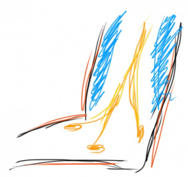
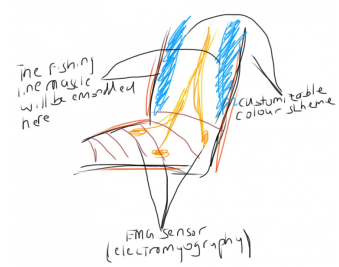
HYFLEX

PORTFOLIO SUMMARY

Escape Technologies

HyFlex





Created By: Ashank Verma and Vineeth Yeevani

Contact: ashank.verma@gmail.com and vineethy@gmail.com

Coach Name: Mrs.Kuei

Contact: lkuei@fremont.k12.ca.us

School: Mission San Jose High School

City, State: Fremont, California

PORTFOLIO ELEMENT A

PRESENTATION AND JUSTIFICATION OF THE PROBLEM

HyFlex

After researching several issues, our team discovered several primary issues with current upper exoskeleton limbs: cost, size, and manufacturing issues. The first issue, cost, has long since been accepted by exoskeleton manufactures because of the exorbitant price of hydraulic actuators which permeate the industry. For example, the cost of one relatively high powered hydraulic actuator is $115 for a 14" stroke actuator (contracting device). The next most important problem is size. The exoskeletons of today are simply too big and cumbersome to fit under clothes and would not be ideal for a patient looking for a small exoskeleton to support his or her body. The next biggest problem is manufacturing. All of today's exoskeletons require hundreds of man-hours to construct and fine tune to the operator's body. Such time is simply not available if these went to the consumer market. That is why we have designed the innovative HyFlex: to solve these problems and successfully help people in need of medical treatment.

Problem Statment

The facts are that many people in the world cannot afford to pay thousands of dollars for physical therapy and other such problems (i.e osteoporosis) which deprive them of the ability to do simple tasks. There is a need for a cheap, easy-to-manufacture-and-set-up product that is compact but effective and efficient for the stakeholder.

Justification of the Problem

In order to justify the problem, our team did extensive research utilizing the internet and our local library. Using these sources we were able to identify common muscle weakening diseases in an effort to improve our product design and satisfy the needs of possible stakeholders.

ARTICLE 1: "Evaluation of the Patient with Muscle Weakness" by Capt. Aaron Saguile of Madigan Army Medical Center, Tacoma, Washington

Summary: This article describes how a doctor should diagnose a patient with a possible muscle weakening disease. Furthermore, the article lists several diseases that could cause these deficiencies. These diseases include HIV, lupus, rheumatoid arthritis, dermatomyositis, polymyositis, and the potassium-related paralyses. The plethora of diseases included here are proved by the article to induce muscle-weakness. The author of the article also lists a series of steps to diagnose the disease that could be causing muscle debility.

Analysis: This article shows that there are a number of different causes for muscle weakness. Some of the cures of these diseases are currently beyond the limits of medical science, such as HIV. People with incurable diseases with muscle weakness need a solution that assists them with their problems until a cure is discovered. The steps that the author provides to diagnose the illness is proven to be time-consuming and cumbersome. During the diagnosis process the patient has to endure the burden of muscle-weakness. This therefore justifies our problem in that a temporary, cheap solution is required for the patient in the interval between diagnosis and therapy.

Saguil, Aaron, Capt. "Evaluation of the Patient with Muscle Weakness." - American Family Physician. American Family Physician, 1 Apr. 2005. Web. 10 Jan. 2015. <http://www.aafp.org/afp/2005/0401/p1327.html>.

ARTICLE 2: "Osteopenia: When you have Weak Bones, but not Osteoporosis" by Harvard Health Newsletter

Summary: This article discusses osteopenia, which is a bone weakening disease that is less debilitating than osteoporosis. Both diseases reduce the density of bones throughout the patient's body and in turn weaken the patient so that they cannot function at the same level as a normal person. The treatments can include exercise, nutrition, and on-going therapy. The article states that over-medicating patients with osteopenia may prove futile. Only weight-bearing exercise is recommended to most.

Analysis: According to the article, many doctors feel that exercise is the best way to reduce the effects and prevent osteopenia from developing into osteoporosis. However, for the elderly who cannot do weight-bearing exercise without aid, the only other option is therapy, which has been shown to not be as effective as exercise. This justifies our claim that bone-disease symptoms such as weakness should be reduced in order to begin exercising. This will help the elderly and those who may also have a muscle-weakening disease to quicken recovery. The four factors (our claim, exercise, nutrition, and therapy) will expedite the recovery process that would otherwise remain a slow one.

"Osteopenia: When You Have Weak Bones, but Not Osteoporosis." Harvard Health Letter (Oct. 2011): n. pag. Osteopenia: When You Have Weak Bones, but Not Osteoporosis. Harvard Medical School. Web. 10 Jan. 2015. <http://www.health.harvard.edu/newsweek/Osteopenia_When_you_have_weak_bones.htm>.

ARTICLE 3: "Physical Therapy" by UHS Tang Center at Berkeley

Summary: This informational website by UC Berkeley's Physical Therapy Center lists several facts about physical therapy at Berkeley. Though not the only renown medical facility, Berkeley's University Health Services are known for their effective treatments of patients who are pain-inflicted, dangerously ill, or near-death. This article gives us a comprehensive view on the physical therapy expenses and the types of diseases treated by therapy, including muscle diseases and osteoporosis.

Analysis: We mainly chose this article to justify our problem in that a cheap but effective solution is needed. The article states that Berkeley's non-program members need to pay $160 for their initial visit and around $100 for each additional visit. The physical therapy duration only lasts 6-12 visits, which could sum up to an astounding $1360 for physical therapy. This amount does not include the fact that further physical therapy after 12 visits may be required, meaning even more money for the patient. People without health insurance would not be able to afford this treatment, which justifies our problem for a cheap and efficient product designed to help patients with muscular and bone diseases .

"Physical Therapy." UHS Tang Center at Berkeley. Berkeley UHS, n.d. Web. 7 Jan. 2015. <http://uhs.berkeley.edu/students/medical/physicaltherapy.shtml>.

To recap everything stated in this element, our team's problem statement is to create a upper-limb exoskeleton to assist those with muscle degeneration and bone weakness in their everyday lives as they go through their treatments and therapy. We cite several texts which show a pressing need for such a device on the market.

PORTFOLIO ELEMENT B

DOCUMENTATION AND ANALYSIS OF PRIOR SOLUTION ATTEMPTS

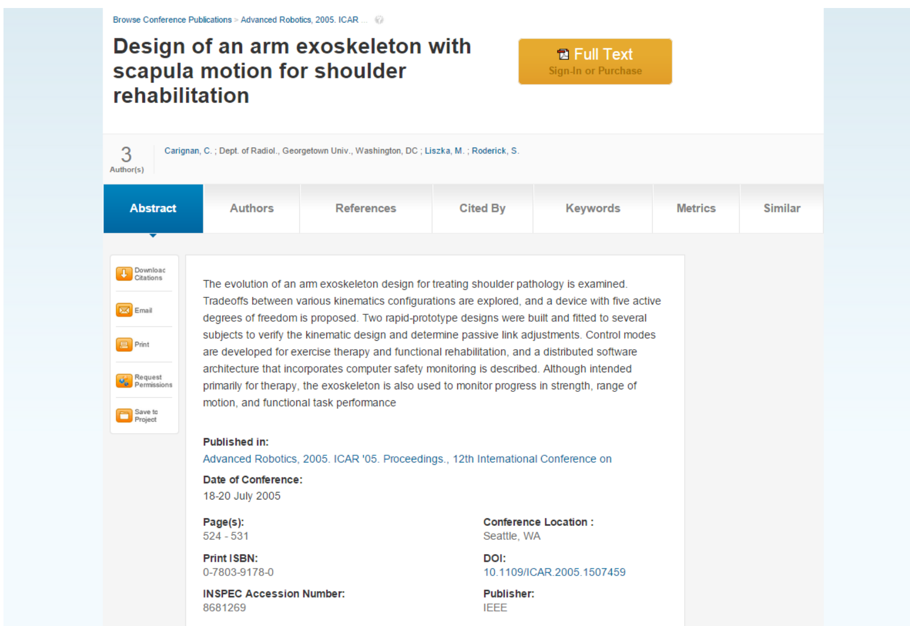
Documentation and Analysis of Previous Solution Attempts

Strengths of "Design of an Arm Exoskeleton with Scapula Motion for Shoulder Rehabilitation"

Found in the credible IEEE Xplore Digital Library that contains thousands of innovative engineering patents, this patent of an arm exoskeleton contains several strengths. First, it is very mobile, in that it has five degrees of motion freedom. Next, this prototype has been developed for exercise therapy and functional recovery of muscle weakness and debility. Finally, this patent can be used to test the extent of arm mobility and performance quality to enhance the following prototype.

Weaknesses of "Design of an Arm Exoskeleton with Scapula Motion for Shoulder Rehabilitation"

Although this concept has many positive aspects, two very prominent negative aspects exist too. The first is that a device like this is heavy and can only be worn for short periods of time. Second, this prototype is very expensive since it contains several DC Motors, which make the price unbelievably high. Also, the mechanism that makes this prototype mobile is expensive as well. The overall cost of this product would be too expensive to middle class patients who are in desperate need of cheap but efficient exoskeletons.



Carignan, C.; Liszka, M.; Roderick, S., "Design of an arm exoskeleton with scapula motion for shoulder rehabilitation," Advanced Robotics, 2005. ICAR '05. Proceedings., 12th International Conference on , vol., no., pp.524,531, 18-20 July 2005

doi: 10.1109/ICAR.2005.1507459

keywords: {distributed processing;medical control systems;monitoring;patient rehabilitation;safety;arm exoskeleton design;computer safety monitoring;distributed software architecture;exercise therapy;functional rehabilitation;kinematic design verification;passive link adjustments;rapid-prototype designs;scapula motion;shoulder rehabilitation;Computerized monitoring;Exoskeletons;Humans;Joints;Kinematics;Medical treatment;Shoulder;Software architecture;Software safety;Virtual reality},

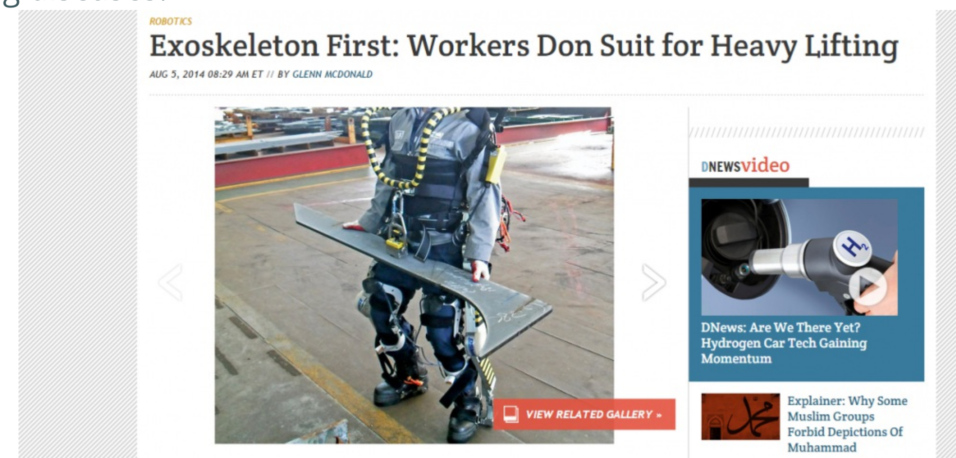
URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=1507459&isnumber=32295

Strengths of "South Korean Wearable Exoskeleton Suit"

A report from Discovery News, this device has strengths which include that the suit is not tethered to a big power source. The power source is within the suit itself, meaning that the stakeholder can use the suit in all locations. Also, the suit can carry its own weight plus an additional 70 pounds of weight, making it very easy to carry heavy items. The suits also have hydraulically powered units that can run for three hours on only one full charge. This is a great advantage as exoskeleton suits usually require a lot of power to operate.

Weaknesses of "South Korean Wearable Exoskeleton Suit"

Although this suit has several strengths, it does have two very major problems. Firstly, the suit is very rigid, so barely any maneuverability within the suit is allowed. Anyone who uses this suit would become sore, as there is only one position that the body can be in. Secondly, this suit is very expensive and would not be feasible for patients with diseases such as osteoporosis or muscle weakening diseases.



