. The constraints will be followed by the safety issues, the impact of engineering solutions, a description of life-long learning, and the budget. The contributions of each team member will be listed, followed by a conclusion of the final project, references and acknowledgements. An appendix may be included.

2. Project Design:

In this section, the design alternatives and their key features and weak points are discussed. Then, the optimal design will be explained in great detail through elaboration on the subunits. Diagrams of the previous and optimal designs are included. After that, the prototype is described. The operation
and testing of the muscle recorder with the gastronemious muscle of a frog is documented as well.

The prototype was chosen based on several concerns including, but not limited to, its safety of use and best possible performance. The prototype is safer since it is made of plastic, as opposed to metal, and it is an enclosure, as opposed to the arm and stand setup of previous designs. The saline solution will be contained in the enclosure, and electrical wires are not exposed. Moreover, the muscle recorder will perform its intended function, since it is directly connected to, and automated by, LabVIEW, and it includes all the necessary subunits such as the Hall Effect system, lever, and stimulator.

2.1 Design Alternatives:

2.1.1 Design One:

The first design suggested was a stepping stone in the progress of this group from a mediocre product idea to an innovative product design. Upon retrospect, this design was rather primitive, and did not offer much improvement over existing lab designs for similar purposes. Design one existed in an open space and was thus allowing the liquid solution to splash all over the lab environment. It allowed for a messy and disconcerting set-up for students, since it would force them to constantly work in a wet laboratory. Also, the first design did not have much originality to it when compared to existing set-ups for labs of similar purpose already here at the University of Connecticut. However, the first design was a place to improve from, and even the longest of journeys begins with a single step.
Design one had the Hall Effect sensor connected by wire to the muscle and the National Instruments box. Furthermore, there were two electrodes connected directly from the National Instruments equipment to the muscle; their purpose was to apply stimulation for contraction. The muscle was connected by hook to the stand set-up, and the free loading weight was connected by string to the muscle. Also, the stand, arm, and clamp set up were assembled completely out of steel. The design was poorly developed for the steel was completely vulnerable to rust.

It was thought that a metal stand was necessary to be used, because of the attractive attributes steel alloys possess. Steel is a sturdy item, in the sense that with the amount of mass and weights being added to it as loads, it would not deform. Also, steel can be made relatively cheaply and is available from a wide range of companies. Since it met constraints with what it was responsible for and agreed reasonably with budget, it was thought as the best approach to making the device. Upon further review, steel’s major fallibility of not being water-resistant deemed it inappropriate for use during this project.

The manner by which design one recorded length measurements was far from perfect. The method for determining force developed in design one for the muscle was a logical one. A force transducer was to be hooked up to the top of the muscle which would then report back to the computer the amount of force being generated.
by the muscle in contraction. This number could then be recorded and applied to a graph. The method described for determining the quantitative length value for the muscle in contraction was insufficient. Frequently, the muscle in question will be about 25 millimeters in length, and thus a meaningful number of significant digits would be two, with a tolerance of plus or minus half a millimeter. The method suggested for evaluating length was to have a ruler next to the muscle which would then allow the user to read off what distance the muscle covers at that moment. There are multiple flaws in this idea, chiefly, this overlooks the fact that the muscle’s length will be changing constantly! From the instant that a muscle length is observed compared to the time its value is recorded, it will have a different length. This also would cause a discrepancy between the readings of the force transducer and the time when the readings for the length are taken. In order to generate a meaningful graph, the moments when the values of length tension were recorded would have to match exactly. There should have been a holster for the ruler so that it would not be jittering or shaking in the palm of the operator, keeping the position of the ruler at rest. Furthermore, all the potential improvements on the ruler’s recordings are moot anyway since a ruler is too inaccurate a device for use on this project. The accuracy of the length measurement must give two reliable significant figures in order to be valid for the purpose of this experiment. A human reading the millimeter value off a cheap ruler would only give a value accurate to plus or minus 3 millimeters if the user does a good job of keeping it steady. The graduates for millimeters are very close together and difficult to read in a pressured environment where the user would be trying to keep up with the recordings of the force transducer. Clearly, this process would need revisions in future designs.

In order to stimulate the muscle in design 1, an artificial muscle stimulator was proposed to be purchased. The RellaMed EMS 500 Digital Electrical Muscle Stimulator was seen as suitable for the aims of this experiment. Of multiple available stimulators online, the RellaMed EMS 500 Digital Electrical Muscle Stimulator met requirements for reliability and budget. It offered a five year warranty, and was offered at a price of $69.00.

An integration system was deemed necessary in order to combine all the acquired data and read out the two graphical relationships sought after. LabVIEW was excellent for this purpose, since it can be programmed to organize data and represent it in a graphical form. LabVIEW is capable of
outputting graphs from a streaming data source, and that is the exact ability which should be harnessed here.

The first design allowed for use with different types of muscle tissue. There are three major types of muscle tissue in the human body. These are skeletal muscle, smooth muscle and cardiac muscle. Cardiac muscle is most unlike the other muscles in that it does not need an electric stimulus to contract. The other two muscles require electrical signal from a neuron to contract. Design one is applicable for these two types of muscle, smooth and skeletal.

The safety of design one was sub par for the set up. The electrodes of the stimulator were in an open environment, exposed to people and items that may be in their surrounding area. This was a possible source for electric shock. In case the leads became worn, or the rubber surrounding the wire becomes punctured, live current would be exposed to anyone around the set up, which can cause major harm if the person was to absorb the given current. Also, there was a possibility of pathogen contraction if the animal specimen was not properly handled. Furthermore, preservative chemicals would be added to the animal in order to keep it fresh and viable, and these must be handled accordingly. Upon completion of the experiment, these chemicals must be disposed of in a safe way in order not to infect the environment.

The life long learning underwent in this project was a sort of rude awakening for the group after doing design one. The main assignment that the group turned in was the project proposal which received an unsatisfactory grade. Our group was hopeful that the extra effort put in would result in a greater value for the grade we would receive. Unfortunately, we once again found ourselves with a failing grade. This led to a realization of the actual demand for work on this project. Over 10 hours per person weekly are necessary for the successful completion of a design on a brand new item. What we turned in on design one was more of a description, not an actual design. Upon retrospect, had the proper amount of hours been spent on not just using what we were already aware of, but investing time into actually designing something new and innovative, our performance would have been better, and the amount of work that was needed down the line for other alternative designs would have been less. However, our group ended up responding to this well.
2.1.2 Design Two:

The second design was an improvement over the first attempted project design. In order to improve upon the past effort, the second design was created keeping in mind errors made in the first design. The approach to this design was to review the old devise, making modifications suggested by our advisors Bill Preushner and Dr. John Enderle. Necessity is the mother of invention, and such is the case with the second alternative design project. The modifications in the second design were created with the aim of obtaining a better product than what was initially offered.

One main difficulty in the first design was that the device was more of a description of an existing product than an original planned out design. Because of this, we aimed to generate some type of unique creative system to separate our project from similar tests already existing. One problem we identified was that muscle freshness was dependent upon the user, and was thus a source for possible error or even loss of viability for the specimen being examined. Upon course of conducting the experiment, the specimen is removed from the saline bath and it is kept in once it is removed from the animal body. The muscle immediately starts to lose its freshness and vitality as an active body part. If the muscle was to dry out, then it would completely stop functioning and no longer be usable in the experiment being conducted. Thus, a saline spray must be applied by the student conducting the experiment so that the muscle will remain fresh and moist. However, this is where a student may foil their whole laboratory exercise. If the student does not apply the spray regularly because of a momentary lapse, then the muscle will die. Additionally, if the student applies the saline solution poorly, the muscle will again expire. Should the liquid not cover the entire surface area of the muscle, then it may become compromised and fail. If elimination of this possible source of laboratory failure was possible, then the experiment could be conducted in a better setting.

Seeing this as a possible realm for design improvement, we developed a system to automate the application of saline process. The method developed added a substantial amount of volume to the design setup. Originally, there was a steel stand housing the whole system. The stand, arm, and its extensions contained the Hall Effect sensor, muscle, free weights, and it was connected by wires to the National Instruments equipment software. In the new design, a second stand was added on the other side of the setup, in order to house the saline solution. The saline solution was to be kept in a squeeze bottle housed in a clamp which would be attached to a second metal stand. Since
the design of the second stand system existed, the positioning of the saline solution would be fixed as the joints between the subunits of the second stand would be rigid. Also, the clamp would be manually adjustable, but once it was in place, it would remain in a fixed position as well. Having the saline solution in a position where it was insured to aim directly at the muscle to moisten the entire surface area of the muscle was the aim. Not paying attention to when the muscle needs moistening was another problem to be solved in the second design. The way to avoid it would be to have a stopwatch running along with the experiment. The stopwatch would be a visual aid informing the student exactly how much time has passed since the last application of saline solution. If the stopwatch was further set to beep at every passing minute or so, there would be an auditory reminder that it was time to moisten the specimen again.

Steel is an excellent metal alloy. It is safe and sturdy, though it is relatively light in weight. Even though this is true, it is unfortunately prone to deformation overtime. This was mentioned in the last design description, but it was corrected in the making of this alternative design. The way steel deforms is upon a moist environment, it combines with oxygen to form the compound iron oxide, commonly referred to as rust. The major problem with rust is that it once begins to take place, it spreads throughout the entire object. In order to avoid this problem, in this case there are three alternatives suggested. One idea was to paint the whole steel surface, because as painted steel is not vulnerable to rust. A better but more expensive solution would be to galvanize the steel, which would protect it more from rusting since the coating would not eventually chip away as paint tends to. Finally, using aluminum instead of steel was suggested because aluminum oxide protects the incumbent aluminum and does not allow for any decay on the inside of the structure. Therefore, it would experience no deformation under moistening over time.

A third modification for the second design is the new method for applying muscle stimulus. In the previous design, the RellaMed 500 was the chosen device to deliver a current pulse to the muscle. The current pulse plays the role of a motor neuron, sending a current to a muscle in order to induce contractions from it. This function of pulse will now be served from the LabVIEW software. LabVIEW can be instructed to develop a current pulse of a specific strength, and then wired to send it out through an electric wire to an outside device. Since LabVIEW is the software already purchased and operated by those the students who will use the device, it is a much more cost effective approach than to go out and purchase some alternate
muscle stimulator. This method takes full advantage of the multiple facets LabVIEW can provide. This design analyzes better the risk of chemical preservatives used to keep the muscle fresh. The main solution used to preserve the muscle is the saline solution liquid. Saline solution is given a more detailed explanation in this section, as all its components are listed. In the solution, there is sodium chloride and water. This compound has a number of medical applications, as it can be used for washing contact lenses, or helping patients who cannot perform normal eating or drinking habits. The great advantage to using this simple saline solution is that since it is made of common chemicals that are prevalent everywhere in our environment, it will not contaminate anything upon its disposal from our laboratory. Once its use is completed, it can be simply tossed down the drain.