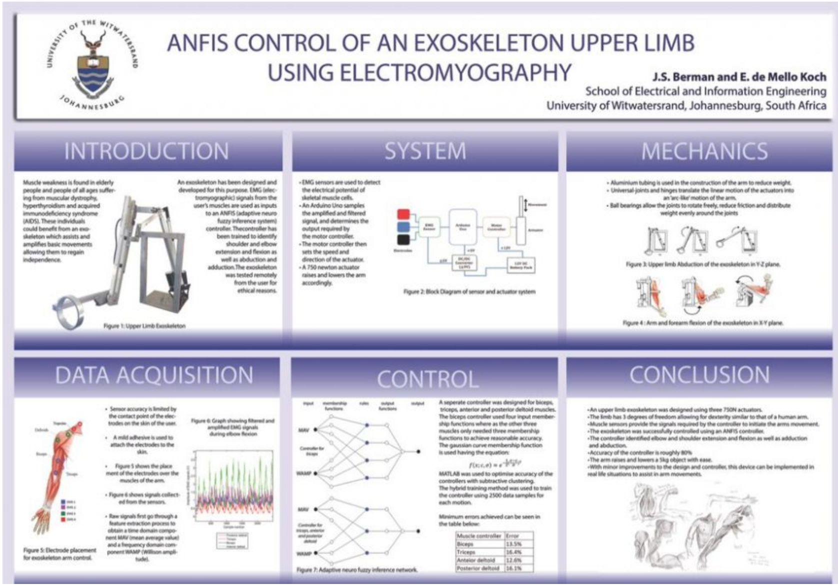
McDonald, Glenn. "Exoskeleton First: Workers Don Suit for Heavy Lifting : DNews." DNews. Discovery News, 5 Aug. 2014. Web. 10 Jan. 2015. <http://news.discovery.com/tech/robotics/exoskeleton-suit-workers-don-suit-for-heavy-lifting-140805.htm>.

Strengths of "Exoskeleton Upper Limb Using EMG"

From the reliable website Instructables, this prototype of an upper limb exoskeleton has several strong points. It contains an extremely intuitive control system which measures the brain signals of muscle contractions. This system is a test-bed for the development of innovative control systems and for future exoskeletons. The prototype has several hydraulic actuators which make the wearer capable of lifting more weight than they could lift without the exoskeleton.

Weaknesses of "Exoskeleton Upper Limb Using EMG"

Weaknesses include the fact that this device needs a constant non-portable power supply, which means that a patient with muscular debility cannot walk around with this device. Furthermore, this device takes a very long time to contract due to the weight of the hydraulic actuators on the exoskeleton. Also, this device needs a support structure because of its enormous size, making it unfeasible for patients with bone diseases or muscular weaknesses.



"Screen Shot 2014-10-13 at 11.06.04 PM.png." Screen Shot 2014-10-13 at 11.06.04 PM.png. Instructables, n.d. Web. 10 Jan. 2015. <http://www.instructables.com/file/F3KQ9T6I1565LS4>.

"UPPER LIMB EXOSKELETON (EXO-ARM)." Instructables.com. N.p., n.d. Web. 10 Jan. 2015. <http://www.instructables.com/id/IRON-MAN-EXOSKELETON/>.

To summarize, all of the prior attempts are too heavy, cumbersome, and cannot be worn by patients with muscle degradation or low bone density. Therefore, it is our conclusion that a new mechanism other than one using hydraulic or DC motors should be used. The above list showcases the numerous attempts to create upper arm exoskeletons. Some of these attempts are not designed to solve the problem delineated in element A, but were explored because they could yield valuable insight into any type of upper limb exoskeleton that we produce. The first and third examples fall into this category. These two were explored only to see if there was any way to adapt the mechanism to fit our purposes. In conclusion, these products show us that any solution developed must be effective, efficient, cheap, and lightweight.

PORTFOLIO ELEMENT C

PRESENTATION AND JUSTIFICATION OF SOLUTION DESIGN REQUIREMENTS

Prioritized Order of Design Requirements

1. Cost - The cost should be between $100 - 200. This is relatively cheap compared to other upper extremity exoskeletons which cost around $2000 - 3000. We placed cost as the highest design criteria because the main shareholder will be middle-class people with muscle and bone diseases.

2. Size - The product must be small enough to fit on the bicep of size ranging from teenagers to adults. Statistics show that more older adults have muscle weakness than younger adults. Therefore we should have more quantity of bicep sizes of adults than bicep sizes young adults. Size is the next most prioritized criteria because people with bone- weakening diseases and muscle-weakening disease cannot keep any proposed solution on their arms without excessive support structures. Also, it would be a benefit if the entire product would not be able to be seen under clothes.

3. Ease of Use - The product must be easy to begin working with. For example, it must take ten minutes to set-up and wear out of the box. Furthermore, it must be easy to wear and control. This is third on our list because any proposed solution should not interfere with the wearer's everyday life. But, if such a solution is not found, then cost and size would be the more important design requirements.

4. Lifespan - The product must last about 1.5 years without repair. 80% of Americans prefer a long-lasting device that doesn't need to be repaired, showing us that an ideal product should last long. This is fourth on our list because it does not interfere with the shareholder's ability to use it during their therapy, but also correlates to the overall product satisfaction.

5. Contraction Time - The muscle in the product should not take more than 5 seconds to contract for efficiency and quickness. Most customers would prefer a quick-to-respond device that does the job. Contraction time is fifth on the list because it relates to product satisfaction, but it does not impede the wearer. It is below lifespan on the list of priorities because we feel that this will not be a primary concern of the stakeholder.

6. Strength - This product should give an additional strength of around 35-50 lbs (depending on the number of coils) capability to the the user so that they will be able to lift moderately heavy loads. A patient with a bone disease would prefer extra strength to do exercise and gain a full recovery. The strength is not as essential to the product, because it does not need to carry a lot of weight as the weight will be distributed between the mechanism and the wearer. Though important, the first five factors are more essential to the product.

7. Weight - The product should be less than 10 lbs for efficient results and the most output of lifting capability. 58% of Americans prefer lightweight devices that would be efficient and produce good results. The is the last design requirement because it would be the least

important to the customer. The customer buys a product based on its efficiency and effectiveness. We believe that the first 6 design requirements are more essential to the stakeholder's experience. Also, any product that is released should be capable of being worn. This requirement is an offshoot of size, because any product that is small enough to fit on the bicep would naturally be light enough.

To summarize, we have seven design criteria as listed above. They have strict pass fail requirements and are ordered according to their importance. After creating this list, our team referenced element B to check if there is a method used in previous attempts that could be adapted. However, all the previous solutions fail requirement number two, which states that any proposed mechanism should be able to be worn underneath the clothes. Therefore, we must research other mechanisms to pass requirement number 2.

Bibliolography:

"America's Health Rankings." America's Health Rankings - State Healthstats. N.p., n.d. Web. 13 Jan. 2015.

Centers for Disease Control and Prevention. Centers for Disease Control and Prevention, 15 Jan. 2015. Web. 12 Jan. 2015.

"FAQ: Medical Statistics." U.S National Library of Medicine. U.S. National Library of Medicine, n.d. Web. 14 Jan. 2015.

"Statistics." Statistics - Group on Women in Medicine and Science (GWIMS) - Member Center - AAMC. N.p., n.d. Web. 25 Dec. 2014.

"Statistics and Data: National." National. N.p., n.d. Web. 27 Dec. 2014.

PORTFOLIO ELEMENT D

DESIGN CONCEPT GENERATION, ANALYSIS, AND SELECTION

Design Concept, Analysis, and Selection

The following is our systematic way of generating a concept. The video is an animation which provides a short but informative description of how our final concept works. Following that, we have an initial design matrix created to help choose from three different methods to power the exoskeleton. The third part is a schematic of our wiring for the proposed prototype.The fourth portion is a system to control the exoskeleton written in pseudo-code. The final portion is an analysis and explanation to everything above.

Credit to: AECSElectromaterials

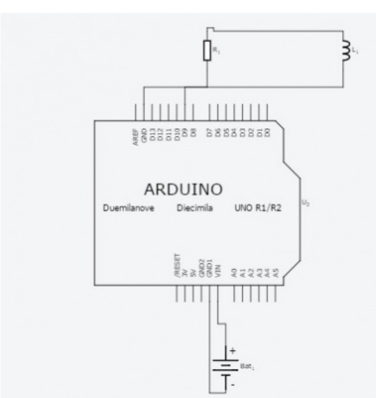
Design Matrix

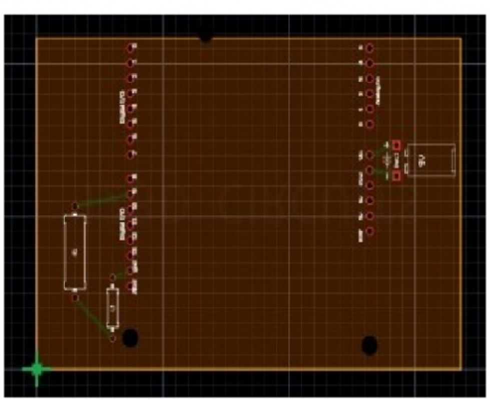
Decision Factors		Hydralic Acuator	Coiled Fishing Line Muscle	Electronic Servo
Criteria	Wt.	1	2	3
Contraction Speed	2.0	1	1	0
Size	2.0	-1	1	0
Ease of Use	2.0	1	1	1
Support Structure	1.0	-2	1	-2
Lifting Capabilities	1.0	1	1	1
Cost	1.0	-1	1	1
Linear or Circular	1.0	1	1	0
Weighted Scores		1.0	10.0	DQ

Which is the Best?
The best overall system is the coiled plasic muscle built out of coiled polyfilament fishing line. Our design matrix proves that this is the best solution to the given parameters. Other solutions that were explored such as Hydralic Acuators could not produce the speed within the smallest form factor. Also, Electronic Servos can not produce a linear motion, therefore, they require massive amounts of support structure on the entire arm. This elimanates them from the matrix.
▶ Winner: Coiled Fishing Line Muscle

Criteria	Definition
Contraction Speed	How fast does the proposed mechanism contract with relation to the human muscle?
Size	Will it be uncomfortably large on the arm? Will it be able to fit under a jacket without be uncumbersome.
Ease of Use	How easy is it control? Does it take conscious thought to control the proposed mechanism?
Support Structure	What kind of structure with it need to attatch it to the human arm? Will the support structure need additional space on the arm. (i.e a full mount reaching the shoulder.
Lifting Capabilities	Can the proposed mechanism lift the same amount as a similarly sized human muscle?
Cost	Total cost of the proposed mechanism. If the cost for a bicep-sized system is more than $100 dollars while producing a good working load.
Linear or Circular	Is the motion linear of circular. If the motion is circular, than the proposed method will be disqualified immediately.

Note on Electronic Servo: It has be disqualified from the matrix because it produces circular motion, not linear motion.





Our schematic shows an Arduino Uno, which is a micro-controller along with a resistor powering an inductor. Inductors are used to limit the amount of current passed through the current. They work by looping large amounts of coiled wire in a small zone. A side effect is that they generate large amounts of heat in the process. As shown in the animation video above, the heat from this inductor will compress the coil, thereby compressing the total length of the coil. Over a large coil, with a large current, this will be extremely powerful, as shown in the following video. The image next to the schematic is a PBC board. This PBC board was generated to show how the prototype control board would look. This next video showcases the power of a large current along with an inductor on a small piece of fabric with embedded coils of fishing line.

Credit to: AECSElectromaterials

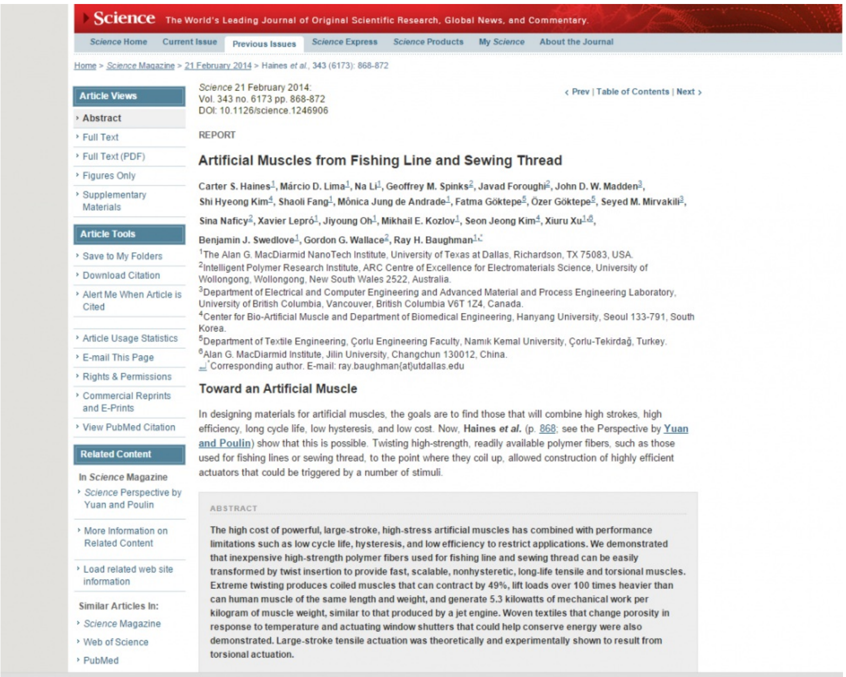
Pseudocode Control System:

```
Init all components;
loop infinitely:
    if EMS detect muscle contraction:
        pass 9 volt current though D9;
    else if EMS detect muscle expansion:
        do activating liquid cool;
    else:
        do nothing;
```

The above is pseudocode for the design. It showcases primitive control structures being used to manipulate the fabric. In the pseudocode, EMS is mentioned as a control system. EMS stands for electromyography sensor. Electromyography is a technique invented to determine if patients have abnormal neuron activity in muscles. It can be purchased in small packages that hook up to the arduino board and attach to your muscle. They provide a good amount of precision in detecting the contraction of muscles.

Credit: SeeedStudio Grove EMG detector

Data and Sources That We Used In Our Design Matrix



Science The World's Leading Journal of Original Scientific Research, Global News, and Commentary.

Science Home | Current Issue | Previous Issues | Science Express | Science Products | My Science | About the Journal

Home > Science Magazine > 21 February 2014 > Haines et al., 343 (6173): 868-872

Article Views
- Abstract
- Full Text
- Full Text (PDF)
- Figures Only
- Supplementary Materials

Article Tools
- Save to My Folders
- Download Citation
- Alert Me When Article is Cited
- Article Usage Statistics
- E-mail This Page
- Rights & Permissions
- Commercial Reprints and E-Prints
- View PubMed Citation

Related Content

In Science Magazine
- Science Perspective by Yuan and Poulin
- More Information on Related Content
- Load related web site information

Similar Articles In:
- Science Magazine
- Web of Science
- PubMed

Science 21 February 2014:
Vol. 343 no. 6173 pp. 868-872
DOI: 10.1126/science.1246906

‹ Prev | Table of Contents | Next ›

REPORT

Artificial Muscles from Fishing Line and Sewing Thread

Carter S. Haines[1], Márcio D. Lima[1], Na Li[1], Geoffrey M. Spinks[2], Javad Foroughi[2], John D. W. Madden[3], Shi Hyeong Kim[4], Shaoli Fang[1], Mônica Jung de Andrade[1], Fatma Göktepe[5], Özer Göktepe[5], Seyed M. Mirvakili[3], Sina Naficy[2], Xavier Lepró[1], Jiyoung Oh[1], Mikhail E. Kozlov[1], Seon Jeong Kim[4], Xiuru Xu[1,6], Benjamin J. Swedlove[1], Gordon G. Wallace[2], Ray H. Baughman[1,*]

[1]The Alan G. MacDiarmid NanoTech Institute, University of Texas at Dallas, Richardson, TX 75083, USA.
[2]Intelligent Polymer Research Institute, ARC Centre of Excellence for Electromaterials Science, University of Wollongong, Wollongong, New South Wales 2522, Australia.
[3]Department of Electrical and Computer Engineering and Advanced Material and Process Engineering Laboratory, University of British Columbia, Vancouver, British Columbia V6T 1Z4, Canada.
[4]Center for Bio-Artificial Muscle and Department of Biomedical Engineering, Hanyang University, Seoul 133-791, South Korea.
[5]Department of Textile Engineering, Çorlu Engineering Faculty, Namık Kemal University, Çorlu-Tekirdağ, Turkey.
[6]Alan G. MacDiarmid Institute, Jilin University, Changchun 130012, China.
[*]Corresponding author. E-mail: ray.baughman(at)utdallas.edu

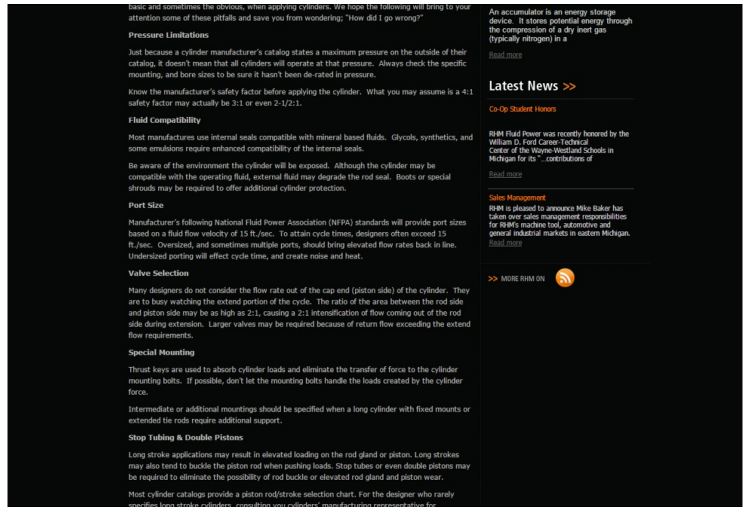
Toward an Artificial Muscle

In designing materials for artificial muscles, the goals are to find those that will combine high strokes, high efficiency, long cycle life, low hysteresis, and low cost. Now, **Haines *et al.*** (p. 868; see the Perspective by Yuan and Poulin) show that this is possible. Twisting high-strength, readily available polymer fibers, such as those used for fishing lines or sewing thread, to the point where they coil up, allowed construction of highly efficient actuators that could be triggered by a number of stimuli.

ABSTRACT

The high cost of powerful, large-stroke, high-stress artificial muscles has combined with performance limitations such as low cycle life, hysteresis, and low efficiency to restrict applications. We demonstrated that inexpensive high-strength polymer fibers used for fishing line and sewing thread can be easily transformed by twist insertion to provide fast, scalable, nonhysteretic, long-life tensile and torsional muscles. Extreme twisting produces coiled muscles that can contract by 49%, lift loads over 100 times heavier than can human muscle of the same length and weight, and generate 5.3 kilowatts of mechanical work per kilogram of muscle weight, similar to that produced by a jet engine. Woven textiles that change porosity in response to temperature and actuating window shutters that could help conserve energy were also demonstrated. Large-stroke tensile actuation was theoretically and experimentally shown to result from torsional actuation.

Credit to: Science.com



basic and sometimes the obvious, when applying cylinders. We hope the following will bring to your attention some of these pitfalls and save you from wondering; "How did I go wrong?"

Pressure Limitations

Just because a cylinder manufacturer's catalog states a maximum pressure on the outside of their catalog, it doesn't mean that all cylinders will operate at that pressure. Always check the specific mounting, and bore sizes to be sure it hasn't been de-rated in pressure.

Know the manufacturer's safety factor before applying the cylinder. What you may assume is a 4:1 safety factor may actually be 3:1 or even 2-1/2:1.

Fluid Compatibility

Most manufactures use internal seals compatible with mineral based fluids. Glycols, synthetics, and some emulsions require enhanced compatibility of the internal seals.

Be aware of the environment the cylinder will be exposed. Although the cylinder may be compatible with the operating fluid, external fluid may degrade the rod seal. Boots or special shrouds may be required to offer additional cylinder protection.

Port Size

Manufacturer's following National Fluid Power Association (NFPA) standards will provide port sizes based on a fluid flow velocity of 15 ft./sec. To attain cycle times, designers often exceed 15 ft./sec. Oversized, and sometimes multiple ports, should bring elevated flow rates back in line. Undersized porting will effect cycle time, and create noise and heat.

Valve Selection

Many designers do not consider the flow rate out of the cap end (piston side) of the cylinder. They are to busy watching the extend portion of the cycle. The ratio of the area between the rod side and piston side may be as high as 2:1, causing a 2:1 intensification of flow coming out of the rod side during extension. Larger valves may be required because of return flow exceeding the extend flow requirements.

Special Mounting

Thrust keys are used to absorb cylinder loads and eliminate the transfer of force to the cylinder mounting bolts. If possible, don't let the mounting bolts handle the loads created by the cylinder force.

Intermediate or additional mountings should be specified when a long cylinder with fixed mounts or extended tie rods require additional support.

Stop Tubing & Double Pistons

Long stroke applications may result in elevated loading on the rod gland or piston. Long strokes may also tend to buckle the piston rod when pushing loads. Stop tubes or even double pistons may be required to eliminate the possibility of rod buckle or elevated rod gland and piston wear.

Most cylinder catalogs provide a piston rod/stroke selection chart. For the designer who rarely

An accumulator is an energy storage device. It stores potential energy through the compression of a dry inert gas (typically nitrogen) in a

Read more

Latest News >>

Co-Op Student Honors

RHM Fluid Power was recently honored by the William D. Ford Career-Technical Center of the Wayne-Westland Schools in Michigan for its "...contributions of

Read more

Sales Management

RHM is pleased to announce Mike Baker has taken over sales management responsibilities for RHM's machine tool, automotive and general industrial markets in eastern Michigan.

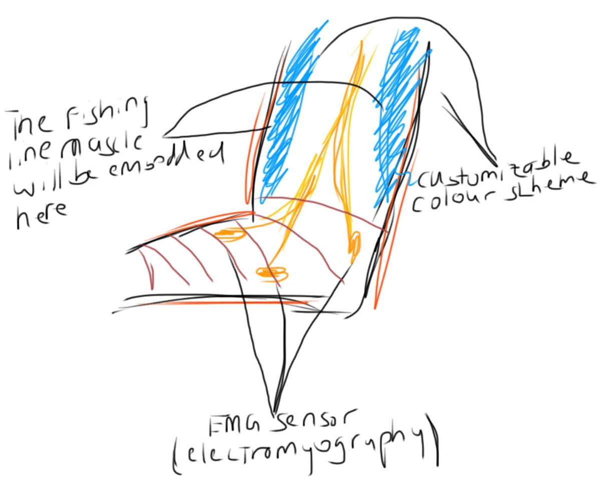
Read more

>> MORE RHM ON

Credit to: RMHfluidpwer.com

Putting all the wiring schematics and design aspects into one product, we get a basic prototype of HyFlex. It will use all the above mechanisms to make a useful, efficient product designed to help patients inflicted with muscle-weakening disease or other physical disabilities.

HyFlex



The three yellow circles represent the EMG sensors (another picture of these sensors is listed above). They will measure the brain signals of contractions and send it to the Arduino Uno, which will then process the information and perform the pseudocode stated above. The Arduino Uno and all other circuitry will be on a protected motherboard located somewhere on the body.The muscle will then be heated by the inductors, which will successfully contract the coil. Furthermore, the fishing line/sewing thread will be embedded into a fabric with a customizable color scheme to make the product look more aesthetically pleasing.

To recap element D, we referred our requirement list to determine if any proposed solution could pass requirement number two, which no previous attempts were able to pass. As a team, we decided that any proposed solution must be biomimetic. Biomimetics are mechanisms which mimic mechanisms that occur in nature. We selected the fishing line/sewing thread muscle while looking for artificial muscles that use everyday materials. As published in science.com, the fishing line/sewing thread muscle is twisted fishing line or nylon multi filament sewing thread. The twisted fishing line is heated and then contracts by up to 30%. In accordance with STEM principles, we researched the various phenomena involved, and have listed them, along with detailed equations in the next element.

PORTFOLIO ELEMENT E

APPLICATION OF STEM PRINCIPLES AND PRACTICES

Applications of STEM Principles and Practices:

Heat Principles:

We discovered the principles of heat through our AP Physics textbook.

Heat Transfer and Thermal Expansion

Heat transfer or **heat flow** constantly takes place between substances at different temperatures. The objects may be in the same state or in different states. Transfer of thermal energy occurs through conduction (directly touching), convection (currents of thermal origin in fluids), or radiation (electromagnetic waves). As substances absorb heat, their internal energy increases, and their molecules vibrate faster. For most substances this increased vibration translates into an increase in length, area, and volume.

Solids that undergo heating and cooling expand and contract. The length of a metal rod or a length of railroad track, for instance, obey the following relationship:

$$\Delta l = \alpha l_o \Delta T$$

where Δl is the change in length due to heating, l_o is the original length of the object and ΔT is the change in temperature in C°.

When solids and liquids are heated or cooled, their volumes in turn increase or decrease as their materials expand or contract. For volumetric expansion of solids and liquids, note the following relationship:

$$\Delta V = \beta V_o \Delta T$$

where ΔV is the change in volume due to heating, β is the coefficient of volumetric expansion, V_o is the original volume, and ΔT is the change in temperature in C°. Also, $\beta = 3\alpha$.

Example

A section of steel railroad track (α for steel = 10.5×10^{-6} /C°) is 4.0 m long. If the air temperature increases from 0° C to 15°C, by how much does the length increase?