There was major group growth in the development of this second design. Our group first learned about the power of LabVIEW in that it is capable of working with our system in a myriad of ways. It is not just a program for organizing and compiling data, but is also a system for sending electrical signals to and from the computer. Utilizing that ability made it a much more powerful tool. More importantly, the group improved better the team work skills. Before, our group was considered dysfunctional and we were not cooperating as effectively as we could have been. But now, the product we produced was a result of the three of us constructing something together. We were in better communication with each other during the making of this design, and it resulted in a more successful paper to turn in. Our growth and progress was encouraging as it led to a feeling of capability. After receiving two bad grades, it was of utmost importance to show to ourselves that we could improve. By dedicating more time to this project, this was accomplished, and the result was satisfying.

2.1.3 Design Three:

Alternative design 3 had modifications that were not so noticeable in the setup of the design. There were crucial progressive modifications which were just as important as any tangible changes in previous alternatives. Alternative design 3 is still far from what our optimal design will be, which is unexpected at this point since changes from design to design up to this point have been major. Designs 1, 2, and 3 resemble each other visually. If one is to look at the diagrams of each of these designs, the similarity in the structure of the setup is consistent. Design 3 was the last design developed featuring a
metal stand, and is very similar to the structure of design 2. One form of modification made in design 3 is that dimensions and realistic constraints were added to the structure of the design. Up until this point, the designs existed with an idea of what sort of spacing and dimensions were going to be needed for and between objects, but this spacing and dimensions were never defined. It was assumed that the setup was going to be small, since the function it had was to hold in place a small muscle, and the set up needing to be no greater than 25 centimeters in height. The saline solution apparatus was known to be needed to be placed at a close distance to the muscle setup since a squirt bottle will only shoot out liquid in a small distance. Though there is reasonable logic behind these ideas, they are insufficient scientifically because they do not provide knowledge of the true location of something. If an attempt is going to be made to manufacture some type of product, then every distance must be measured to a specific number of significant figures. The quantitative value for the positioning of objects that are inter working together will indicate exactly where these objects are located, and allow us to manufacture them later on easily. This was deemed to be a reference for our own building later on, so as if we were ever curious where to place something, we could quickly refer to this as a blue print and take care of our own problems. The distances labeled on the diagram are figured to be extremely helpful later on since it would provide one less thing to worry about when we actually went ahead to build the device. Unfortunately, this material ended up not being as advantageous as previously hoped since the design was completely reformed in optimal design. Our group anticipated that alterations would be made and that distances would need to be recalculated and adjusted, but did not anticipate that basically all the expected values for structure were going to eventually changed. A well defined structure was supposed to be a foundation for other amendments made to the project, but the whole setup was deemed to be useless. In retrospect, reaching this stage of setup did teach us valuable lessons about positioning though. Critical thinking took place in how much distance an item will take up, which was a thought process previously not undergone by our group. When we sat down to determine where things were going to be placed, we had to take elements into account that we did not plan on. What this led to was constant adjustment and readjustment of exactly where something was placed. As an example, when determining how long the base for the secondary saline solution stand was needed to be, it would seem by inspection that it should be symmetric to the muscle stand which is across from it. Upon review by ourselves, we determined that it was wise to make it a little
shorter since it could serve its purpose from a distance without being as long as the base. The longer the base, the more sturdy the structure would need to be, which is a good attribute for something with multiple extensions and parts attached to it. However, in the case of the saline solution stand, it only has one real extension, the arm and then the clamp for the bottle. The base for this does not need to be as extensive, and reducing materials and size will make changes in the future quicker, easier, and most importantly, cheaper. The greater the volume of material needed, the more expensive the project is becoming. Various adjustments were made for various reasons throughout the third design.

Another modification in this project was the positioning of the Hall Effect sensor. Initially, the Hall Effect sensor was placed lofted in the air on the left side of the pole belonging to the stand set up. Upon review, this positioning was deemed unsatisfactory because of the problems it could potentially create. Our group wanted to make sure that the students of our setup were safe, and that we could minimize possible potential damage to the sensor. We realized that the original setup of where the Hall Effect sensor was failed to meet these two objectives. Furthermore, it would be difficult to place it on the top of the pole, since it would require some sort of attachment fixture to the pole. In order for the Hall Effect sensor to function properly in the above setup, it would have to remain stationary. Attaching the sensor appropriately in that desired spot would be an arduous task. The sensor would need more than a clamp to function properly, since a clamp is not reliable enough to make it remain still. A clamp could slip, a clamp could be adjusted by someone unknowingly just fooling around with it, and a multiple number of things could go wrong with that method of holding the sensor still. Therefore, some machinery would have to be involved in order to attach the sensor onto the pole, probably by the method of soldering. Moving the position of the sensor could potentially eliminate an extra amount of work, and the sensor should not be in that position due to other issues anyway. There was a safety hazard involved with the Hall Effect sensor in the case described above. The sensor is a live circuit with wires running into it, and the position in previous design lends it to be in a dangerous point because of how it could interfere with somebody handling the apparatus. Should someone attempt to load or adjust a muscle, the open circuit would be right there sitting next to their hands. It would be a laboratory technique error to toy with the placement of the muscle with the National Instruments interface operating, but it is an error which another user would be likely to eventually do. Therefore, in order to eliminate a
spot where something could go wrong in the laboratory, the sensor had to be moved. Also, the Hall Effect sensor is a delicate circuit, and must be treated as so. If students were repeatedly bumping their hands into the structure, then it would weaken over time. Again in this case, to do so would demonstrate poor lab technique by the user, but it is something that could happen and eliminating its possibility is a great idea. Upon review of these three threats posed, the positioning of the Hall Effect sensor had to be moved.

Putting the Hall Effect sensor on the bottom surface near the LabVIEW interface box solves all the potential problems listed above. Even though the Hall Effect sensor is an open circuit and thus exposes live wire, its hazardous nature can be reduced. This can be managed by placing the device out of a position where hands will traffic frequently. The best spot for this would be near the interface box. This is a surface which does not need adjustments the way the actual apparatus does. People’s hands will generally be moving the parts of the functioning system, not as much by the interface itself. The second problem of attaching the instrument to the pole is obviously eliminated by placing it on the bottom surface of the design. Simply having it lie on the bottom will be sufficient for what it needs to accomplish, and this is the simplest possible placement for the stand. The third error leak in the sensor placement is also alleviated by the modified sensor positioning. The sensor is not something which we want bumped into and subject to damage over time. Again by moving it out of a higher traffic area, it will come in contact with a human body much less.

2.2 Optimal Design:

2.2.1 Objective:

The muscle recorder is a device designed to record the Force-Velocity and Length-Tension Relationship for a variety of muscles at various stimuli percentages. The Force-Velocity should be able to record both shortening and lengthening contractions of the muscle. Most devices used in other laboratories measure only the shortening (concentric contraction) of the muscle, and this device will also be able to measure the lengthening (eccentric contraction) of the muscle. With the use of the LabVIEW® program, the graphs showing the Force-Velocity (for both shortening and lengthening) and Length-Tension Relationships should be acquired and displayed. This device will be implemented by the students in a Biomedical
The device to be designed needs to be durable and one that it is easy to carry around because it will not be a stationary device. It will be an acrylic enclosure consisting of a lever arm attached to the enclosure’s wall, it has two shelves, and a pump reservoir. The muscle is attached to the lever by nylon, and the brass weights are attached to the lever as well. The Hall Effect system, the the pump, and the force transducer are electronically connected to the PCB board directly parallel to the lever arm. The reservoir made out of the same acrylic as the enclosure houses the saline solution pump which sprays the muscle. An electrode will stimulate the muscle with a current pulse provided by a LabVIEW® program. The setup will be connected to the National Instrument’s equipment and a computer with LabVIEW® software.

The optimal design for this semester features many more modifications than expected from last semester. The optimal design had a brand new system setup radically different from its predecessors. The material to be used for the muscle recorder enclosure was changed from plastic to acrylic, the dimensions were also modified, as well as the reservoir and its placement within the enclosure. Also, a brand new saline spray system was introduced to the project in this stage. The pump was adjusted from an AC pump to a DC pump in order to provide a more professional look in our project. A new force transducer was purchased, and many modifications in the LabVIEW® program were implemented. These are the multiple creative innovations invoked on our optimal design. A diagram of the setup is shown below:
2.2.2 Subunits:

2.2.2.1 Plastic casing

The reason for the plastic casing is the modification which we made on the original design. One issue that was found in the project all along was that it was considered a remake of previous existing works, and did not involve many innovative processes to make it a true creative design. A description is well different from a design, and up until this point our project was not distinguishable from anything else done in the past. What defines our project now is the enclosure of all the subunits involved in it. An innovation we developed is to house a muscle stimulator in a containment dome, and it qualifies our project as a brand new design, something we came together and made. A device that had not existed in any way, shape, or form. Beyond just housing all the equipment that is supposed to be in the structure, the containment plastic box acts as a spatter shield. Saline solution will splash a little bit as it is applied to the muscle. In previous muscle stimulation labs, it simply would get moisture all over the place, making for a messy lab environment. This casing is an innovative way of keeping the work station clean, and not allowing for a wet lab surface.