Solution

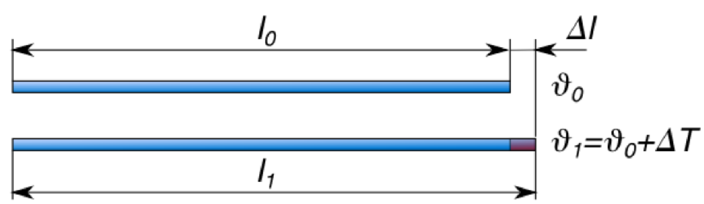
Using $\Delta l = \alpha l_o \Delta T$:

$$\Delta l = (10.5 \times 10^{-6}\ /C°)(4.0\ m)(15°) = \mathbf{6.3 \times 10^{-4}\ m\ linear\ increase}$$

Example:

A yellow brass cube with sides of 10 cm is cooled from 100°C to 20°C. By how much does its volume change? (α for yellow brass = 20.3×10^{-6} /°C)

Credit to Cliff Notes AP Physics Textbooks



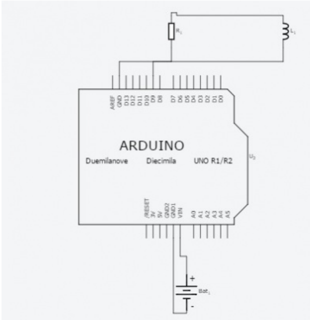
The thermal expansion coefficient of Nylon is 66.6 * 10^-6 (m / (mK)) (where m = meter and mK = milliKelvin). This is about three times the thermal expansion of Aluminum. Because of the contraction due to length, this means that there is more fishing line in an area. Also, we must take into account that each piece of fishing line is made of thousands of individual fibers, so the effect is multiplied by the number of fibers. Altogether the equation looks like:

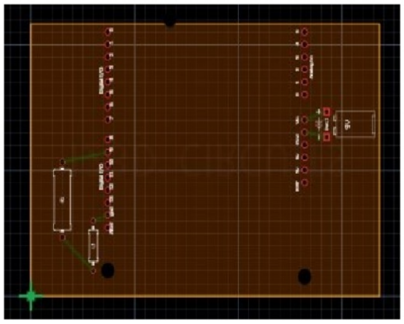
$$\Delta I = \alpha I_o \Delta T$$
$$\Delta(I) = (66.6 * 10^6)(.3)(50)(1000)$$

This yields a total contraction of 0.1 meters. Considering that the original length of the fishing line was 0.3 meters, this is a total contraction of 33.3%. This equation assumes that there are one thousand individual nylon fibers along with a temperature change of 50 degrees celsius. Either of these variables can change and still yield high contraction percentage.

Electronic Principles:

In order to learn about electronics, we extensively researched Arduino Uno, which is a flexible microcontroller, popular with many DIY fans. Since we want to contract the fishing line electronically, we researched inductors. Inductors are passive two terminal electronic components which resist electric current. A side effect is that they heat up very rapidly. A component like that would be perfect for our purposes. Aside from that, we constructed a wiring diagram to showcase how a simple circuit along with a Arduino Uno, a resistor, and an inductor could be made into a PBC board which would be easy to manufacture.





Created by our team along with Autodesk 123D Circuit

Along with this, we searched for a control system that would seamlessly integrate into the stakeholder's life. In accordance with STEM principles, we reached out to specialists. Doctors everywhere use EMG sensors to test for neural activity, we learned. We decided to modify an EMG sensor to be used to sense the contraction of muscles. The sensed contraction will send a signal to the Arduino Uno, and then the micro controller will send 9 V of electricity through the inductor. This will cause a temperature increase which will in turn cause the fishing line to contract.

In compliance with STEM principles, we extensively researched heat that is generated by inductors.

$$R = R_0(1 + \alpha(T - T_0]))$$

$$R = 100(1 + (3.9 * 10^{-3}(100 - 20)))$$

This equation shows the change in temperature when a change in resistance is implemented. We will be using this equation to calculate how much electricty to supply to the inductor. Using these values, we will be able to determine how long the muscle takes to contract, including the usage of the equations listed above.

To confirm all of these equations, we requested Amit Nigam, an engineer at Cisco Systems and an AP Physics tutor, to peer review all of our work. Mr. Nigam agreed with all equations and diagrams presented here and has approved that we acted in accordance with STEM principals. We also requested Ramesh Yeevani, who is a Director of Engineering at Cisco System, to verify the electronics and check or wiring PCB board. We got confirmation from Mr. Nigam and Mr. Yeevani to prove our credibility and our research.

To summarize, this element is dedicated to providing detailed documentation of STEM principles and practices. To verify all of the claims listed in the science.com article, we researched thermal expansion and contraction equations. Also, we researched how to control the exoskeleton, and agreed upon a system that uses a cheap Arduino Uno available at our local electronics store and EMG sensors, which would connect to the Arduino Uno. Finally, we created a schematic of the final electronic setup excluding the EMG sensor and requested it to be checked by Ramesh Yeevani, who is a Director of Engineering at Cisco Systems and Alok Verma, a Director of Software Development and Engineering at Amazon. We also requested Amit Nigam to review all of our physics equation and diagrams to ensure accuracy and to prove our reliability. All of their feedback and comments have been taken into account, which is what you have read thus far.

PORTFOLIO ELEMENT F

CONSIDERATION OF DESIGN VIABILITY

Consideration of Design Viability

1. Cooling Mechanism - The main obstacle to our product is the cooling mechanism. Cooling directly relates the to the stroke time. (Stroke time is the amount of time that the muscle takes to heat up and cool down The cooling mechanism will need to cool down extremely fast.

Our solution to the cooling mechanism problem is to place a liquid cooled computer fan in the system which will cool down all the systems. This will be efficient and quite effective at solving the thermal problem.

2. Heat Transferrence - The second most important obstacle is the heat transferring from the device to the arm. This is less important than the cooling problem as the cooling problem affects the usability of the product, whereas the heat transference affects the user comfort. Although both of these are very important, the cooling problem is more important than heat transferrence.

Our solution to this problem is to use ceramic tiles that are commonly used in bathroom showers. These ceramics have a high temperature yield and will effectiviely block out all of the heat generated.

3. Battery Life - The third most important problem is battery life. Cooling and heating requires large amounts of battery life as seen in our calculations on element D. This problem is beneath 1 and 2 because it not at all vital to the usability of our product or the user comfort but to the total usability time.

To mediate this issue, we researched supercapacitors which should be able to effectively solve the battery time issue. These will retain the battery strength, allowing for more usage time.

4. Lifespan - The fourth most important obstacle is the lifespan of the product. Although the three obstacles above are more important than the lifespan of the product, the lifespan is also a significant hurdle. The estimated lifespan of this product is around 1.5 years, which is a decent time for a lifespan but could be improved. 60% of Americans care about effiency and effectiveness rather than the lifespan of a product, bolstering the lifespan obstacle's position on our prioritized list.

Our solution to this is to make the HyFlex out of many smaller muscles which will not only increase the lifespan, but also the control and the battery usage by fine tuning the system to respond in the most efficient way possible.

5. Aesthetic Value - The final obstacle on our prioritized list of hurdles is the aesthetic value of the device itself. This is the least of our priorities as we want to make a product that fulfills the stakeholder's demand and not necessarily make it aesthetically pleasing. However, this is still our last obstacle, and we do want to make a well-rounded device. 57% of Americans prefer an effective and efficient device over an aesthetically pleasing product

To overcome this obstacle, we have made the fabric lining the muscle itself available in several colors to satisfy stakeholders who prefer an aesthetically pleasing device.

To compare our product's viability with other products' viabilities, our team made a solution matrix where we compared important factors of our product, the HyFlex, to the same factors of other products designed for the same solution. We researched several products and then filled out a solution matrix. Furthermore, to prove that we are not biased, we gave the same research and evidence (websites can be found below) to physicist Mr. Nigam and engineer Mr. Yeevani who filled out a template of the solution matrix we created. Our solution matrix is the first one and Mr. Nigam's and Mr. Yeevani's solution matrix is underneath our matrix. (-2 is the lowest score of the scoring system and 2 is the highest score of the system).

Solution Selection Matrix

	Cost	Size	Contraction Time	Battery	Total
Solution Selection Criteria	Score	Score	Score	Score	Score
TITAN Upper-Limb Exoskeleton	-2	-1	1	-1	-3
HyFlex	1	1	1	1	4
EXO-UL3	-2	-2	2	-2	-4
RUPERT	-2	-1	1	1	-1
sEMG	-2	-1	1	1	-1

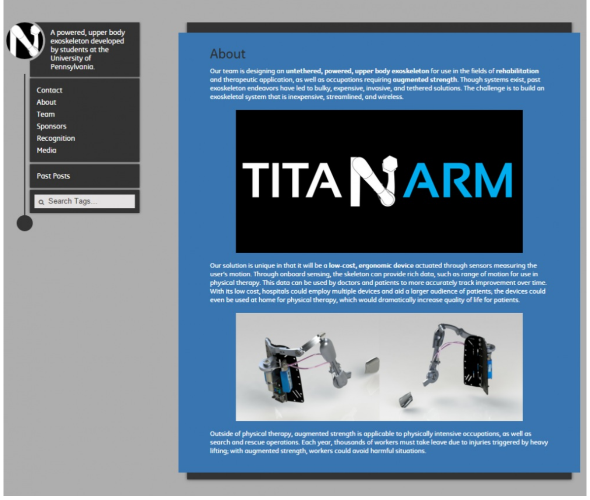
Our Solution Matrix

Solution Selection Matrix

	Cost	Size	Contraction Time	Battery	Total
Solution Selection Criteria	Score	Score	Score	Score	Score
TITAN Upper-Limb Exoskeleton	-2	-2	2	-1	-3
HyFlex	1	2	1	1	5
EXO-UL3	-2	-2	1	-2	-5
RUPERT	-2	-1	2	2	1
sEMG	-2	-2	1	2	-1

Mr. Yeevani and Mr. Nigam's Solution Matrix

As you can see, the total scores for all devices are very close to each other, and HyFlex comes out on top in both solution matrices. The weakest device presumed by our team and Mr. Yeevani and Mr. Nigam is the product EXO-UL3. This product has the worst performance compared to all other deviced based on our research and the products' respective websites of information. The following are samples of the information our team used for research on all the devices. Mr. Nigam and Mr. Yeevani got the information of HyFlex from our design requirements, application of STEM principles, and other analysis and statistics we gave them.



The Titan Arm is a strong upper limb exoskeleton. Drawbacks include extraordinary cost and large weight on shoulders and back.

Figure : Multi degrees of freedom (DOF) conceptual model of the upper limb exoskeleton (The additional DOF that will allow hand grasping is not illustrated). The black color represents links, the red color represents powered (actuated) joints, and the green color represents multi axes force sensors.

It is anticipated that the proposed research will advance the current knowledge in the field of modeling human muscles and their mathematical formulation. This knowledge will be further used to create a novel HMI and will permit a better understanding of the interaction between human and robot at the neural level. In addition, the proposed research will provide a tool and fundamental understanding regarding the development of an assistive technology for improving the quality of life of the disabled community. The proposed scientific activity will promote interdisciplinary collaboration between students and faculty members from the fields of electrical engineering, mechanical engineering, bioengineering, and rehabilitation medicine.

UL3 is designed for tethered use for extremely heavy objects and was created to showcase factory level technology.

The design of a wearable upper extremity therapy robot RUPERT IVtrade (Robotic Upper Extremity Repetitive Trainer) device is presented. It is designed to assist in repetitive therapy tasks related to activities of daily living which has been advocated for being more effective for functional recovery. RUPERTtrade has five actuated degrees of freedom driven by compliant and safe pneumatic muscle actuators (PMA) assisting shoulder elevation, humeral external rotation, elbow extension, forearm supination and wrist/hand extension. The device is designed to extend the arm and move in a 3D space with no gravity compensation, which is a natural setting for practicing day-to-day activities. Because the device is wearable and lightweight, the device is very portable; it can be worn standing or sitting for performing therapy tasks that better mimic activities of daily living. A closed-loop controller combining a PID-based feedback controller and a iterative learning controller (ILC)-based feedforward controller is proposed for RUPERT for passive repetitive task training. This type of control aids in overcoming the highly nonlinear nature of the plant under control, and also helps in adapting easily to different subjects for performing different tasks. The system was tested on two able-bodied subjects to evaluate its performance.

Published in:
Virtual Rehabilitation, 2008

Date of Conference:
25-27 Aug. 2008

Page(s):
163 - 167

Conference Location :
Vancouver, BC

E-ISBN :
978-1-4244-2701-7

DOI:
10.1109/ICVR.2008.4625154

Print ISBN:
978-1-4244-2700-0

Publisher:
IEEE

INSPEC Accession Number:
10205324

RUPERT is a design created with much of the same purpose as our product. However, the product is very heavy and usability is low.

sEMG-Based Control of an Exoskeleton Robot Arm

Baocheng Wang[1], Chenguang Yang[2], Zhijun Li[1,3,⋆], and Alex Smith[2]

[1] Department of Automation, Shanghai Jiao Tong University, Shanghai, China
[2] School of Computing and Mathematics, Plymouth University, UK
[3] College of Automation Science and Engineering, South China University of Technology, Guangzhou, China
zjli@ieee.org

Abstract. This paper investigates the processing of surface electromyographic (sEMG) signals collected from the forearm of a human subject and, based on which, a control strategy is developed for an exoskeleton arm. In this study, we map the motion of elbow and wrist to the corresponding joints of an exoskeleton arm. Linear Discriminant Analysis (LDA) based classifiers are introduced as the indicator of the motion type of the joints, and then with the force of corresponding agonist muscles the control signal is produced. In the strategy, which is different from the conventional method, we assign one classifier for each joint, decomposing the motion of the two joints into independent parts, making the recognition of the forearm motion a combination of the results of different joints. In addition, training time is reduced and recognition of motion is simplified.

Keywords: sEMG, LDA, exoskeleton, force estimation.