We choose plexiglass which is the brand name for acrylic or PMMA (polymethylmethacrylate). The thickness of the plexiglass is \(\frac{1}{4}\) inch (0.635 cm). This product is an excellent choice for signage, security, or any other project requiring holes. This acrylic is a very versatile material having great impact strength yet light weight (it is less than half as heavy as glass: it is 43% as heavy as aluminum and 70% as heavy as magnesium). Sheets have from 6 to 17 times greater impact resistance than ordinary glass in thicknesses of .125" (0.317 cm) to .250" (0.635 cm). When subjected to blows beyond its resistance, acrylic sheet reduces the hazard of injury because it breaks into large relatively dull edged pieces which disperse at low velocity, due to the light weight of the material. It is easy to work with, can be sawed, drilled, glued, painted, formed, and machined like wood or soft metals. Besides, as our project demands, it is resistant to corrosion and to most chemicals. This acrylic can be easily attached to other surfaces using round head wood screws, round head bolts, sheet metal screws, oval head screws or bolts used in conjunction with finishing washers, and threaded rod used with cap nuts. Flat head screws, bolts and other fasteners which require countersinking should not be used, because a countersunk hole is almost the same as a notch and a potential fracture point. Holes
for fasteners should be drilled oversized to allow for thermal movement of it. The size of the ordered piece of plexiglass is 4ft x 8ft x ¼ in. (1.219 m x 2.438 m x .635 cm) which was ordered from Central Stores. This big piece was cut in with the panel saw in the machine shop. The following dimensions 8in x 12in x 24in (20cm x 30cm x 60 cm) make up the muscle recorder enclosure. The edges were filed for an even finish. The pieces were glued together using Dichloromethane. This chemical acts as a solvent burning the acrylic edges and gluing them together. Plexiglass is easy to drill but it needs to be done slowly because if done too quickly, or if it is not well supported it might split or crack around the hole. Doors were cut as two pieces of plexiglass measuring 6 in x 24 in (15cm x 60cm). This measure was implemented to reduce the stress on the sides of the box. The doors will are attached in the sides by hinges and screws.
**Shelves:**

As it turned out, there were 3 different shelves which were added to the box setup. The first shelf is to provide a stand for the Hall Effect sensor. The second shelf was to provide housing for the force transducer to rest upon. The third shelf was to provide shielding for the Hall Effect sensor and PCB board. Notice in particular about this shelf that it has holes punched along the side of it. This was done in order to allow for insertion locations of fishing line to connect the muscle to the lever and to the box structure. Shown on the right side of the diagram is fishing line hooked into the box. This was provided as an illustration of how effective this method can be in order to attach anything we want to any location which we find most advantageous for whatever various purpose. If it is decided that the more left the muscle is attached the better it is, then the fishing line can be hooked through a hole on the left side of the flatboard.
Hinges:

The hinge is single-handedly responsible for the holding up of the door which could be a relatively heavy device. A hinge is small, and responsible for holding much weight in comparison with its small size. Because of this, the single door was split into two separate doors, each hinged on opposite sides of the box. The force that was initially going to be placed on each hinge was now divided by 2, giving for less strain placed on each hinge. To further reduce the strain, we added multiple hinges to each side of the door. A total of 6 hinges were used to make the total strain on each hinge multiplied by a factor of one-sixth. This added to the overall durability of the device. The hinges we used were of the style below. We folded them and screwed them in with the assistance of members of the machine shop.

2.2.2.2 Lever Arm

A stainless steel hollow rod was chosen to be the material required to build the lever arm of the design. It was found after the team search for it in a hospital’s orthopedic center, in websites, and in the machine shop of the university. There were different types of rods found in the machine shop. The best option for the lever arm was the tube with the smallest diameter in order to reduce the mass. There is a drilled hole though the rod for a pin placement to be attached to the enclosure. The pin
will connect to the wall of the enclosure acting as a fulcrum for free rotation of the lever.

The magnet was placed on the lever, and the Hall Effect sensor is placed parallel to the lever onto an arm attached to the enclosure’s wall.

The brass weights will be hanging in the left side of the lever arm, and the muscle will be hanging in the far right side of the lever.

The brass weights will be hanging in the left side of the lever arm, and the muscle will be hanging in the far right side of the lever.
The steps to build the lever arm were:

- Measurements of the lever arm design
- Easy technique to build the pin to hold the lever arm
- Obtained a long piece or steel rod and then was cut to one and a half inch (1 ½ ”) (3.81cm)
- Obtained 2 bolts that measured two inches (2”) (5.08cm)
- Inserting the piece of rod through the drilled lever hole
- Placing the rod on top of the two bolts that were held in place in a clamp
- The rod and the bolts were welded together using propane fuel to form a one solid piece
- The hole in the lever is slightly bigger than the rod to prevent any friction affecting the lever arm
- Gorilla glue was used to bond the magnet to the lever arm
- Cut a small piece of plexiglass to function as an arm or platform where the sensor will be placed
• Distance between the magnet and the sensor should not be more than two centimeters (2cm)

• Small spacer (cut in half) can be placed around the lever to prevent motion from side to side during testing

• Holes 1 ½” (3.81cm) apart were drilled in the enclosure’s wall to insert the bolts which were tightened by nuts inside and outside of the enclosure

The lever features an excellent ability to rotate in place. What in place refers to in this case, is not every point along the lever as that would be a physical impossibility. Rather, the lever rotates about a single point which is on the fulcrum of the device. If this were an idealized math problem, any challenges with the lever would have just been met and satisfied. Unfortunately, this is a real world 3-D engineering project, and therefore, more problems exist which we would have to deal with high as the lever can go to as low as the lever can go, and we want the lever to rotate as such. The y-direction motion of the lever rotates about the fulcrum, and stretches from as high a motion. Additionally, if the points that the end of the lever forms as it goes along an orbital path about the fulcrum were to be examined, it would be observed that it forms a circle. The x-direction is thus also defined from the same rotation since the radius squares, which is the longer length from the fulcrum to the end of the lever squared, equals the sum of the squares of the change in position of the x and y coordinates of the end of the lever. Basically, if r is the radius which can also be considered lever length, then

\[ x_2 + y_2 = r \]

This equation implies that the rotation of the lever in the x-y plane is one we can calculate and ultimately utilize in pursuit of a graph for this operation. However, it does not imply anything about motion of the lever in the z-direction. What this implies, which is true, is that motion in the z direction of the lever is disruptive to the entire project. Therefore, we had to place something to hold the lever in a constant position in the y-z and x-z planes. Because of this, we engineered two stops in place in that direction and those are left observable on the fulcrum.
2.2.2.3 Force Transducer

The Economy Force Sensor, part number CI-6746 purchased from pasco.com, is an excellent, low-cost, general-purpose force sensor for the student lab. It has an output between -8 volts and +8 volts and a range between -50 N and +50 N. In other words, it produces -8 volts for -50 N, 0 volts for “zero” force and +8 volts for +50 N. The sensor has strain gauges mounted on a specially designed “S-bend beam”. The beam has built-in over-limit protection so it will not be damaged if a force greater than 50 N is applied. Below is a picture of the force sensor:
## Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
</table>
| Output voltage                | +8 V for +50 newtons (pushing)  
-8 V for -50 newtons (pulling) |
| Output noise                  | ±2 millivolts |
| Force slew rate               | 30 newtons/millisecond |
| Bandwidth limit               | 2 kilohertz  
(internal low pass filter) |
| Output drive                  | 12 meters of cable without instability. |
| Beam deflection               | 0.28 mm |

### Resolution

0.03 N or 3.1 grams

### Zero (Tare) Function

push button

### Force-overload Protection

mechanical stop prevents forces of more than 50 N from damaging the sensor

### Pin Configuration

8-pin DIN plug

### Support Rods

mounts on standard 12.4 mm support rods
The force sensor reads the force that the muscle is exerting, and then it sends the reading to LabView through connections to the PCB board. In order to connect it to the PCB board, an 8 pin female socket was purchased. Listed below are its specifications:

<table>
<thead>
<tr>
<th>PIN</th>
<th>SIGNAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ANALOG INPUT (+), ± 10 V MAX</td>
</tr>
<tr>
<td>2</td>
<td>ANALOG INPUT (-), ± 10 V MAX</td>
</tr>
<tr>
<td>3</td>
<td>N/C (gain switch in 6500 Interface)</td>
</tr>
<tr>
<td>4</td>
<td>+5 V, 100 mA total</td>
</tr>
<tr>
<td>5</td>
<td>POWER GROUND</td>
</tr>
<tr>
<td>6</td>
<td>+12 V POWER 50 mA total</td>
</tr>
<tr>
<td>7</td>
<td>-12 V POWER 50 mA total</td>
</tr>
<tr>
<td>8</td>
<td>ANALOG OUTPUT (700 and 750)</td>
</tr>
</tbody>
</table>
An integral piece of the device is the force transducer. A transducer is a tool that converts one type of energy to another for various purposes including measurement or information transfer, it takes the analog reading of how much force is produced and translates it into digital code which is then readable by a computer. The LabVIEW® software is capable to acquire signals that will be provided via the User Interface. This acquisition can then be stored and read; in addition it can then be exported and used in Microsoft Excel. If a student were assigned to do this part of the task, it can easily comply with the existing materials. In reality students will need to use the device in a laboratory of one of a required course in the Biomedical Engineering department. Students will need to set up the experiment, record data, and write a program that would take the data with inputs and outputs like force, velocity, length, tension, shortening and lengthening aiming to make it work and obtain graphs of the force-velocity and length-tension relationships. Direct measurement of displacement arises in studying the contractility of isolated muscle and it can be done as a means of transducing a physical quality into electrical signals.

Force is defined through the equation $F = M \times A$. As a result it depends on two quantities: mass, which is a fundamental quantity; and acceleration, which is derived from two other fundamental quantities, length and time. The unit of the force is the Newton which is the force required to accelerate a mass of 1 kg by 1 m/sec^2. Since the earth’s gravitational acceleration is essentially constant with time and varies in a known manner with location and height, it provides an excellent means whereby known masses can be used to create an accurately calculable force. The static calibration of force transducers is usually carried out in this way. A means by which a force can be measured can be by balancing the unknown force against the gravitational force of a standard mass. Isometric conditions are achieved if the maximum displacement of the transducer is sufficiently small for it to have no significant effect on the force produced.

When external forces are applied to a stationary object, stress and strain are the result. Stress is defined as the object's internal resisting forces, and strain is defined as the displacement and deformation that occur. More specifically, strain is defined as the fractional change in length. For a uniform distribution of internal resisting forces, stress can be calculated by dividing the force applied by the unit area, and strain is defined as the amount of deformation per unit length of an object when a load is applied. Strain is calculated by dividing the total deformation of the original length by the...
original length. While there are several methods of measuring strain, the most common is with a strain gauge, a device whose electrical resistance varies in proportion to the amount of strain in the device. There are several methods of measuring strain, and the most common is with a strain gauge, a device whose electrical resistance varies in proportion to the amount of strain in the device.

Mass x Acceleration. The two quantities: mass which is a fundamental quantity; and acceleration which is defined from length and time. Measurement of isolated muscle under isometric conditions can be made by attaching one end of the muscle to a force transducer and the other end to a fixed frame of reference. Isometric conditions are achieved if the maximum displacement of the transducer is sufficiently small for it to have no significant effect on the force produced.

There are several methods of measuring strain, and the most common is with a strain gauge, a device whose electrical resistance varies in proportion to the amount of strain in the device. The most widely used gauge is the bonded metallic strain gauge. The metallic strain gauge consists of a very fine wire or, more commonly, metallic foil arranged in a grid pattern. The grid pattern maximizes the amount of metallic wire or foil subject to strain in the parallel direction. The cross sectional area of the grid is minimized to reduce the effect of shear strain and Poisson Strain. The grid is bonded to a thin backing, called the carrier, which is attached directly to the test specimen.