1 Introduction

Myoelectric signals (MES) can be used to detect a human user's motion intention. The information extracted from MES, recognized as patterns, can be used in a control system, known as a myoelectric control system (MCS), to control rehabilitation devices or assistive robots. The most important advantage of myoelectric control is hands free control compared with other types of control system, such as body-powered mechanical systems (e.g. joysticks and keyboards), which

sEMG was created to showcase EMG technologies application in exoskeleton use. The sEMG is not created for commercial use.

To summarize everything above, our product has 5 obstacles that must be solved before building a final product. We have plausible solutions to all of the problems described above. However, when finalizing the prototype design, we must take into account our problems otherwise the product will not work. Also, we contacted Ramesh Yeevani and Amit Nigam and requested that they make a solution matrix utilizing various statistics found on the websites in our bibliography and the performance of HyFlex as dictated by the information in element E.

Bibliography:

"About Titan Arm." Titan Arm. University of Pennsylvania, n.d. Web. 12 Jan. 2015. <http://titanarm.com/about>.

"An Adaptive Upper-Arm EMG-Based Robot Control System." An Adaptive Upper-Arm EMG-Based Robot Control System. Academia, n.d. Web. 14 Dec. 2014. <http://www.academia.edu/5227043/An_Adaptive_Upper-Arm_EMG-Based_Robot_Control_System>.

"EXO-UL3." UCLA: Bionics Lab. UCLA, n.d. Web. 2 Jan. 2015. <http://bionics.seas.ucla.edu/research/exoskeleton_device_3.html>.

"RUPERT." National Center for Biotechnology Information. U.S. National Library of Medicine, n.d. Web. 11 Jan. 2015. <http://www.ncbi.nlm.nih.gov/pubmed/17281846>.

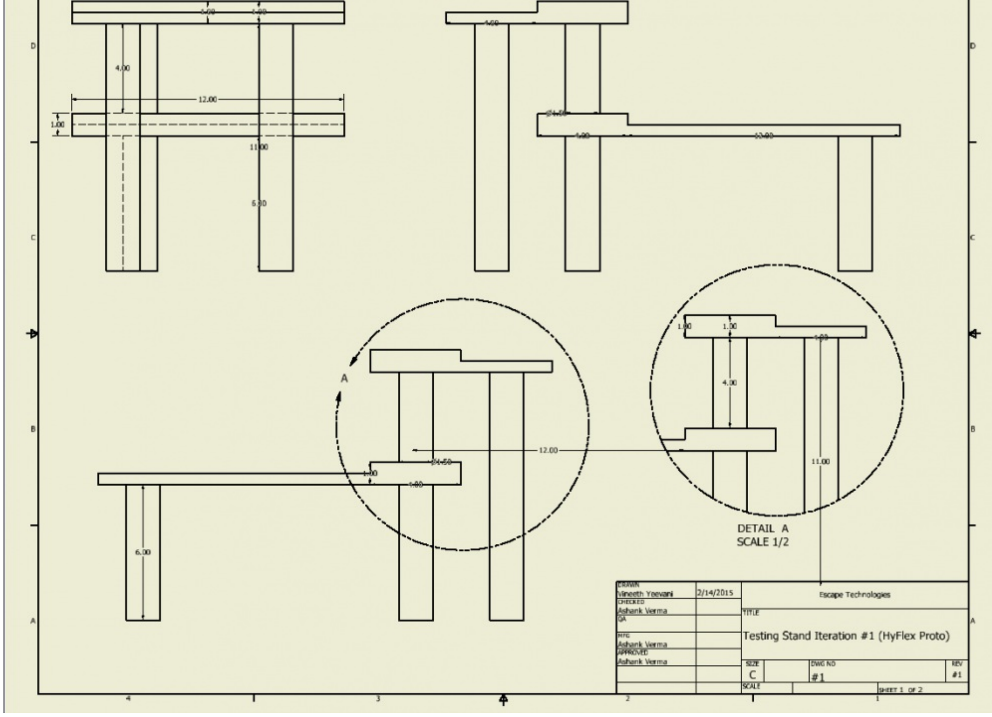
PORTFOLIO ELEMENT G

CONSTRUCTION OF A TESTABLE PROTOTYPE

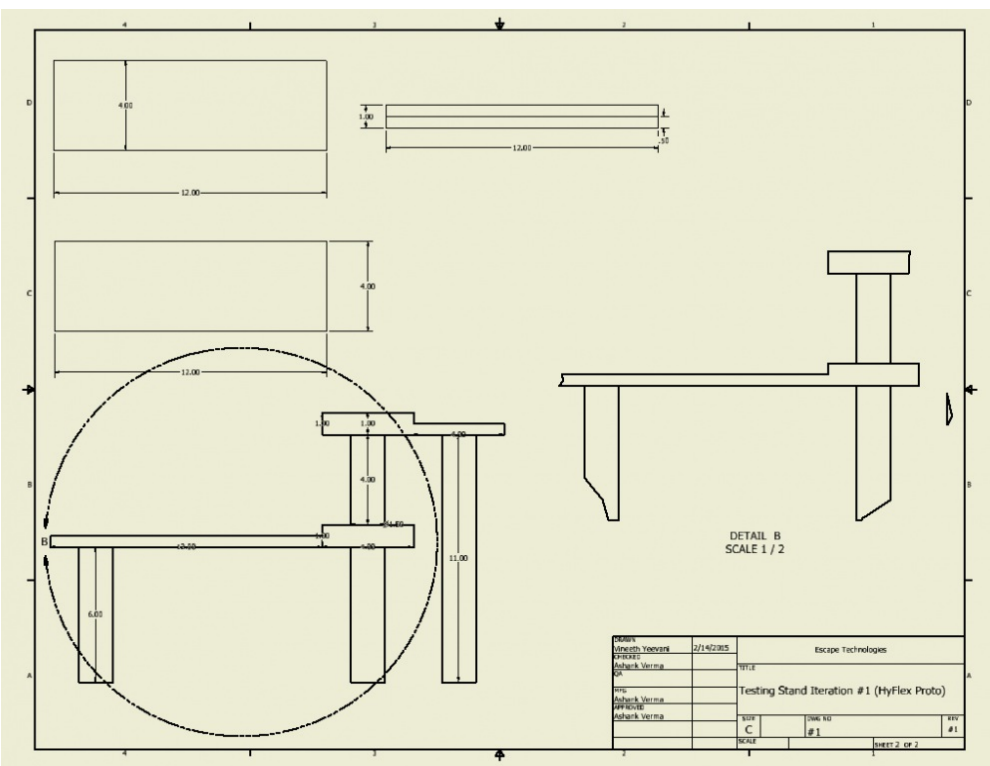
Construction of a Testable Prototype

Our final design iteration of a testable prototype includes the following mechanisms: Circuitry, Muscle Heating Mechanism, Contraction Sensing Mechanism, and Muscle Contraction Mechanism.

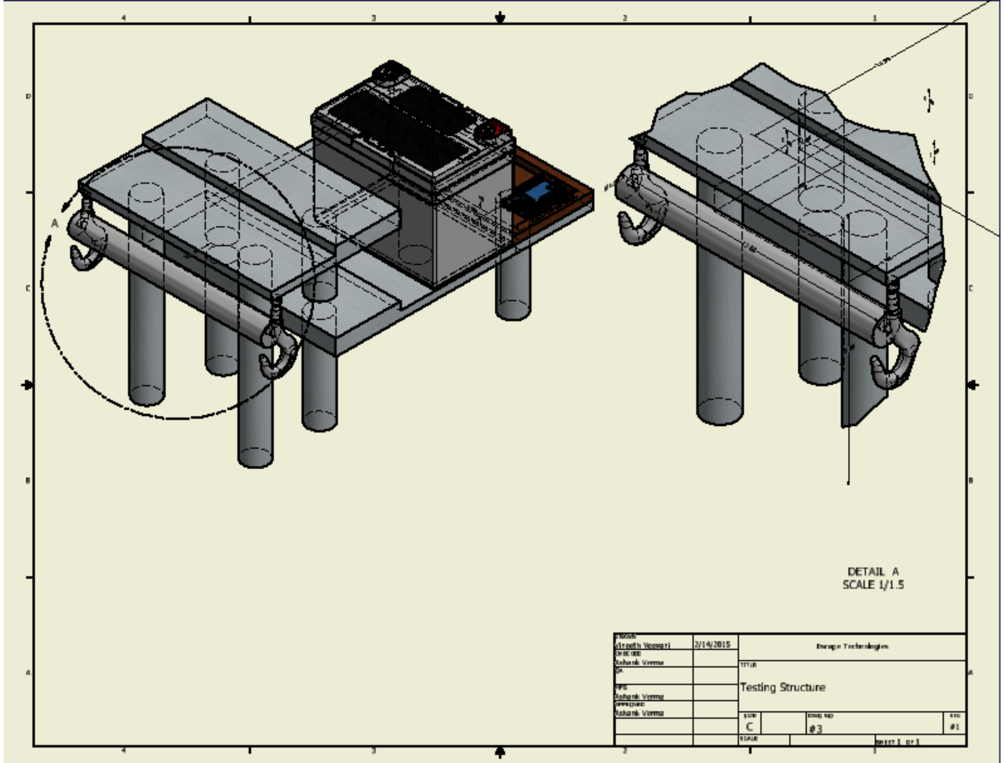
Before we commence the construction of a testable prototype, we will need a testing stand, made up of birch wood. The following are a series of pictures of testing stand design concepts and a first iteration.



Our prototype will be tested using a stand at first, and then will begin final testing on humans after the contraction values are verified. To the left is the stand on which the prototype will be tested. The stand is supported by six pylons and will be made out of birch wood. The structure will be strong and light. These pictures are drafts of the testing stand. Below, there are final build pictures. The testing stand will be used to test two different iterations of the HyFlex muscle at the same time.



This is the final model of the testing superstructure. The battery is a generic car-battery. The arduino board is on a container which will keep the board from shorting. We will add a fan if it is necessary.



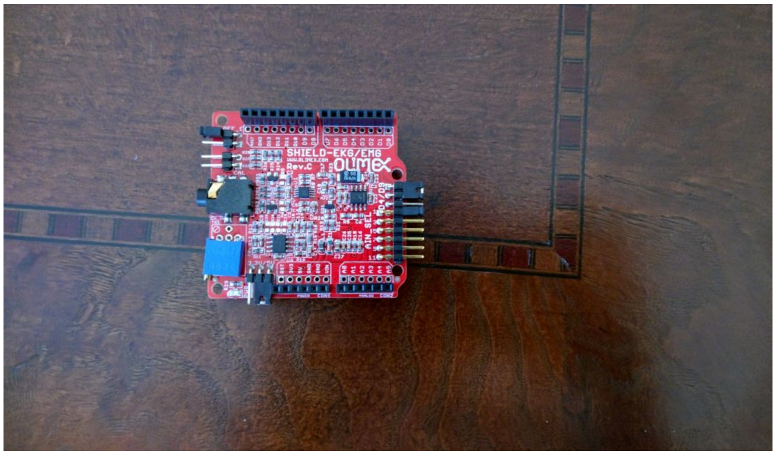
This is the third and final engineering design of what a final iteration of a testing stand will look like.

This is a picture of the first iteration of our testing stand. The Arduino Uno will be safely secured in the left corner of the testing stand so it doesn't short anything. The car battery will go on the lower platform and serve as a counterweight to keep the stand from tipping over. HyFlex will be attached to the higher platform and will hang down. It will be connected to weights and the muscle should contract when heated.

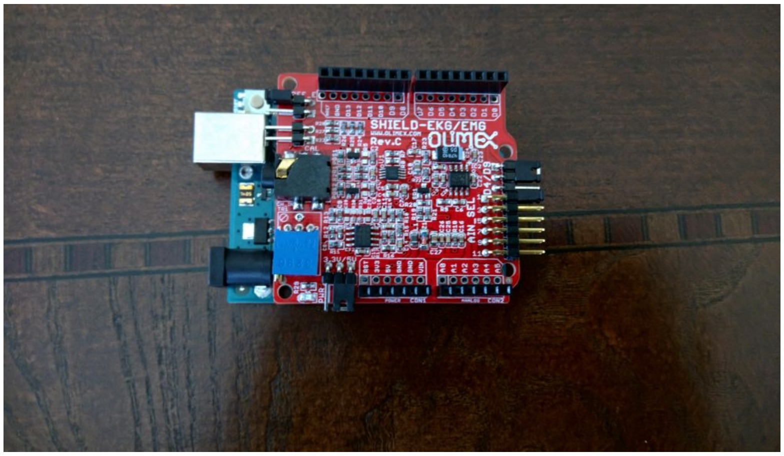
Circuitry and Muscle Heating Mechanism

All our mechanisms in our product will be linked by circuitry. Our CPU is on the Arduino Uno Board, which will be programmed to receive input from the EMG sensors and will send several commands to the muscle. This is the primary aspect of our product.

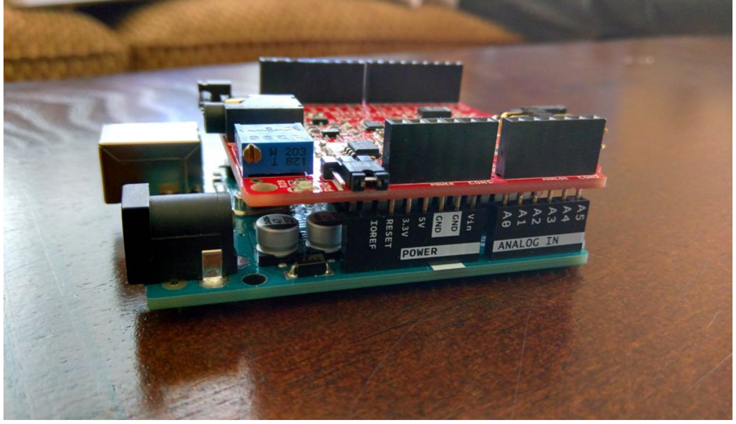
This is a picture of the Arduino Uno microcontroller board. It contains 6 analog inputs, 14 digital input or output pins, a 16 MHz resonator, a reset button, and several more pins and connections. The only connections needed are USB cable, battery, or AC to DC adapter. The Arduino Uno has a flash memory of 32 KB, a SRAM of 2 KB, and a clock speed of 16 MHz. Furthermore, the Arduino Uno board is very light, as it is only 25 grams.



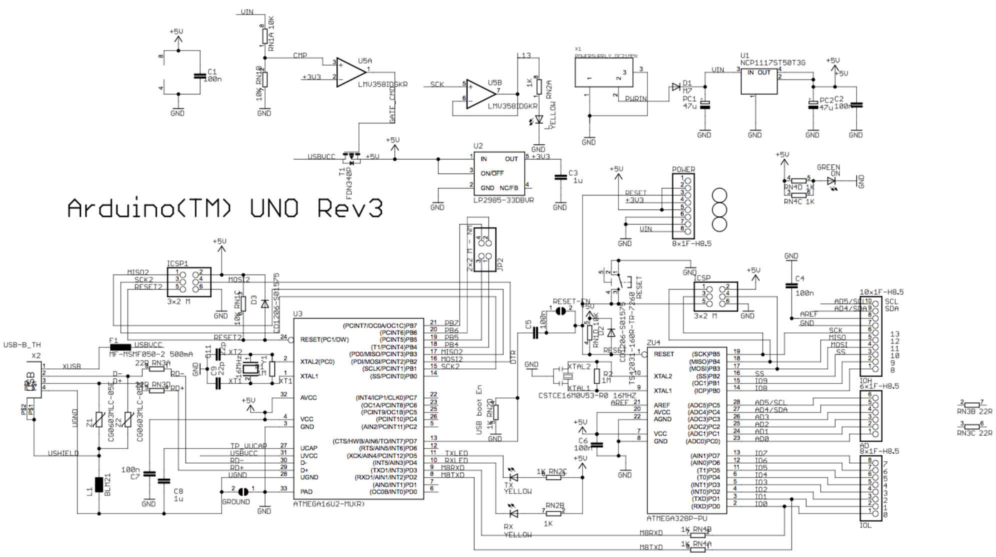
This is a picture of the Olimex Shield-EKG-EMG. This is a board we purchased which can receive and capture electromyography signals and relay them directly to Arduino Uno. It has an input connector for the EMG Sensors and is compatible with our Arduino Uno. It will go directly onto our Arduino Uno as can be seen in the following pictures.



The Olimex Shield-EKG-EMG will go on top of the Arduino Uno, seen in this picture. The Shield has several interfaces on the board that easily mount onto the Arduino Uno's I/O interface slots.

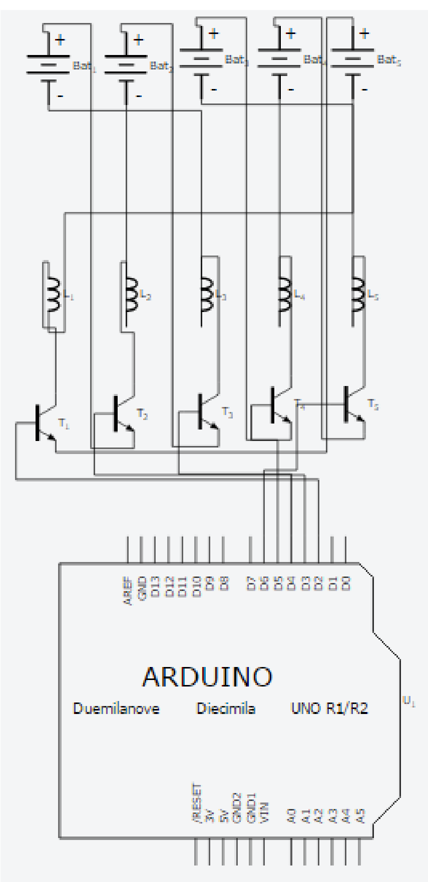


This is a side view of how the Olimex Shield-EKG-EMG mounts onto the Arduino Uno board.



This is a schematic of the Arduino Uno that we are using.

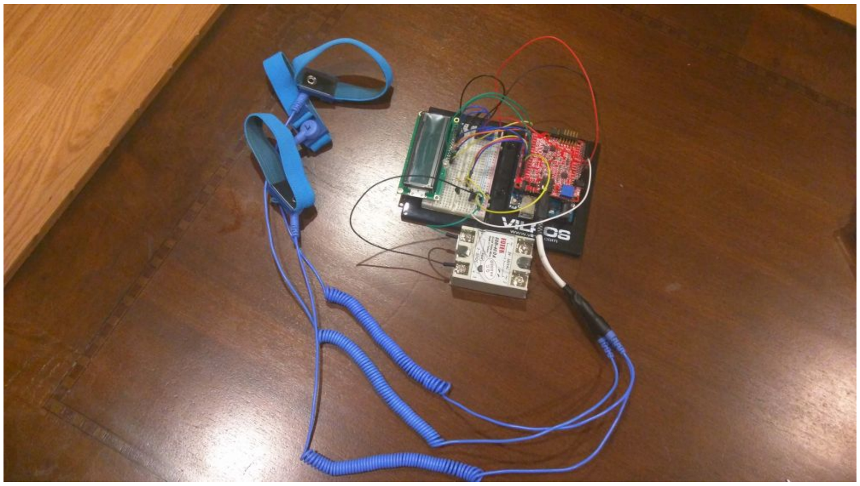
Image Credit to Arduino™



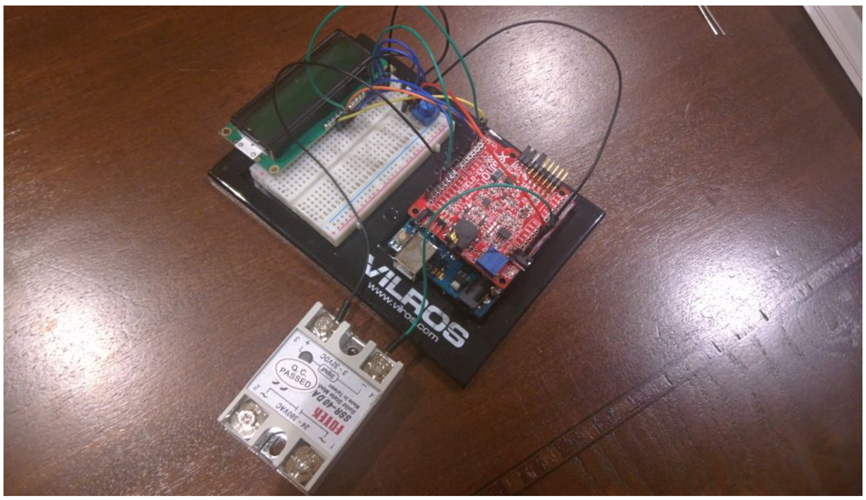
The schematic on the left is the driver circuit. Its job is to receive messages from the Arduino Uno that the muscle has flexed and subsequently release large amounts of current that the HyFlex muscle can then use to contract. The circuit uses five batteries along with five transistors and five heating filaments. The current driver circuit will use 9 volts from each of the five batteries.

When the Arduino receives an amplified signal from the Olimex Shield EKG-EMG, it will then signal the five transistors to switch open. Subsequently, the batteries will release a current which will travel to the heating filaments, heating them, and in turn, activating the muscle.

This circuit will eventually be replaced with a relay switch that will be able to handle upwards of 24 volts.



This is an initial iteration of the circuitry on HyFlex. The blue straps are the EMG sensors. (Note: All circuitry visible in this picture can be condensed to a smaller size).



This is a closeup of the initial iteration of the circuitry on HyFlex. The Arduino Uno with the Olimex-EMG-EKG Shield is on the right and the breadboard with additional circuitry (a potentiometer, LCD screen for testing purposes, and a relay).

Contraction Sensing Mechanism

The EMG sensors can pick up very minute changes in electrical potential which will correspond to the amount of electrical potential change in the motor or interneurons directly under the skin on the surface of the muscles. The Olimex Shield EKG-EMG will then amplify this signal. The signal is then converted from true-analog to a number from -1048 to +1048 which will then be analyzed through the Arduino Uno and then relay a signal that will command the driver circuit to allow current to pass from the battery to the heating filament. This entire process will take very little time since all calculations and analysis will occur in real time, around 10 milliseconds. The image underneath is the variable amplification mechanism which relays a true analog current to the Arduino, as described above.

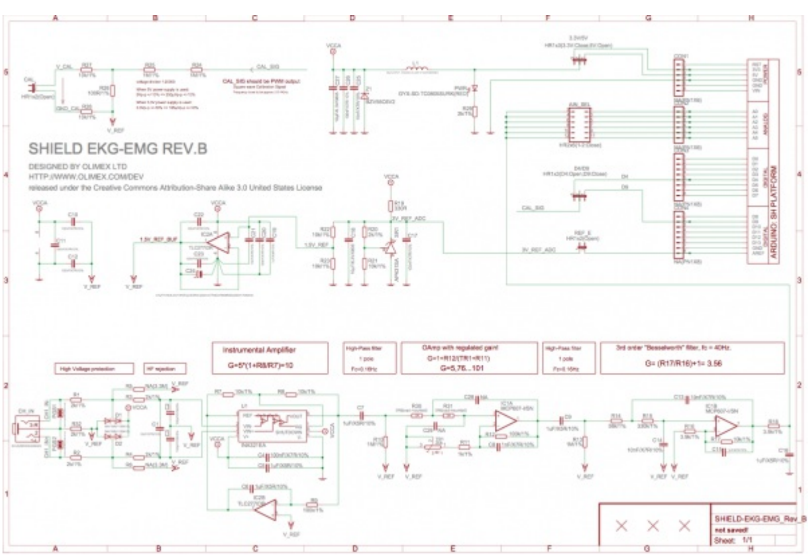
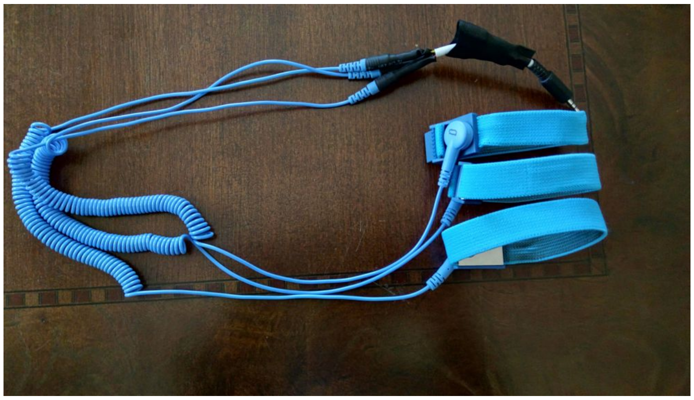


Image: Variable amplification circuit from Olimex to amplify electrical potential differences on the surface of the skin.



These are pictures of the EMG Sensors. The picture on the right is how the EMG Sensors should be strapped on.

```
int arr[500];  //init int array of 500
int x = 0; //init count for sum
void setup(){
  pinMode(0, INPUT); //init analog

                                    //conv.
  Serial.begin(9600);
  pinMode(13, OUTPUT);
}
void loop(){

  int z = analogRead(0);  //init read
  arr[x] = z;
  if(x == 500){
      int sum = 0;
      for(int i = 0; i < 500; i++){
      sum = sum + arr[i];
    }
    sum = sum/500;
    Serial.println(sum);
    x = 0; //reset count to 500
    delay(100);
// analyze ave. for flex
    if(sum < 15 || sum >= 53){
      Serial.println("Sensing Flex");
    }
    delay(100);
  }
  x++;

}
```

Contraction Sensing Code Snippet

The code on the left is the signal analyzing code that receives a signal from analog pin 0, or a muscle flex from detected by the EMG sensors. At this point, the loop function is activated which will create an array of 500 integers. The array will be populated by the values retrieved from the EMG sensors, and an average will be determined. The average electrical potential of a human's skin at rest is approximately 50 for a 15 year old male. If another person were to wear the device, then a new resting average would have to be calibrated. (Note: From this point forward, the average resting potential will be referred to as ARP and will have a value of 50.)