### 2.2.2.4 Hall Effect Sensor

This entire project is contingent upon an accurate measurement of the displacement of the muscle. In order to generate graphs of length versus tension, the length must be recorded. In order to know the value of the velocity of the muscle, its length must also be a quantized value. This means that the measurement device for the length of the muscle must be a reliable accurate tool. A Hall Effect sensor has the ability to sense displacement of something which it is tied to. Hall Effect is defined as the development of a voltage between the two edges of a current carrying conductor whose faces are perpendicular to a magnetic field, and a Hall Effect Sensor is a device that converts the energy stored in a magnetic field to an electrical signal by means of the Hall Effect. The Hall Effect principle states that when a current-carrying conductor is placed into a magnetic field, a voltage will be generated
perpendicular to both the current and the field. The read out of the device is a voltage, and this voltage corresponds to a specific length. The voltage must be transformed to its corresponding length, and then uploaded into the computer. The Hall Effect sensor will be connected to a circuit whose output voltage is connected to the connector block and to the computer by means of stripped end wires. The Hall Effect sensor we ordered is from Newark.com. It has the following features and specifications

A hall voltage cannot be measured in the absence of a magnetic field; the output in that case will be zero. A common mode voltage will be observed if the voltage at the terminals is measured with respect to ground. Since the voltage itself is low, it needs to be amplified. Moreover, large magnetic fields do not damage the Hall Effect sensor. The Hall Sensor device has four terminals, and it produces a voltage output. Its voltage is relative to the current, magnetic field, and the angle.

**Description**

- Hall Effect Magnetic Sensor
- Supply Voltage Max: 24VDC
- Supply Voltage Min: 3.8VDC
- Supply Current Max: 15mA
- Operate Point Max: 40G
- Release Point Min: -40G
- Sensor Terminals: Through Hole
- Mounting Type: Through Hole RoHS Compliant: Yes
2.2.2.5 Pump

The pump is a DC pump that is going to be used to spray the muscle with saline solution. It is a 12 volt DC pump that has a long life brushless motor that is ideal for continuous duty applications in addition to a durable magnetic rotor and ceramic shaft. It has low power consumption that is compatible with solar power supply and requires low or no maintenance. It can be installed at an incline or submersed in the liquid solution. A picture and the specifications of the DC pump are included below.

Specifications

<table>
<thead>
<tr>
<th>Inlet 16 mm, 5/8 in O.D.</th>
<th>Discharge DCP11 13 mm, 1/2 in O.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2007 ver.</td>
</tr>
<tr>
<td></td>
<td>2005 ver.</td>
</tr>
<tr>
<td>Maximum Flow</td>
<td>550 L/Hr, 145 GPH</td>
</tr>
<tr>
<td></td>
<td>500 L/Hr, 132 GPH</td>
</tr>
<tr>
<td>Maximum Head</td>
<td>170 cm, 5.6 ft</td>
</tr>
<tr>
<td></td>
<td>120 cm, 3.9 ft</td>
</tr>
<tr>
<td>Voltage</td>
<td>12V DC</td>
</tr>
<tr>
<td>Nominal Power</td>
<td>5 W</td>
</tr>
<tr>
<td>Nominal Current</td>
<td>0.25 A</td>
</tr>
<tr>
<td>Maximum Liquid Temp</td>
<td>60°C, 140°F</td>
</tr>
<tr>
<td>Dimension</td>
<td>95 mm L x 70 mm W x 70 mm H</td>
</tr>
<tr>
<td></td>
<td>3.7 in L x 2.75 in W x 2.75 in H</td>
</tr>
<tr>
<td>Measurement include inlet &amp; discharge ports</td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td>368 g, 13 oz</td>
</tr>
<tr>
<td>Power Connection</td>
<td>2 wires, 4 pin male Molex</td>
</tr>
<tr>
<td>Mounting Option</td>
<td>Screws, rubber suction cups or adhesive</td>
</tr>
</tbody>
</table>
2.2.2.6 Voltage Regulators

In order to connect the components to the PCB board and insure that the voltages are compatible, voltage regulators are used. Two voltage regulators were ordered:

a) The 5 volts regulator

This regulator is a linear voltage regulator that has a single output and a current equivalent to one amp. It is very similar
to the one used in the EKG project. It was ordered from
digikey.com, part number LM340T-5.0-ND. This monolithic
3-terminal positive voltage regulator employs internal current-
limiting, thermal shutdown and safe-area compensation, making it
essentially indestructible.

### LM340 Electrical Characteristics (Note 4)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Input Voltage (unless otherwise noted)</th>
<th>Output Voltage</th>
<th>5V Units</th>
<th>10V Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symbol</td>
<td>Condition</td>
<td>Conditions</td>
<td>Min</td>
<td>Typ</td>
</tr>
<tr>
<td>$V_O$</td>
<td>Output Voltage</td>
<td>$T_J = 25^\circ C$, $5 \text{ mA} \leq I_O \leq 1 \text{ A}$</td>
<td>4.8 5 5.2</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>$P_O \leq 15W$, $5 \text{ mA} \leq I_O \leq 1 \text{ A}$</td>
<td>$V_{\text{MIN}} \leq V_{\text{IN}} \leq V_{\text{MAX}}$</td>
<td>4.75 5 25  V</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$(7.5 \leq V_{\text{IN}} \leq 20)$</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>$\Delta V_O$</td>
<td>Line Regulation</td>
<td>$I_O = 500 \text{ mA}$</td>
<td>3 50 mV</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$T_J = 25^\circ C$</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\Delta V_{\text{IN}}$</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$0^\circ C \leq T_J \leq +125^\circ C$</td>
<td>50 mV</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\Delta V_{\text{IN}}$</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$(8 \leq V_{\text{IN}} \leq 20)$</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$I_O \leq 1 \text{ A}$</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$T_J = 25^\circ C$</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\Delta V_{\text{IN}}$</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$0^\circ C \leq T_J \leq +125^\circ C$</td>
<td>25 mV</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\Delta V_{\text{IN}}$</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$(8 \leq V_{\text{IN}} \leq 12)$</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>$\Delta V_O$</td>
<td>Load Regulation</td>
<td>$T_J = 25^\circ C$</td>
<td>10 50 mV</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$5 \text{ mA} \leq I_O \leq 1.5 \text{ A}$</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$250 \text{ mA} \leq I_O \leq 750 \text{ mA}$</td>
<td>50 mV</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$5 \text{ mA} \leq I_O \leq 1 \text{ A}$, $0^\circ C \leq T_J \leq +125^\circ C$</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>$I_O$</td>
<td>Quiescent Current</td>
<td>$T_J = 25^\circ C$</td>
<td>8 mA</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$0^\circ C \leq T_J \leq +125^\circ C$</td>
<td>8.5 mA</td>
<td>V</td>
</tr>
<tr>
<td>$\Delta I_O$</td>
<td>Quiescent Current Change</td>
<td>$I_O \leq 1 \text{ A}$</td>
<td>0.5 mA</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$T_J = 25^\circ C$, $I_O \leq 1 \text{ A}$</td>
<td>1.0 mA</td>
<td>V</td>
</tr>
</tbody>
</table>
These are some of its features:

<table>
<thead>
<tr>
<th>DC Input Voltage</th>
<th>35V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal Power Dissipation (Note 2)</td>
<td>Internally Limited</td>
</tr>
<tr>
<td>Maximum Junction Temperature</td>
<td>150°C</td>
</tr>
<tr>
<td>Storage Temperature Range</td>
<td>−65°C to +150°C</td>
</tr>
<tr>
<td>Lead Temperature (Soldering, 10 sec.)</td>
<td></td>
</tr>
<tr>
<td>TO-3 Package (K)</td>
<td>300°C</td>
</tr>
</tbody>
</table>

b) The 8 volts regulator:

This regulator is used to make the force sensor compatible, voltage wise, to the rest of the components. It is also ordered from digikey.com, part number AN77L08-ND. It is a single output linear voltage regulator is suitable for the low-voltage equipment. Below are this regulator’s block diagram and features:

- Built-in overcurrent limit circuit
- Built-in rush current prevention circuit at input voltage rise
- Built-in overheat protection circuit

Features
- Built-in input short-circuit protection circuit
# Block Diagram (AN77LxxM series)

![Block Diagram](image)

Note: The number in ( ) shows the pin number for the AN77Lxx series

### AN77L08, AN77L08M (8V, 100mA type)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Conditions</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output voltage</td>
<td>$V_O$</td>
<td>$T_J = 25°C$</td>
<td>7.68</td>
<td>8</td>
<td>8.32</td>
<td>V</td>
</tr>
<tr>
<td>Line regulation</td>
<td>$\text{REG}_{\text{IN}}$</td>
<td>$V_I = 8.82$ to $18.82V$, $T_J = 25°C$</td>
<td>---</td>
<td>5</td>
<td>80</td>
<td>mV</td>
</tr>
<tr>
<td>Load regulation</td>
<td>$\text{REG}_{\text{L}}$</td>
<td>$I_O = 0$ to $100mA$, $T_J = 25°C$</td>
<td>---</td>
<td>12</td>
<td>80</td>
<td>mV</td>
</tr>
<tr>
<td>Bias current under no load</td>
<td>$I_{\text{Bias}}$</td>
<td>$I_O = 0mA$, $T_J = 25°C$</td>
<td>---</td>
<td>1.1</td>
<td>1.6</td>
<td>mA</td>
</tr>
<tr>
<td>Bias current fluctuation to load</td>
<td>$\Delta I_{\text{Bias}}$</td>
<td>$I_O = 0$ to $100mA$, $T_J = 25°C$</td>
<td>---</td>
<td>3</td>
<td>5</td>
<td>mA</td>
</tr>
<tr>
<td>Bias current before regulation start</td>
<td>$I_{\text{leak}}$</td>
<td>$V_I = 7.2V$, $I_O = 0mA$, $T_J = 25°C$</td>
<td>---</td>
<td>1.5</td>
<td>5</td>
<td>mA</td>
</tr>
<tr>
<td>Ripple rejection ratio</td>
<td>RR</td>
<td>$V_I = 8.82$ to $10.82V$, $f = 120Hz$</td>
<td>53</td>
<td>63</td>
<td>67</td>
<td>dB</td>
</tr>
<tr>
<td>Minimum input/output voltage difference 1</td>
<td>$V_{\text{I0Hv0L1}}$</td>
<td>$V_I = 7.2V$, $I_O = 50mA$, $T_J = 25°C$</td>
<td>---</td>
<td>0.12</td>
<td>0.25</td>
<td>V</td>
</tr>
<tr>
<td>Minimum input/output voltage difference 2</td>
<td>$V_{\text{I0Hv0L2}}$</td>
<td>$V_I = 7.2V$, $I_O = 100mA$, $T_J = 25°C$</td>
<td>---</td>
<td>0.27</td>
<td>0.51</td>
<td>V</td>
</tr>
<tr>
<td>Output noise voltage</td>
<td>$V_{\text{no}}$</td>
<td>$f = 10Hz$ to $100kHz$</td>
<td>---</td>
<td>135</td>
<td>---</td>
<td>μV</td>
</tr>
<tr>
<td>Output voltage temperature coefficient</td>
<td>$\Delta V_o/T_x$</td>
<td>$T_J = -30$ to $+125°C$</td>
<td>---</td>
<td>0.53</td>
<td>---</td>
<td>mV/°C</td>
</tr>
</tbody>
</table>

**Note 1:** The specified condition $T_J = 25°C$ means that the test should be carried out within so short a test time (within 10ms) that the characteristic value drift due to the chip junction temperature rise can be ignored.

**Note 2:** Unless otherwise specified, $V_I = 9V$, $I_O = 50mA$ and $C_0 = 10μF$. 

---

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2.2.2.7 LabView

Computer Software:

Acquire data with LabVIEW®

National Instruments LabVIEW® is designed to make interfacing with any measurement hardware simple. With interactive assistants, code generation, and connectivity to thousands of devices, LabVIEW® makes gathering data as simple as possible. Because LabVIEW® provides connectivity to virtually any measurement device; you can easily incorporate new LabVIEW® applications into existing systems without losing your hardware investment. Regardless of your hardware requirements, LabVIEW® provides an interface to make connecting to Input/Output (I/O) easy. With National Instruments LabVIEW®, you can acquire and generate signals from plug-in boards, USB devices, and Ethernet-based systems. These I/O capabilities, combined with special data types and measurement analysis functions, are specifically designed to get the measurements you need from your physical sensors as quickly and easily as possible.

Measurements with LabVIEW® include:

- Temperature
- Voltage
- Resistance
- Pressure
- Strain
- Current
- Pulse
- Force
- Vibration
- Frequency
- Period
- Sound
- Light
- Digital Signals
Analyze Data with LabVIEW®

National Instruments LabVIEW® software has more than 600 built-in functions for signal synthesis, frequency analysis, probability, statistics, math, curve fitting, interpolation, digital signal processing, and more. You can also extend NI LabVIEW® with application-specific processing for sound and vibration, machine vision, RF/communications, transient/short-time duration signal analysis, and others. With LabVIEW®, you can choose among multiple programming approaches to implement math, signal processing, and analysis. This gives you the freedom to select the most appropriate approach for the problem or situation.

Present Data with LabVIEW®

After one acquires and performs analysis on the data, one likely needs to present the data. Data presentation encompasses data visualization, report generation, data storage, Web publishing, database connectivity, data management, and more. The National Instruments LabVIEW® graphical development environment includes hundreds of built-in functions and tools for data presentation, and one can add more functions with application-specific NI LabVIEW® toolkits.

Building LabVIEW program:

Our first step at building the program is one that reads the Hall Effect sensor output. The program was tested with the Hall Effect sensor, and it was determined to be functional. Below is the block diagram of the program:
This program was then expended. The final program, shown below, stimulated the muscle and reads the output of the force sensor, and turns on the motor in order to spray the pump when the muscle recorder is off. It also allows for the entering of data concerning the muscle.

This VI features a case structure with the following settings: run, spray and off. The following is the block diagram for the run position. This allows for the muscle stimulation and the reading of results. In the spray setting, a clock was added in order to run the pump for a designated time inserted by the user. The device doesn’t work while on the off position even though LabVIEW may be running.
Since there is a bug in the program that needs to be fixed, this is not the final version of the program. The final version will be included in the Final Presentation or in an updated report to be uploaded next week.

The muscle has to be stimulated by an electric pulse of about 12 mA so that the muscle responds by contracting. In the body, this is done by the natural source of the motor unit, the nervous tissue which directly connects to the muscle fiber. In our case of this fabricated version of contracting a muscle, a muscle stimulator, should be used as opposed to the natural motor unit source in the body. A muscle stimulator is simply a current pulse which is directly attached to skeletal muscle. LabVIEW® is capable of being programmed to deliver this current pulse on its own, and this would be a cheaper way of implementing the stimulation since LabVIEW® already exists in the setup of this lab. The LabVIEW® program dictating how much current should be applied should be written by our group, and not left to be the responsibility of the students who are going
to actually use the setup in the Biomeasurements laboratory. Once the software starts the stimulation sent to the muscle, it records the voltage from the Hall Effect sensor against the time.

We will like to use a real-time functional electrical stimulation system that delivers customized stimulation patterns, acquire and store data, monitor the muscle responses to stimulation, and modify the stimulation patterns in real time to reflect physiological alterations in muscle responses. Using the multithreading capabilities of LabVIEW® to simultaneously deliver stimulation patterns, acquire and monitor the data through PCI boards, and modify the stimulation patterns in real time to reflect physiological alterations in muscle responses seem to be a good way of stimulating the muscle. FES (functional electrical stimulation system) is the use of electrical stimulation to activate artificially the muscles of patients with central nervous system dysfunction to help them to restore functional movement, such as standing or walking.

Elements needed:

- Data Acquisition (DAQ)
- LabVIEW®
- PXI/Compact PCI

Requirements:

- Operate under isometric and nonisometric modes

- Deliver the stimulation patterns with negligible timing errors between each pulse and between each train

- Modulate or truncate the stimulation trains automatically at the user-defined muscle performance level, such as switching from a constant frequency train to a variable frequency train when the muscle force falls below a desired level due to fatigue

- Acquire and store muscle performance data for subsequent analysis

- Write the data in a form that is compatible with existing analysis software
• Interface easily with the user

• Provide safety mechanisms to prevent undue stimulations being delivered to the patient

For electrical simulation, a pair of electrodes can be placed on the muscles for electrical stimulation. A Grass stimulator driven by a PC to stimulate the muscles through the electrode pair can be used. Timed Transistor Logic (TTL) pulses from the PC drive the Grass stimulator. The Grass stimulator puts out a corresponding amplified pulse at each rising edge of the TTL pulse. Then the amplified pulse is delivered to the patient’s muscle through electrodes placed on the muscle. When there is no motion, the muscle contraction as isometric. Isometric contraction involves an increase in muscle tension without a change in muscle length. When there is motion, the contraction is nonisometric, or isotonic. Isotonic contraction involves an increase in muscle tension with an accompanied change in muscle length. Using a DAQ board to collect and store muscle force, angular position, and velocity data on the PC for later analysis is needed.

DAQ Boards:
DAQ board is a basic A/D converter coupled with an interface that allows a personal computer to control the actions of the A/D, as well as to capture the digital output information from the converter. A DAQ board is designed to plug directly into a personal computer's bus. All the power required for the A/D converter and associated interface components is obtained directly from the PC bus.

PXI:
PXI (PCI extensions for Instrumentation) is a rugged PC-based platform for measurement and automation systems. Features:

• Rugged, compact package with slots for five peripheral modules
• Compact chassis for remote controllers or 1 or 2-slot embedded controllers
• Compatibility with both 3U PXI and Compact/PCI modules
• Quiet acoustic noise emissions as low as 41 dBA
• 300 W universal AC power supply
• Low-cost, low-power system ideal for remote, real-time, and data acquisition applications
2.2.2.8 Relay

Before purchasing the DC pump, we had originally purchased an AC water fountain pump from Petsmart. It was not a good idea to use an AC pump because of the difficulties it poses in regards to its automation by LabView. Moreover, the AC pump plugs into the wall, and including it in our device would indicate poor planning and engineering as well as a sloppy job. Additionally, the pump we were originally going to use is not as powerful as the DC pump we ended up using; there was a significant time delay between the moment the pump is turned on and the time it actually sprays its target.

Since LabView generates a DC voltage and the muscle recorder device needs to be completely automated by LabView, our solution to the DC LabView voltage and the AC pump voltage incompatibility is to purchase a DC coil relay. A relay is an electrically operated switch. The main things to consider when purchasing a relay are the PCB board it will be attached to, the relay’s voltage- 120 V for our purposes- and the relay’s current. The relay we chose is from the Tyco Electronics website, model number KUP-11D15-5. This relay is a basic enclosed relay with a DC coil input and a bracket mount case. It must operate at 75% of the nominal voltage or less, and it typically had 10 milliseconds release time. It has the following features:

<table>
<thead>
<tr>
<th>Product Type Features:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Termination Type</strong> = .187 x .020 Quick Connect Terminals</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Electrical Characteristics:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Contact Current Rating (Amps.)</strong> = 10</td>
</tr>
<tr>
<td><strong>Coil Resistance (Ω)</strong> = 21</td>
</tr>
<tr>
<td><strong>Actuating System</strong> = DC</td>
</tr>
<tr>
<td><strong>Coil Power, Nominal (W)</strong> = 1.20</td>
</tr>
<tr>
<td><strong>Input Voltage (VDC)</strong> = 5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Body Related Features:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Series</strong> = KUP</td>
</tr>
<tr>
<td>Polarized = No</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Configuration Related Features:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Contact Arrangement</strong> = 2 Form C, DPDT, 2 C/O</td>
</tr>
<tr>
<td><strong>Coil Magnetic System</strong> = Monostable</td>
</tr>
<tr>
<td><strong>Coil Suppression Diode</strong> = Without</td>
</tr>
<tr>
<td><strong>Coil Selection Criteria</strong> = Nominal Voltage</td>
</tr>
<tr>
<td><strong>Coil Latching</strong> = Without</td>
</tr>
<tr>
<td><strong>LED Indicator</strong> = Without</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Industry Standards:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RoHS/ELV Compliance</strong> = RoHS/Not</td>
</tr>
<tr>
<td>ELV Compliant</td>
</tr>
<tr>
<td><strong>Lead Free Solder Processes</strong> = Not</td>
</tr>
</tbody>
</table>
Contact Related Features:

- Mounting Options = Plain Case
- Enclosure = Enclosed
- FCC Part 68 Isolation = No
- Relay Type = General
- Contact Material = Silver Cadmium Oxide

Approx. Dimensions (L x W x H) (mm [in]) = 38.90 x 35.70 x 48.40 [1.532 x 1.406 x 1.907]
- Wiring Diagram = 2 Form C
- Approved Standards = UL Recognized, CSA Certified

RoHS/ELV Compliance History = Converted to comply with RoHS not ELV directives

Other:

Brand = Potter & Brumfield

A picture of the relay and its wiring schematic are also found below.

**Wiring Diagrams**

*2 Form C*

![Wiring Diagram](image)

*Recommended Load Polarity for Optimum Arc Suppression.*
### 2.2.2.9 Relationships

#### Testing of subunits:

In order to test if the muscle recorder device is working properly, a series of experiments and measurements need to be obtained. The velocities should be varied, and the muscle should be stimulated at different levels with constant loads. The experiment should be repeated using the same stimulation level but with varying loads. The data should be compared and contrasted with the available data from past experiments in addition to the theoretical outcomes. The LabVIEW program could be tested for accuracy by comparing the results of an experiment conducted in the Physiology lab to the results of same experiment conducted using LabVIEW.