After each average of 500 values is calculated, it will be tested to see if the average is less than 15 or greater than 53. The values, 15 and 53, have been experimentally determined. We did this by observing the relative averages output when a muscle was flexed. Upon flexing, we noticed that averages were almost always greater than 53 or less than 15. When an average output satisfies the "if-statement," then the message "Sensing Flex" is subsequently output. This logic will then be connected to code that will trigger the driver circuit.

Muscle Contraction Mechanism

The contraction mechanism is the center of our product. The contraction mechanism uses coiled fishing line at high tension to produce vertical contraction and expansion. The process to prepare the coiled fishing line (which collectively will be bound in a muscle) is shown in the following steps.

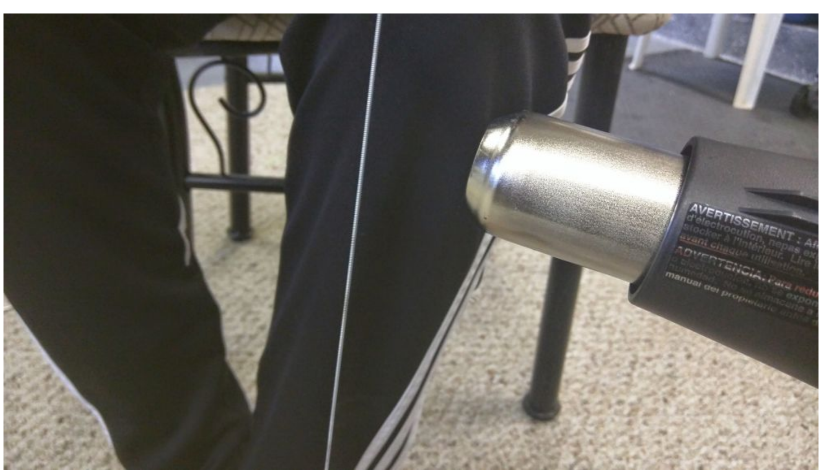
The mechanism is prepared by taking a length of fishing line and tying a weight on it. The amount of weight should be determined by experimentation and will depend on the length of fishing line, the type of fishing line, whether it is monofilament or not, and its test weight. The following are steps to coil the fishing line.

1. Tie the weight to the fishing line.

2. Insert the end of the line that is not tied into a high-powered drill.

3. Then hold the weight to prevent the weight from turning but do not relieve tension from the fishing line as the coiling process requires tension in the fishing line.

4. Start drilling. Following that, the line must be coiled until visible coils begin to reach the top of the drill.



5. Finally, the line must be heated and cooled repeatedly at high tension to prime it. The priming process converts the axial movement, that most materials have when contracting, to vertical movement.

After priming, the line will be able to contract when there is tension and when sufficient energy is available in the form of heat.

Final Prototype Iteration

Using all the above mechanisms combined, a final prototype of HyFlex can be ascertained. The following is a thorough and detailed description of how the final HyFlex prototype will function.

Preparation

Firstly, the user will slide on the EMG sensors: one will go on the bicep, another underneath the bicep, and the last one on the bony part. These EMG sensors will immediately start tracking changes in electrical potential within the muscle.

The Arduino Uno attached to the Olimex Shield EKG-EMG will be encased in a slim superstructure and will be connected to the EMG sensors. The code listed above will be already uploaded to the Arduino Uno, along with additional code of the driver circuit. Once switched on, the code will be looping and running constantly.

The coiled fishing line will be bounded by yarn or string and the coils will be kept parallel to each other in order to maximize efficiency and heat absorption by the coils. Furthermore, there will be infinitesimal inductors or heating microfilaments, which will emit heat by converting electrical current to heat. This heating filament will be embedded in yarn. The fishing line coils will absorb this radiated heat and contract.

Flexing

When the user flexes, a series of actions will instantaneously occur. Firstly, the EMG sensors will detect the major disparity in electrical potential within the bicep. These signals will be transmitted to the Olimex EKG-EMG Shield and will be subsequently amplified to make it measurable by the Arduino Uno. These amplified muscle contraction signals will be sent to the Arduino Uno, which will instantiate an array of 500 integers. Signals will constantly be amplified and relayed to the Arduino, and these signals will be assigned a numeric value, which in turn will be assigned to a position in the array. Once this array has been filled, an average will be determined. If this average exceeds an experimentally determined threshold, then the Arduino will trigger the driver circuit.

Once the driver circuit has been triggered, five 9 V batteries (connected via parallel circuitry) will release an electrical current, which will quickly travel across the circuit towards the inductors buried within the yarn and coils. This will immediately start heating of the inductors and microfilament, and within a matter of seconds, visible contraction of the muscle can be witnessed.

All this happens in a matter of 2-3 seconds. Contraction can be seen around the 4 second mark.

Cooling

Once the arm has reached a resting point, the EMG sensors will detect no major change in electrical potential. As a result, the instantiated array will fill up 500 values whose average will be below the threshold. This value will be used to signal the Arduino Uno to command the driver circuit to prohibit heating. After the heating stops, the muscle will cool down at a rapid pace, resulting in expansion.

All mechanisms of HyFlex and the detailed description of a final iteration of HyFlex listed above have been thoroughly reviewed by Mr. Verma, Mr. Yeevani, Mr. Nigam, and Mrs. Kuei. These mechanisms will be tested throughout the following elements to further improve the product.

PORTFOLIO ELEMENT H

PROTOTYPE TESTING AND DATA COLLECTION PLAN

Our testing plan will be broken down into several different steps, testing each of the design requirements. Before the testing plans, we will model our cost. Then, we will test the viability of different sizes of HyFlex by testing the scalability of HyFlex. Third, we will test the lifespan of the product. Fourth, we will test the contraction heating mechanism, which will include the design requirements. Fifth, we will test the strength of HyFlex. Finally, we will test the contraction sensing code, which will include a test on contraction time.

Cost Modeling

Going through the prioritized list of design requirements listed in element C, cost is the first highest priority. This design requirement stated that the price of HyFlex must be less than $200. Our prototype costs just under $100, after buying most of the materials needed. However, because our prototype is not fully complete with heat resistive materials and human testing, we calculate that a full prototype, with all components, will be around $150. We calculate that in order to create profit margins, we will price it at around $160. With a much more refined process, we will be able to shave $25 off of our final price, which will end up at a price of around $145. This estimated, legitimately tested price clearly exceeds our initial estimated cost of the product. Because the price of all needed materials that we have bought is under $200, we have passed the requirement of cost imposed in element C.
An approximate cost model with high priority is listed below:

1. EMG Sensors with Olimex EKG-EMG - $50

2. Arduino Uno With Required Accessories - $38

3. Coiled Fishing Line - $25

4. Driver Circuit and Other Circuitry Connections - $15

5. Batteries and Replacement - $12

6. Microfilament/Inductors - $11

Total Cost: $151

Testing Plan for Sizing and Contraction

Our next test, size, must be created with the different sizes of human limbs in mind. In order to prove that our device can fit everyone, our device must show that it can be scaled. We will build several test units of various lengths, heat them, and contract them. If each of the coils contract by 10% then the Hyflex will have passed the test. If more than 85% of the units have passed the test irrespective of size, then the product will have passed the sizing test.

Our test has been designed as such due to the difficulty of building an "on-body" prototype. Therefore, we need to know if all the systems and subsystems can be scaled to fit any size.

Our testing plan for the size of the Hyflex consists of three separate steps:

1. Build four separate contraction mechanisms. Build each with specifications of 4 inches, 6 inches, 8 inches, and 10 inches. Use the same heating mechanism for each one. This heating mechanism consists of a 20 Ohm heating filament.

2. Contract each muscle after curing process is complete. After, two strokes* we will do one final stroke where we will measure and record final contracted length.

3. Finally, plot the data from the testing measurements. Our requirements for a functioning muscle is a contraction of 10%. Therefore, in order to pass, each muscle of 4, 6, 7, 10 inches must contract around 0.4, 0.6, 0.8, and 1 inches respectively. If they all contract the given length within an error range of plus or minus 0.05 inches then we will consider them as successfully passed.
*Stroke is defined as contracting and then releasing.

Testing Plan For Lifespan

Our next testing plan is to test for lifespan for the product. This test will include a series of experimentation on groups of three, fully primed coils. If the fully primed coils can withstand 150 cycles of heating and cooling, then they will have passed the lifespan test.The lifespan plan is important since it will prove the viability of our product as a long-lasting one. The following are steps for the lifespan testing plan.

1. Prepare 3 fishing line coils as described in element G. Place the coils parallel to each other. Bind the 3 coils using yarn or string.

2. Hang a 5 pound weight off the bounded coils without letting the weight touch the ground. Make sure that a counterweight is holding the HyFlex from the top.

3. Repeatedly use the heat gun to heat the bounded coils until contraction ends. Let the coils cool down until expansion stops. Repeat 150 times.

Testing Plan For Heating Mechanism

The heating mechanism has been built to the specifications described in element G and consists of two wooden rods wrapped in heat resistant tape with a 20 Ohm heating filament coiled around the two rods and where the contraction mechanism will be inserted between the rods.

In order to test the heating mechanism, we must measure the temperature of the heating mechanism to be 75 degrees Celsius in a time of 5 seconds.

We will conduct the test as follows:

1. The heating mechanism is positioned horizontally on a marble bench with a fire extinguisher nearby. We then heat the contracting mechanism four time each with a heating length of 4 seconds followed by a cooling period of 3 seconds with a 40 volt charge. We have established these times based on the fact that our contraction measuring detects contraction signals for 4 seconds.

2. Carry out the test and record the temperature. Plot all results and compare them with the pass/fail requirements listed in the previous element.

Testing Plan For Strength

To test the contraction mechanism, we will use 3 coils and experiment to see how much weight it lifts up.

We feel that this testing plan will accurately reflect real world usage because of the easy way to scale up the product to 9 coils lifting 15 pounds or even 18 coils lifting 30 pounds. The following is the testing plan for the contraction mechanism and for the strength of the HyFlex.

1. Coil fishing line using the steps described in Element G. The specifications in Element G will be a guide in order to produce several coiled fishing lines. Remember to prime the coiled fishing lines thoroughly and evenly in order to attain coils with higher tensile strengths.

2. Wait for 180 minutes for the priming of the fishing line to fully settle in. Three hours is the experimentally determined time that will thoroughly settle the coils for contraction and expansion. Exactly this time needs to be enforced after priming of the coiling lines has been consummated to acquire the desired results.

3. Bind all prepared fishing line parallel to each other using yarn. The yarn should be alternatively looped throughout the coiled fishing line to produce efficient results. The yarn can also be used as an aesthetic aspect of the product, one of the lower-ending design requirements in our product.

4. Hang several weights off the bounded coils to test the limit. The weight should not touch the ground and should be suspended in mid air. This will ensure constant elasticity within the coils upon contraction.

5. Mark the starting position of the weight with a prominent pen to observe contraction length. This line may vary after repeated process of heating and cooling, so mark a new line each cycle.

6. Repeatedly heat and cool coils.

7. Record data.

Testing Plan For The Contraction Sensing Code

The final testing plan is for the Contraction Sensing Code. This testing plan will test how efficient and how responsive the code listed in element G is. If this code outputs "Detecting Flex" 5 out of 7 times for a 47-year-old and a 15-year-old, then the test will have passed. Also, this plan will test to see how responsive the EMG sensors are and how much time it takes to output the signal. Here is how the test will occur:

1. Upload code to the Arduino Uno. This will continuously run the loop given in the code in element G (you can find this in the void loop function).

2. Strap the EMG Sensors to the test subject. Open the Console in the Arduino program.

3. Command the test subject to flex, and record whether or not the program outputs "Detecting Flex." This will determine the viability of the contraction sensing code and speed of the contraction signal sending.

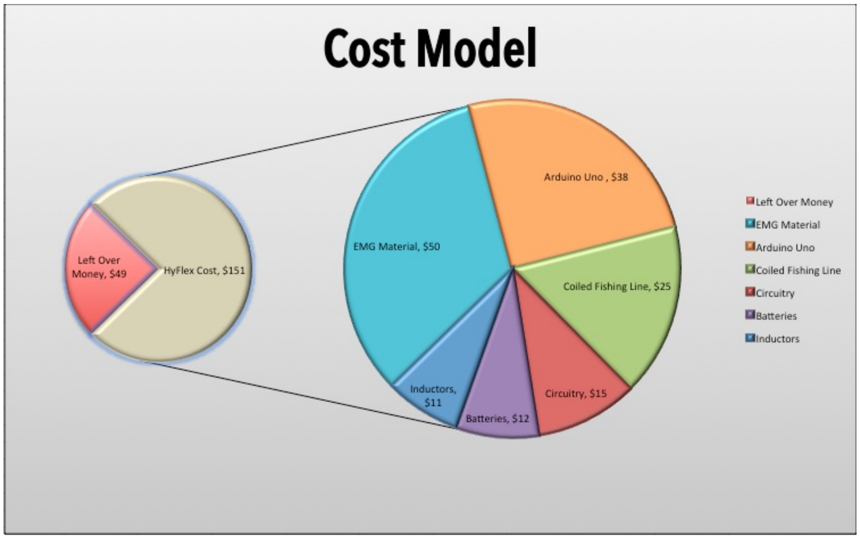
The above testing plans have been thoroughly reviewed and commented on by Ramesh Yeevani, Alok Verma, Ling-Ru Katy Kuei, who are our mentors in this project. Also, Amit Nigam independently reviewed our testing plans and approved them to provide thorough and detailed testing.

PORTFOLIO ELEMENT I

TESTING, DATA COLLECTION AND ANALYSIS

Testing, Data Collection And Analysis

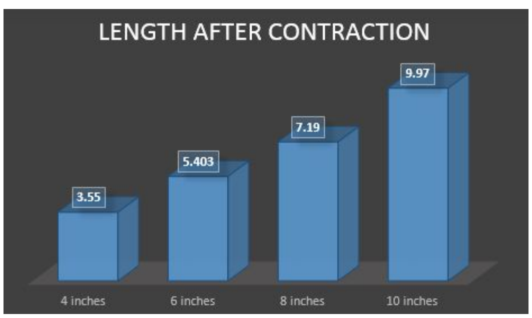
Cost Modeling

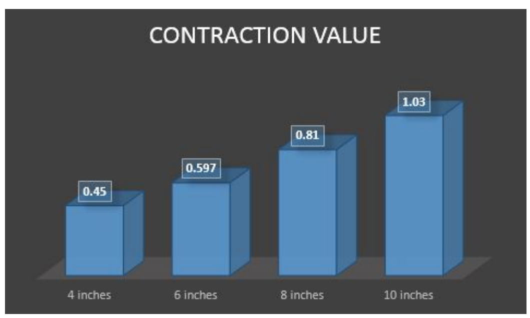


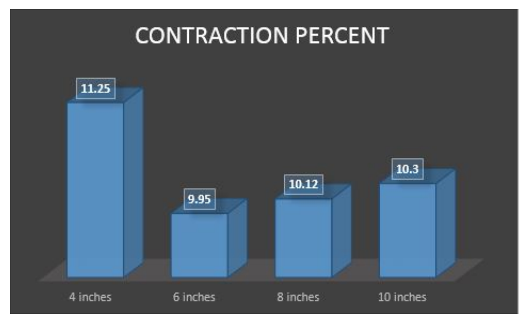
This is a cost model of the price of HyFlex. Our total budget, or estimated price of the product, was $200, as can be seen in the left pie. The HyFlex costs approximately $151, broken down into 6 parts: EMG Material, Arduino Uno, Coiled Fishing Line, Circuitry, Batteries, and Inductors. Each respective price can be seen in the right pie. (Note: Each section of the right pie includes some manufacturing charge depending on the type of material.)

Sizing Test Results

Our first test is the sizing test. We performed this test first because it allowed us to perfect our design and streamline our contraction mechanism manufacturing process. Overall, the Hyflex passed this test with exceptional results: all of the contraction values were very close to ten percent as we expected.
All muscles have passed the test.







The above graphs show the testing results of the sizing test. The 4 inch muscle provides 11.25 percent contraction, making it the most efficient muscle. Overall, this indicates a trend: shorter length muscles are contract more readily than longer length muscles. This can be attributed to a much more efficient heating system that can only be used on smaller systems. Because of this test, we know that in order to make the system reach the zenith of efficiency, we must build everything in smaller mechanisms which will then be linked up. However, longer length muscles will not be very disadvantaged. The longer length muscles contracted a little less than than shorter length muscles, but the longer length muscles vary only a little compared with the shorter length muscles. Therefore, the longer and the shorter length muscles are all viable for usage.

The first graph shows the length after contraction. For example, the first bar in the first graph shows the contraction length of 3.55 inches, contracting from 4 inches. The next three bars have contraction lengths using muscles with lengths 6 inches, 8 inches, and 10 inches respectively.

The second graph has values calculated using the measured values taken from the first graph. The values on top of the bars in the second graph is calculated by subtracting the contracted length from the original length of the muscle.

The third and final graph has values on top of the bars which are percentages. These percentages are calculated by dividing the contraction values from the second graph by the original values: 4, 6, 8, and 10 inches. These percentages enable us to compare different efficiencies of different muscle lengths.

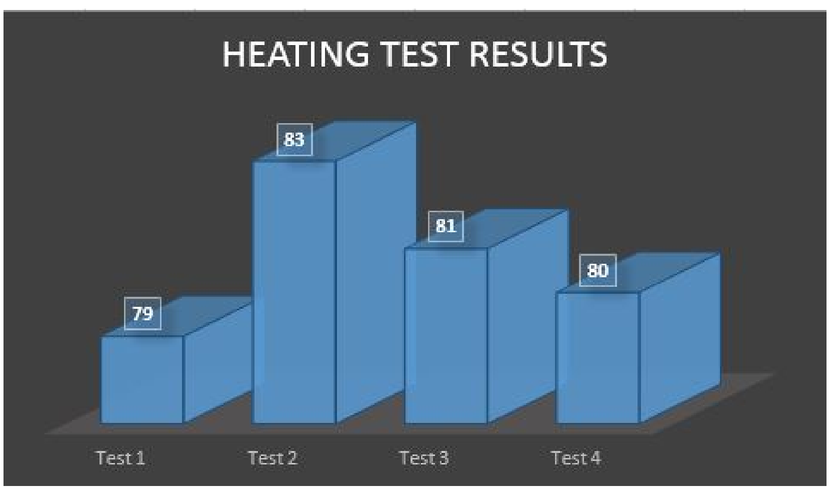
These graphs prove that any variable size (up to 10 inches at most) is viable for users with different bicep sizes, making HyFlex more ubiquitous in user range.

Lifespan Test Results

One of the core elements of our product is lifespan. Therefore, in order to test lifespan, we did 150 heating and cooling cycles, which were preceded by 10 priming cycles to "set" the muscle. We let this test run automatically.

Our results for this test were successful. After heating and cooling repeatedly for 3 seconds on three seconds off, respectively, there was no wearing-out on the muscle. Everything was fully functioning. To retest, we let the HyFlex run for 700 cycles of heating and cooling, but there were still no visible deformities of the muscles. As a final test, we left the HyFlex (that ran for 700 cycles run) for another 300 cycles, totaling 1000 cycles. There were still no physical deformities, but there was a noticeable increase of responsiveness as measured by the time after heating until time to return to original length. This fact will change our manufacturing process for the next generation of HyFlex muscles.

Heating Mechanism Test Results

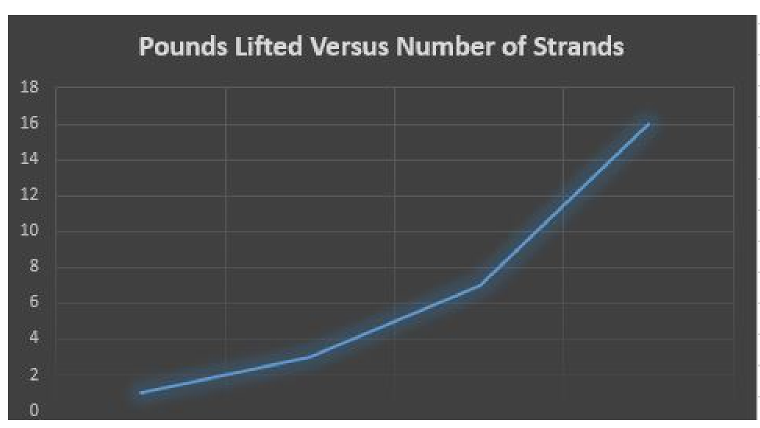


All values in the above graph are in Celsius.

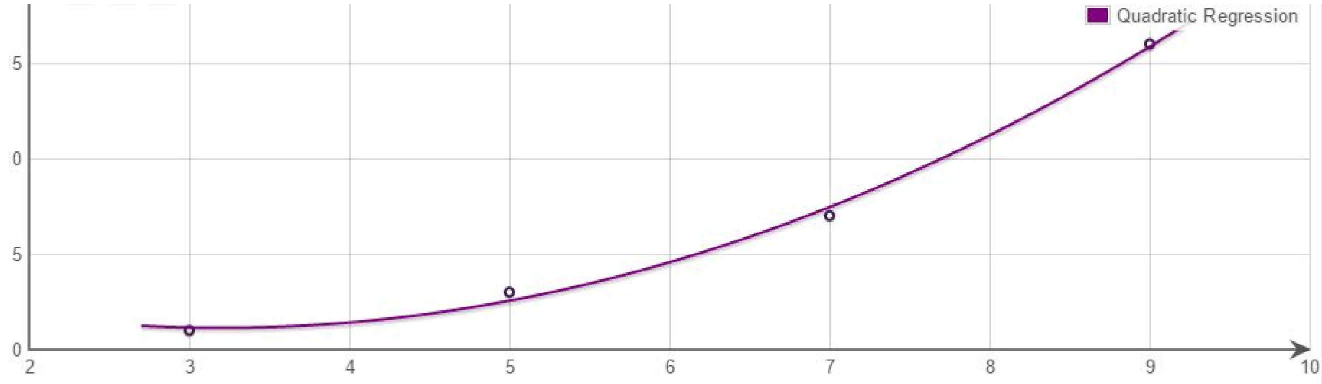
The next component that we tested was the heating mechanism. The heating mechanism was tested by heating the mechanism 5 times and then measuring it once. If the heating cycle that is measured is above 75 degrees Celsius, then the heating mechanism (inductors and microfilament) has passed. To test for consistency, we tested it four times. In each test, the heating mechanism worked flawlessly, easily passing the test posed. A problem that we have discovered with our current set-up a lack of heat dispersion. To solve this we will wrap all mechanisms with the heat resistant material that covers the wooden rods in our testing setup, denying any heat to pass outside of the heating filament.

Strength Test Results

The graph to the right is a graph of the amount of pounds lifted relative to the the number of fibers used. The data that we have depicts a quadratic curve. The graph shows the relative trend toward higher and higher weights with increased fibers. In order to accurately determine how any future models would perform, we used online statistical regression tools to create a modelling quadratic equation. The below equation models our data points. The graph to the right of the equation is a plot of the equation



transposed over our data points.

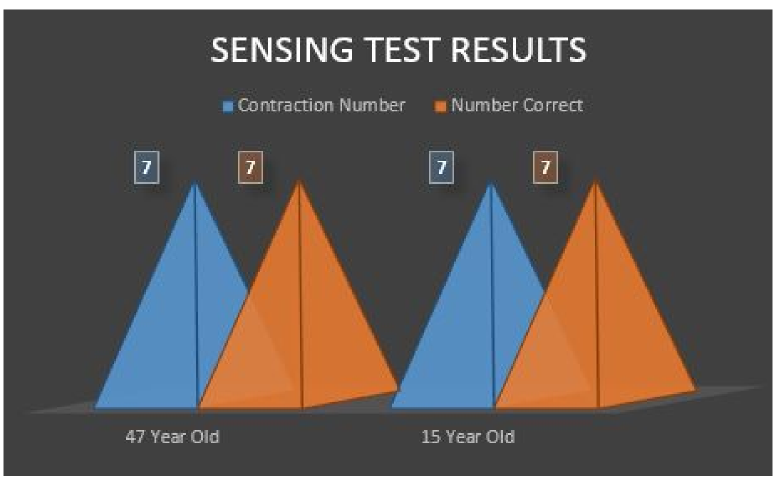


$$y = ax^2 + bx + c$$

$$y = 0.4375x^2 - 2.8x + 5.6125$$

This is a quadratic regression of the graph above.

Contraction Sensing Code Test Results



We have tested our contraction sensing mechanism to sense all contractions perfectly without missing any contractions. To test this, we had two different male, one 47 year old, and one 15 year old. Each of them contracted 7 times with 3 seconds in between (with EMG sensors strapped). This, in conjunction with our contraction sensing code, has worked flawlessly and passed our test.

The graph on the left shows the results. The result on the left is the 47 year old and the number of contractions sensed is 7. Because our requirement for passing the test as stated in element H is seven contractions sensed. The pyramid on the right is the 15 year old. The results are also 7, which is a perfect score passing the sensing mechanism. Overall, the contraction sensing code seems to have perfectly output definite results.

Weight of Product

One of the requirements listed in element C was weight. Our total setup weight is 8 pounds which is two pounds less than the requirements in element C. The weight however will be completely different in a final product because of the streamlining of all subsystems. However, due to the limitations of our current electrical setup, we must add 5 pounds to our total weight. Due to the streamlining we will be able to remove 2 pounds. However, if we use super capacitors in the future then we will be able to shave even more weight off our product resulting in a total weight of 9 pounds placing us one pound under the limit imposed in element C.

As before, our testing results have been supervised, analyzed, and commented on by our mentors Mr. Verma, Mr. Yeevani, Mr. Nigam, and Mrs. Kuei.

PORTFOLIO ELEMENT J

DOCUMENTATION OF EXTERNAL EVALUATION

No content available

PORTFOLIO ELEMENT K

REFLECTION ON THE DESIGN PROJECT

No content available

PORTFOLIO ELEMENT L

PRESENTATION OF DESIGNER'S RECOMMENDATIONS

No content available