Individual components may be tested using an oscilloscope, and making sure that such that components are calibrated correctly.

#### Length-Tension Curve:

One of the purposes of the ultimate device is to generate a length versus tension graph. The x axis would be the independent
variable length, and the y axis would be the dependent variable tension. As the length of the muscle changes, the tension it generates changes as well. Unfortunately, due to the nature of the system, the system is nonlinear. Sarcomeres reduce in length when they contract. The action of the actins’ head overlapping the myosin filaments physically reduces the size of the muscle. The order of the reduction is extremely small, a good order to measure the length is between 0 and 3 micrometers. The curve generated shows three general stages, contraction, plateau, and relaxation. The curve also shows how changes in loading affect the tensile force development, and this allows for external work to be performed. The relationship between length and tension can be surprising when examined, since a very small change in length results in a relatively great increase in tension. This is why the muscle becomes such a powerful tool for doing work.

**Force-Velocity Curve:**

The other curve developed by the experiment is a curve analyzing force versus velocity. On this graph, velocity is the independent variable on the x axis, and force is the dependent variable on the y axis. The way the relationship develops is that a muscle undergoes shortening and lengthening under constant loads. In the case of this lab design, the constant load shall be the weight applied which is physically connected to the muscle. The velocity during shortening is measured by the devices already set in place, and the resistive force is recorded from the force transducer. The two terms are related inversely, and as velocity goes up force goes down. As force goes up, velocity goes down.

**Force-Velocity Relationship:** muscle tested under isotonic (constant force) experimental conditions to investigate muscle viscosity. The muscle and load are attached in a lever. The muscle stretched to optimal length at the start of the isotonic experiment which begins by attaching a load, stimulating the muscle, and recording the position. Duration of responses are approximately equal regardless if it is small or large load. Also, the heavier the load, the less total shortening. Maximum velocity is calculated numerically from the position data. To estimate muscle viscosity, this experiment is repeated with many loads at the same stimulation level and maximum velocity is calculated. Clearly, the force-velocity curve is nonlinear and follows a hyperbolic shape. If a smaller stimulus than maximum is used to stimulate the muscle, then a family of force-velocity results.
**Shortening and Lengthening**

Isotonic contraction is the shortening of the muscle. If the tension developed is greater than the external force or load acting on the muscle, the muscle will shorten. Non-linear viscous damping presents a hyperbolic relation between force and velocity. Coincidentally, the force-velocity curve generated by the isotonic experiment of muscle is hyperbolic, thereby setting the stage for the assumption on non-linear muscle viscosity. The gastrocnemius muscle has a duration of contraction of about 1/15 of a second. The Hall effect sensor measures the distances the weights travel when the muscle is stimulated and also lengthened. Sensor produces a linear range voltage output with magnetic field present. The sensor produces a voltage change, which is converted to a contraction distance. This distance is to be compared against the contraction time. A timer integrated into the software determines the contraction time.

**In our experimentation:**

- Stimulate the muscle
- Record voltage vs. time
- From voltage get distance of contraction
- Distance converted to velocity from time recorded
- Force-Velocity curve generated via Active X control of Excel
- Other curves as Length-Tension are extrapolated from this data
- Display visually in LabView

**TESTING REQUIRED FOR THE RELATIONSHIPS:**

Obtain fresh muscle to conduct the experiment. Have a working Hall Effect sensor for testing and calibration. Need to measure the rate of shortening and lengthening of muscle contraction under different loads. Use the lever arm for isometric conditions to reduce the force of gravity and the inertial force of the load at the muscle. A variable for change in muscle length from resting length might be needed. Finally, the user needs to experiment when the muscle is first stretched to its optimal length to the start of isotonic experiment.

**ISOTONIC CONTRACTION EXPERIMENT**

- Muscle will shorten to exert a tension greater than the external load
- Stimulate muscle
• Record position
• Repeat experiment with different loads at the same stimulation level
• Obtain and calculate maximum velocity from position data

_force-velocity curve_
• Begin the recording
• Stimulate muscle once at maximal stimulus (to show when muscle shortens with no load)
• Place five grams (5 g) of weight to the lever arm
• Allow it to stop moving
• Stimulate several times at each weight until muscle can no longer lift the load
• Measure height of the response at the peak for each recording in millimeters (mm)
• Record the time required for each peak of the contraction in seconds (s)
• Calculate the velocity (V), average of distance (mm) by average of time (s)

_isometric contraction experiment_
• Experiment at constant length
• Measure and record the minimum physiological length of the muscle
• Record at zero
• Place 5g of weight
• Calibrate
• Tighten muscle
• Position stimulator electrode
• Moist muscle
• Record position and force

_length-tension curve_
• Set muscle at shortest physiological length
• Calibrate at 0g
• Deliver a single pulse at maximum stimulus
• Change to new length
• Calibrate then wait few minutes
• Enter a new length
• Stimulate and repeat as many times as necessary
• Stimulate at its longest physiological length
• Reset muscle to its shortest length
• Wait few minutes
• Stimulate, then record tension

The force-velocity relationship is characterized by a rapid force drop in muscle with increasing shortening velocity and a
rapid rise in force when muscles are forced to lengthen. These
colors can be used in developing artificial muscles as well as
in performing surgical reconstructive procedures with various
donor muscles.

**ISOTONIC ACTIVE FORCE-VELOCITY PROPERTIES:**

The force-velocity illustrates that the maximum force generated
by a muscle is a very strong function of its velocity, or that
muscle contraction velocity is dependent of the force resisting
the muscle. A muscle is stimulated maximally and allowed to
shorten or lengthen against a constant load. The muscle velocity
during shortening or lengthening is measured and then plotted
against the resistive force. The mathematical form:

$$(P + a)V = b (Po - P)$$

$a$ and $b$ = constants derived experimentally
$P$ = muscle force
$Po$ = max. titanic tension
$V$ = muscle velocity

As the load imposed on the muscle increases, it reaches a point
where the external load is greater than the load which the
muscle itself can generate. The muscle is activated, but it is
forced to lengthen due to high external load which is known as
eccentric contraction. The main features of eccentric
contractions are:

- Absolute muscle tensions are very high relative to the
  muscle’s maximum titanic tension
- Unlike concentric contractions, the absolute tension is
  relatively independent of lengthening velocity

During lengthening at other than zero load work is done on the
muscle. The work done on a muscle to lengthen it is supplied by
its antagonists or by the dissipation of potential or kinetic
energy in structures to which the muscle is attached. The force-
velocity properties of lengthened muscle are more complex than
those of shortening muscle. For example: if during an isometric
titanic contraction (occurs when a motor unit has been maximally
stimulated by its motor neuron) a frog muscle is suddenly loaded
with a force, $F$, that is greater than the maximum titanic force,$Po$, there is an initial, very rapid lengthening followed by
slower lengthening (more constant) slower lengthening might
allow the construction of a force-velocity curve for this part
of the elongation. Most of the available studies on the force-
velocity properties of lengthening muscle have used iso-velocity stretch as independent parameter. At low lengthening velocities, force rises through much or all of the stretch. At high lengthening velocity, force tends to rise continuously to a yield point, after which it continues to rise but at a lower slope than previously, or remains relatively constant, or sometimes declines momentarily or continuously. It is possible to adjust the level of muscle activation by changing the stimulation frequency. Being able to activate a muscle partially by using supersaturating stimulus frequencies allows an investigation of the force-velocity properties of the muscle. To determine the optimal length of muscle for producing titanic tension for example one can:

- Set muscle to a length judged to be shorter than optimum
- Stimulate tetanically at 100Hz for 0.5 seconds
- Repeat stimulation at 2 min intervals
- Lengthening the muscle between each trial in steps of .25 mm until titanic force begins to decline with further increase in length
- Experiments to involve iso-velocity lengthening of muscle
- Stretch applied during plateau of a titanic contraction
- The length of the muscle before the stretch set at or slightly shorter than the optimum
- Trials with titanic stimulation, with or without stretch, to be paced regularly at 2 min intervals

- The distance of stretch is proportional to the elapsed time since the onset of stretch
- Muscle performance might tend to decline through a series of trials with stretch
- At the end of the experiment, muscle held at its optimum length and fix it at that length
- The muscle length then can be measured

2.2.2.10 PCB Board

One aim of this project was to build and print a Printed Circuit Board (PCB). Before designing the PCB board, there should be a similar model virtually using PSpice, and physically using breadboard designs to ensure that the system is working properly. The software to design the PCB boards can be obtained from www.expresspcb.com. After one obtains the PCB, one can solder the components to it such as regulators, Hall Effect sensor, and then it would need to be mounted on the designated
enclosure place. The time to build and have the PCB board shipped to the team was not going to be enough for the day of the final presentation. Therefore we will need to employ the breadboard. The breadboard is a temporary circuit to test ideas. In it one can change connections or replace components. To convert a circuit diagram to a breadboard:

- Concentrate on connections, not positions on the circuit diagram

- The IC (chip) is a good starting point, therefore position it in the center of the board and work around it pin by pin, putting all the connections and components for each pin in turn

- After connecting all parts:
  
  o Check all connections carefully
  o Check that parts are the correct way round
  o Check no leads are touching (unless they are in the same block)
  o Connect the breadboard to power supply and press the push switch to test the circuit
How Express PCB works

This is the steps that we would need to take if the PCB board was to be design.

1. Download the free CAD software
   a. It includes SCH for drawing schematics and express PCB for circuit board layout.
   b. Software is easily installed and it runs of Windows 98 and XP.

2. Draw a schematic with the Express SCH program
   a. By placing components on the page and wiring the pins together.
   b. The schematic can be linked to the PCB file, so the PCB knows what needs to be connected together.

3. Design the PC Board
   a. Designing 2 or 4 layer boards using the Express PCB program is easy.
   b. Start by inserting the components footprints, then drag them into position.
   c. Next, connect pins by drawing the traces.
   d. If the schematic file is linked to the PCB, the Express PCB program will highlight the pins that should be wired together in blue.

4. Instant quotes
   a. After completing the layout, it can be determined how much it will cost and how long it will take to have the boards made.
   b. The Express PCB program displays exact manufacturing cost by selecting the Computer Board Cost command from the "layout Menu".
5. Order the Board: order it directly from ExpressPCB layout program over the internet

a. Run ExpressPCB and select Order Boards Via the internet form the layout menu.

b. In the order form fill in name, address, e-mail address, and quantity of boards.

c. To pay for boards, they bill the credit card the exact amount shown by the Cost Command.

d. They encrypt the credit card number, along with the entire order before it is sent over the internet.

e. Press the “Send” button to place order.

f. It is sent directly to the ExpressPCB server.

2.3 Prototype

The prototype is an example of what a real live working model could be. Because of this, the prototype is fully functional just as a real model would be. The prototype will be capable of producing the same desired effect as the actual device, and the prototype will be modeled for future designs by other University of Connecticut members.

The design of this prototype is based around a hub for all of its electrical components. All of the electrical components meet together in a bus along the protoboard. One bus carries a live voltage of 12 Volts, and one carries the ground voltage. The third voltage source is shown in V2, which has a potential of -12 Volts. It only has one output terminal though, as it was only supplied to one source on the board. Below is a design drawing of the protoboard:
Below is a photograph of the actual circuit:
The two diagrams above is an idealized model of the protoboard shown above. The protoboard shown above corresponds with the following power supply below supplying it voltage as well. The local ground is the middle wire on the left 12 volt voltage supply. The positive twelve volt terminal is the right terminal on the left side. Then, the ground from the left side, the local ground, is connected across the power supply to the right hand positive terminal. Now this sets this terminal to 0 volts. Because the power supply is commanded to deliver a 12 volt difference potential, the only way to develop that with a 0 V positive terminal is to have a -12 volt negative terminal. Because of that, the negative value on this terminal produces
the target -12 Volt value. Now all three voltages which need to be supplied to the proto board have been created, and are thus deliverable by proper wire leading all across the board. These voltages are -12V, 0V, and 12V.
Below is a diagram of what was begun to be illustrated well above. The first discussed topic of this section is how the system is wired in parallel. Once the power supply setup is established, then it can be described how the system is wired in parallel accordingly. Shown below is how the circuit was wired up. Ground (the top voltage) is wired to the power supply ground. $V_1$ (the middle voltage) is the $+12$ voltage. $V_2$ (the lower voltage) is the $-12$ V supply.

The rest of the long bus is shown below:
The diagram above shows 2 hubs where activity happens. The two hubs are located near the bottom of the board. The first
involves an output for 12 Volts, and an output of 5V. One difficult challenge we faced in the building of this board is the transformation of 12 Volts to 5 Volts. This can be done by a step-down transformer, but upon conversation with Dave Price he recommended use of a voltage regulator. A voltage regulator takes an input voltage, and outputs the regulator voltage as a result. Therefore this 5 Volt regulator shown below transformed 12 volts into 5 volts.
The terminals of the regulator are labeled 1, 2, and 3. Terminal 1 is the live wire feed of 12 Volts. Terminal 2 is the ground feed of 0 Volts. Terminal 3 is the output 5 Volt lead. This is further clarified in the schematic below.

In the diagram above, the inside circuitry of the regulator is displayed. Also, this schematic is a little different than the photo in that it is flipped upside down. The reason it is still applicable is because the left to right order of the 3 leads is consistent in each diagram.

The diagram below shows how the 5V regulator was wired into our protoboard.
This 5 volt lead needs to have an input into the force transducer 8-pin DIN input, and also to the Hall Effect sensor. The Hall Effect sensor needed 3 leads to operate properly. These three leads are the positive 5V lead, the ground 0V lead, and then the output voltage lead. A diagram of this is given below.

From this illustration it can be gathered that the left terminal is the positive 5 Volt lead, the middle terminal is the local ground lead, and the output is the right lead. The xxx is writing on the Hall Effect sensor, which indicates which side is which. The opposite side of the sensor without writing can be shown below. This side instead has a circle and a black background.
The three metal wires coming out of the sensor are the positive, ground, and output leads described above. Although, because of the orientation of the sensor, this time the output is on the left, the ground terminal is in the middle, and the live 5 Volt lead is on the right.

The outputs of the sensor are sent into LabVIEW by connection to a red and black lead wire and then are input into a DAQ. LabVIEW is then capable of decoding the voltage signal and outputting it into a graph.

The clips below are used to connect to the Hall Effect sensor. The red lead is connected to the live output lead of the
Hall Effect sensor, and the black lead is connected to a local ground. The local ground can be any wire connected to the ground bus on the protoboard.

The red lead and black lead are lead outs of a BNC cable. A BNC cable has terminals which can be received by the DAQ. This is done by the input terminal of the analog in signal receiver. The cable and connection port are shown below.
Below is shown the connection of the cable connector to the DAQ in its proper terminal. There are multiple terminals on the DAQ board, but only 2 are analog inputs. Therefore, our choices of where to place the connecting BNC cable were only A0 and A0.
1. Shown below is the BNC cable placed inside connector port A0 1.

The force transducer was a difficult element of the design to add to the project. The reason for that is because of the
complicated electronic voltage requirements for making connections to the multiple terminals necessary for proper function. Shown below is the transducer itself.
The left side of the transducer shows a wire lead coming out of it. This wire lead powers the sensor, and also has a lead for the sensor’s output. The pin which it uses is called an 8-pin din, and its multiple ports make it more difficult to operate than the previous device described above. In addition to the 8 pin DIN, a connector was added which can connect to the pin and be inserted into the protoboard. This connector head is shown below.
This connector serves the function of having the 8 pin DIN head inserted into it. The 8 pin DIN is shown below.

This DIN is then analogous to the output of the connector it is inserted into. The pin’s output is represented by the output of the connector’s pins. Thus, the output of those pins equals the input of these pins above. This causes a pitfall for error though, since the pins will not be directly wired to these inputs. Because of this, extra care must be taken to put the pins in correct order. The order which is correct is illustrated in the schematic on the next page.
This first image shows the input numbers of the 8 pin inserts:

The angles and lengths which are detailed are not of any great relevance, but the number of the holes are. These numbers above correspond to the following numbers on the outputs of the connector. These are shown in this second image:
Again, the details provided are not as important as the numbers of the pins in the image. These pins correspond to what voltage is supplied to the female end of the connector. The voltages which were necessary to be supplied are diagrammed below.

The next step along this project was arranging the alignment on the protoboard so that the voltages illustrated below came to fruition. Understanding what pins required what voltages were needed was done by calling the PASCO company and asking them for technical support. They continued to tell me which pins needed what, and even though they made errors, ultimately we ended up with this design:
The above diagram was materialized on the protoboard as shown below:

The two wires coming out of the left from underneath the connector are the two lead output clips. One is the ground, and the other is the live wire. The live wire will read 0V when no force is applied to the active hook on the force transducer. When 1 Newton is applied to the hook, the output voltage will increase by 160 mV. Therefore, there is a direct correlation between the quantity of readout from the device and the force which it experiences. The 8 pins on the right are all aligned along with the input pins as shown in the schematics. Also, one of these inputs is the tricky -12 Volt input which was explained above.
Stimulator:

The stimulator has the function of applying voltage to the muscle upon command from LabVIEW. This is done in this case by the needle shown in the diagram below.

The red and black leads which come out of the back of the stimulator are the voltage inputs for the device. The red lead has quantity 5 volts and the black lead is a ground so it has 0 Volts. To have the metal within these leads touching appropriate contacts, we stripped the wire and spliced it. This is shown on the next diagram:
These red and black leads are then connected to the DAQ by a similar BNC cable to the one shown above. The BNC alligator clips are then attached to these two metal exposed leads. All the signals which are feedback to the device are now ultimately integrated in LabVIEW, which then outputs the graphs we aimed for.
3. Realistic Constraints:

Based on the optimal design, the muscle recorder incorporates engineering standards including, but not limited to, realistic economic, environmental, sustainability, manufacturability, ethical, and health and safety constraints. As an engineering standard we will be measuring and calculating in the International System of Units (SI) units.

Economically, this project met the available budget. Our aim was to keep the cost low. This was achieved by using components that are compatible with NI equipment and LabVIEW® software. This device doesn’t need a high maintenance cost since the parts we have purchased are durable.

Environmentally, this product does not induce noise. The saline solution used is made up of sodium chloride, or salt, in sterile water. This solution is used for many applications such as dealing with patients that can not eat or drink and promoting nasal health; therefore, it can be rinsed or dumped down the drain without being a water contaminant. Since we are dealing with muscles, the only environmental concern is the appropriate handling and disposal of the muscle. At the end of each experiment, students or faculty need to get rid of the muscle in the correct manner. It should be placed in a waste disposal bag for waste disposal service, or one can wrap the remains in a lot paper and tie securely to prevent spillage. This can be placed in a plastic bag and it need to be refrigerated until garbage collection.

The sustainability is also an important aspect of our design since the durability and life span under the operation conditions should be considered. The durability of the device depends on the students, proper cleaning if any saline solution is spilled, and the temperature at which the device is being exposed. Most of the time, the labs are kept under a moderate temperature. The only items that will need to be replaced would be the muscle to be tested and the saline solution.

The manufacturability of the device is challenging yet within our capabilities. No one was harmed during the manufacturing process in the testing. The measurements are taken easily with the help of measurement devices, and the usage of the NI program represents no problem at all. We made this device as light as possible so it would be easier for students or faculty to move
it around as needed. Most importantly, all the items we needed for the design of the device were found very easily.

Ethically, this product is designed considering the safety and health of the users. None of the parts are chosen for appearance over safety. This technological device therefore does not violate the code of ethics because no one using the device will be put at risk. Plagiarism is not a problem in this design since research has been done, and we haven’t found a device that will perform the different aspects of our device including, but not limited to, the use of NI and LabVIEW® software to stimulate the muscle, the lengthening of the muscle and the automated spraying of the solution. Some people believe that is immoral to experiment with different parts of animals, and some might not even want to participate in such experiments. These are personal ethical beliefs; they do not impact the design of the device. Gloves are going to be provided in order to handle and touch the animal muscle.

Health and safety are the most important aspects of a design. This device doesn’t contain any allergens and is safe for users who know how to operate it. As stated before no noise in the design will be enough to cause hearing loss or harm anyone at this level. None of the products used are toxic, hazardous or radioactive. Proper disposal of the muscle was described above to prevent any hazard. As mentioned earlier, the saline solution is not toxic but items should be cleaned after using this solution. When the stimulus is programmed by the software, the needles should always be connected to the muscle even if the voltages used in the experiment are not extremely dangerous.
4. Safety Issues:

Based on the design of this device; electrical, mechanical, biological and chemical hazards are safety issues that need to be taken into consideration. All the materials are safe for the users. Electrically, there is no risk for students or faculty because no direct contact of parts connecting others is necessary. Extra care should be taken while connecting the needles to the muscle since voltage will be produced. The NI equipment is safe to work with since the safety of it was tested by the company. The device and its set up is designed in a way that it is sturdy, and set up is place on top of a table station. This set up provides a safe environment because no cables are around therefore no tripping would occur. Moreover, a shelf was included for the storage of extra wires and such. One of the major safety issues in the experiment during the manufacturability of the device was the machining of the plastic enclosure.

The plexiglass used for the enclosure of the muscle recorder device is a very strong acrylic. The thickness of it used in the project was thick enough so it does not brake easily. In the machine shop the plexiglass was cut in the panel saw. This machine has to be operated by personnel in the machine shop because it is a very dangerous machine, and only well trained students are allowed to operate it. The plexiglass gets very hot once cut and hot pieces fly everywhere. Safety glasses must be wore at all times to reduce any accidents in the machine shop. To prevent cutting hands, the best way to polish the rough edges is deburring the acrylic pieces. The chemical used to glue the enclosure also needs to be taken care into account. Try to wipe out residues of the chemical left in benches and other places. Wash hands after handling this product. If a great amount is spilled in the plexiglass, then a new piece of it should be cut to replace the damaged one. This is recommended because the chemical will burn the piece and its properties will be lost. Making the fulcrum also required help from the personnel in the machine shop. Extreme care must be taken because in order to attach the metal rods welding was necessary. Propane fuel was used and accidents like burns or fires can occur. Gorilla glue, used to seal the magnet to the lever is a very strong product and any spillage would be almost impossible to be removed in proper cleaning is not applied. Even your skin can become irritated if one does not wash hands after using this glue.
In general, all actions taken in the machine shop should be discussed first with the personnel. Any action to be taken should be first revised and supervised by the machine shop personnel.

5. Impact of Engineering Solutions:

The optimal design of the muscle recorder has global, economic, environmental, and societal impacts. With the help of the muscle recorder device and its applications and the use of NI and LabVIEW® software, students would be able to appreciate the impact of the Biomedical Engineering solutions for this particular device and the experiment that is performed with its assistance.

This device is used globally since virtually everyone is familiar with muscle contractions and how they affect our organism and every activity we perform. Some might not be fully aware of the different types of contractions and how they are related and different from each other, or how one can obtain measurements and graphs from experiments. One thing is for sure and it is that throughout the world, experiments with muscles dealing with contractions are being made in order to gain more knowledge about this important aspect of our lives since it can affect every single task we perform. We know for example that, in the University of Connecticut, the Physiology and Neurobiology department has a lab for the Human Physiology and Anatomy course that currently measures contractions in a frog muscle basically for the shortening or concentric contraction of the muscle using different forces. Moreover, both NI equipment and the LabVIEW software are used internationally.

Economically, this device should not impact engineering solutions for the reason that all the components used in the design of the device are relatively inexpensive compared to other market prices. The only expensive item included or needed in the set up of the experiment would be the software and the computer. The software and the computer in this case should not be an issue, as we have these items offered by the Biomedical Engineering Department and the students using these devices will be students enrolled in this particular program. Replacing parts for this device is non-expensive and the cost can be maintained to the lowest since the lab can use one set up of the device and teams can take turns to perform the experiment. It would be really nice if more than one station was available, as it would
let students spend and experiment more time with the device. Students will need at least twenty different forces to be measured in order to obtain maximum contraction velocity. We think that the more time students spend during the experiment, the more knowledge students will be able to get out of it.

The use of the muscle recorder can help to find out if certain activities are not being performed in the right manner or if unusual things are happening inside the muscle. Also one can find the system the muscle belongs to, or if certain movements or activities are not being executed as they are supposed to, and their maximum ranges can be obtained as well. It also helps athletes to perform at their highest potential by finding out the relationships of force-velocity and length-tension. Failure for a variety of sports can also be detected from quadriplegic to elite athletes. For power athletes it seems that eccentric contraction movements are more useful than concentric ones.

Environmentally, the design of this product will mean little harm to the ecosystem and other people. The materials used in the set up can be fully thrown away or recycled after they no longer functioning or if any part needs to be replaced. As mentioned earlier, proper disposal of the muscle should be followed to prevent biological or chemical hazards. The environment in which the device and the experiment are located would also make a great difference. People need to be aware that dealing with electronic devices would mean good storage, proper cleaning, no extreme temperatures or harsh conditions. In a societal context, this design and all the aspects that make part of it can greatly impact the way people see and use the features of the muscle recorder. Students in general will be able to know that skeletal muscles produce a force that is proportional to the muscle length - which will be specified as the Length-Tension relationship. The other force would be the muscle contraction velocity - which in this experiment is known as the Force-Velocity relationship. There are many classes, labs, books, literature that try to teach basic features of the muscle and how it can be stimulated to give meaningful results using data in graphs. None of the found experiments include the extra features we are adding to this new device and we are sure that students will greatly appreciate this advancement in the field because it does not only give you knowledge about muscle contractions, relationships, usage of NI and LabVIEW® software but in addition it serves as a tool for future students to really think about the applications behind the experiment and the way this device can be redesigned to add features as well as
to develop more accurate techniques in a future. Society can greatly be benefited from the experiments this device will be able to reproduce since as mentioned earlier, some of these measurements can efficiently help athletes and the way they can perform in different activities. Many people are not aware that many of the injuries and soreness that one can experience happen during the eccentric or lengthening contraction. Therefore, by fully having access to the understanding of these aspects people and especially athletes can be prevented from performing wrong activities that can lead to harm to different muscles.

6. Life-Long Learning:

In the process of building our muscle recorder, we had a chance to apply the knowledge and techniques acquired during our study of biomedical engineering. We built a LabVIEW program, designed a circuit, built the device setup and tested the device. It also will be tested with a muscle. We learned to troubleshoot the device and correct the errors as they come up.

The group overall had a slow start, as one underestimated the amount of time and effort that had to be put in building the muscle recorder device. There is a great difference between building a device and in operating it in a laboratory setting, as one should fully understand each aspect of the design that is being performed and demonstrated. We began by building the LabVIEW program. Although we were familiar with the LabVIEW software, dealing with and creating a LabVIEW program is always a challenging and rewarding experience because this program has numerous features and different ways of designing the program. Our LabVIEW program demands a lot of corrections since controls the entire device. Next, we bought several components and subunits for our device such as the voltage regulators and the force sensor. We started building the plastic enclosure as well. After the components came in and the enclosure was built, we tested the device with LabVIEW. At this point we realized how extensive and demanding the troubleshooting process is.

Due to the team member’s conflicting schedules, it was difficult to have team member meetings on a regular basis. Every team member worked on a part then came together to combine their respective parts. We believed that this technique would improve on our time management techniques. And last but not least, communication about the progress made regarding the project is
essential, and lack of communication proved to be problematic as it hindered our progress in building and testing the device.

7. Budget:

This table lists the cost of the products and materials needed to build the muscle recorder device. The budget was subject to many changes, and it increased in a considerable manner, but it was always kept reasonable. The aim was to keep the cost as low as possible because the department does not know how many stations will be needed in the laboratory. The device also needs to be practical and durable given that it is going to be used quite often by different students. The computer software needed for the display of the force-velocity and length-tension relationship is the LabVIEW® software program which is available in the Biomedical Engineering labs as well as other Engineering labs, therefore there is no need of purchasing this program. The muscle cost can be subject to change as we do not know if we need to buy and dissect the muscle, or if we would obtain it through the physiology and neurobiology department. The lever arm was built with parts found in the machine shop and the team was not charged for them.

<table>
<thead>
<tr>
<th>ITEMS</th>
<th>COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>BNC Cable</td>
<td>$5.00</td>
</tr>
<tr>
<td>Saline Solution</td>
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</tr>
<tr>
<td>Pump and parts</td>
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<td>Plexiglass</td>
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<tr>
<td>PCB Board</td>
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<tr>
<td>Hall Effect sensors (2)</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>$400</strong></td>
</tr>
</tbody>
</table>
8. Team Members Contributions to the Project:

**Team Member 1: Roua Taha**

Roua was responsible for building the LabVIEW program and troubleshooting it. She also researched and ordered several subunits necessary for the functioning of the muscle recorder such as the force sensor, the voltage regulators and the water pump. Purchasing the components obviously is an integral part of building the device, and it was scheduled to be completed during the first semester of senior design. Yet, modifications to the device and the incorrect ordering of parts explained the need to order new components. After all the components arrived, Roua connected the circuit to LabVIEW and tested the device. She encountered errors in LabVIEW that she is fixing. Roua also worked on several parts of this report including the introduction, some parts of the project design, the constraints and the life-long learning. She also wrote parts of the operations manual. Last but not least, Roua is assisting in the design of the PCB board.

**Team Member 2: Angela Correa**

Angela worked for the most part in building the plastic enclosure and the pump reservoir. She obtained the plastic and the stainless steel lever arm, and she built the device based on the design agreed upon by the group. She also brought some components such as the probes. Angela did a great job on the enclosure as a whole; it meets all the requirements of a light weight device that abides by the constraints and safety issues posed on it. Angela also drew all the muscle recorder designs in Visio. She worked on aspects of this report as well, including but not limited to, parts of the project design, the safety issues and the budget. Lastly, Angela worked on parts of the operations manual, primarily the maintenance.

**Team Member 3: Mark Mazmanian**

Mark worked for the most part on the electronics aspect of this device. He built the electric circuit to connect the components to the LabVIEW program. He was also the liason between our group and the Physiology and Neurobiology department here at UConn. He spoke with members of the PNB department about the steps necessary to obtain and euthanize a frog. He was able to get a muscle from a freshly euthanized frog. The muscle is to be used in testing of the device. Mark also worked on several
aspects of this report, in addition to his section in the operations manual.

9. Conclusion:

The muscle recorder is a new device that is being sponsored by Dr. John Enderle. This device needs to be able to stimulate a muscle, and from there be able to show the Force-Velocity and Length-Tension relationship curves in which the Force-Velocity curve needs to be able to show lengthening as well as shortening of the muscle. Similar products and similar patents were found but none seem to have the characteristics that are unique to this device. One of the unique characteristics is that this device instead of using a muscle stimulator that can be purchase, it uses software to generate the electrical current needed for the muscle to simulate contractions. The measurements that one will be able to obtain from this device with the help of a transducer and a Hall effect sensor will be force, velocity, length, and tension. Most of the calculation needed will be obtained and processes in the software itself, which will be providing the feedback of the curves. Once students build and test the device, they will know how many sets of data are needed to obtain the needed relationships by comparing to old data found in the literature. The different parts needed in the casing are mentioned as well as the position each element in the casing will have. This casing should be a portable device and it also serves as a way of protecting the important components, like the transducer and the sensor. We know it is important the way the muscle is handled and a description of the pump is given as well as the safety issues, and the constraints related to this device and experiment. The introduction and the objectives provide the information and background needed for the project. An updated optimal design was provided to show the difference between the one written last semester and this semester. All new components are listed as well as their prices and how the budget was affected.
10. References:


11. Acknowledgements:

We would like to express our gratitude to our kind advisor and esteemed client Dr. John Enderle, who has been supportive of our group despite the complications the group encountered along both semesters.

We would also like to thank Dave Price for his valuable input regarding our project design this last semester.

Penny Dobbins in the PNB department, helping our team obtaining the frog muscle.

Dave Kaputa for his knowledge and help with the LabView programs.

Richard and Serge in the machine shop.

12. Appendix: