Power Tool Operation- Rat Model

BME 301

2/26/2019

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Abstract

Long term muscle fatigue and damage due to large eccentric loadings on the muscles are commonplace for industrial workers. Though this problem is widespread it is not well understood as human testing is of course not possible. Our project proposes to use rat models to better understand these injuries by creating a device which provides eccentric loadings to the rats. This in turn will force the rat to exert a certain amount of force with its arm before being rewarded with a pellet. Our design will use a linear actuator to provide the eccentric loading and will be coupled with the Vulintus Mototrak in order to gage the forces the rat is applying

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Introduction

This semester, the team is continuing its work on the design of a device that can simulate the use of power hand tools in rats. This work will be used to study the effects of repetitive use of industrial power hand tools like threaded fastener tools that create large impulses experienced by the user. Over time, these forces can cause chronic injuries.

The design will be a variation of an already existing device that can measure static forces applied by rats. This device will require rats to hold onto it and withstand the dynamic forces introduced by a linear actuator into the system.

The current objective of the team is to design a device while taking into account electrical and physical constraints. Eventually we will build a working apparatus to be used in research.

Motivation

Today the workplace's leading cause of pain, suffering, and disability is work-related musculoskeletal disorders (MSD's). The Occupational Safety and Health Administration has attributed them to possibly over 600,000 injuries and illnesses. This in turn accounts for 34% of all work days lost according to the Bureau of Labor Statistics and costs up to $20 billion annually in direct workers' compensation in addition to its even greater indirect costs [1]. The focus of this project pertains to those MSD's that have to do with the arm and wrist. These cases are found especially in fields that require repetitive motion and exertion of the arm [2].

The exact causes of these disorders are not well known. So much so, that in the 2010 National Manufacturing Agenda of the National Institute of Occupational Safety and Health, it was recommended that biomechanical research be put into the cause of MSD’s [3]. The focus of the project is to begin conducting tests on rats that will accurately replicate the use of power tools and hopefully induce MSD like symptoms to eventually analyze.

Existing Devices

This design will be the next step to an already existing device. Currently there is an apparatus that measures static forces applied by trained rats. Rats are kept in an 10” x 12” x 4.75” acrylic box that has a small hole (2.5” x 0.4”) located such that the rats are only able to use their front right limbs during testing. There is a handle that is located 0.75” outside of the hole that the rats have successfully been trained to pull. The research conducted had an increasing regiment that required rats to pull harder over time in order to receive food pellets. This design and testing method has proven the efficacy of using an isometric pull test on rats to train them while also collect data [4]. The proposed design will change the static nature of the current device into a dynamic one.

Problem Statement

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Background

Biology and Physiology

Workers in many different fields that include repetitive tasks are affected by MSD's. They affect many parts of the body including muscles, bones, nerves, vasculature, tendons, and ligaments [5]. When it comes to working with industrial power tools we are concerned about the musculoskeletal components of the upper extremities, specifically the bone. Bone structure can be manipulated by repetitive loading of the tissue [3][6]. With an increase in loading impulses generated by industrial power tools, it can be assumed that these tools would cause changes to the makeup of the underlying bones. This change in makeup could be a cause to increases in chronic injuries. For example, bones of patients with MSD's were scanned and found to have increased blood flow and blood pooling [3][7]. This could mean the bone is inflamed and this in turn could put the subject at higher risk of injury. In a related study, it was found that forestry workers who were exposed to hand-arm vibrations were more prone to MSD's then those who just did manual labor in the same field [8].

Current Model

The current device is known as the Vulintus Mototrack seen in Figure 1. The research team at Temple University currently runs its investigations using it. The Mototrak is a complete system that includes a cage, controller, behavior module, pellet dispenser, auto positioner, and the MotoTrak software. Utilizing this system rats were trained and data was collected to determine the average reach force and the average reach duration.

Figure 1 - Vulintus Mototrack: This is the Vulintinus Mototrack with the cage, controller, and pellet dispenser.

Client

Our client, Prof. Radwin, works in industrial and systems engineering as well as biomedical engineering at the University of Wisconsin - Madison. His interest in research deals with injuries that occur in the industrial workplace. Professor Radwin works with a team at Temple University on this project. The research team at Temple University currently runs its investigations using the Vulintus Mototrak. The Mototrak is a complete system that includes a cage, controller, behavior module, pellet dispenser, auto positioner, and the MotoTrak software. Utilizing this system rats were trained and data was collected to determine the average reach force and the average reach duration.

Design Specifications

The client requests a device which provides an opposing force to the rat's pull. There will be forces applied to the rats through a linear actuator. Also, reach duration should be able to be changed by the researcher. The opposing force should begin immediately once the rat begins to pull on the handle. The rat must retain it's grasp on the handle for a given amount of time in order to receive it's food (the food should not fall out immediately once the rat pulls on the handle). The threshold reach duration should range from 25 to 250ms (rat should hold on until force threshold is reached).

Preliminary Designs

Designs Considered

Nippon Linear Actuator

This linear actuator, shown in Figure 3, has the ability to provide a continuous force of 1.8 N which is exactly the force requirement for our application as the test specimens are able to apply on average 1.5 N. I addition to the favorable force output the Nippon actuator is very compact with a length of 8.5 cm makes it an ideal size to fit into a rat cage. An additional benefit of this option is that it offers a large input range from 10 - 240V can allow for a large degree of adjustability when it comes to varying the speed. The main drawbacks of this option is the price of $431 and that the company, Nippon, has proven difficult to work with, it took almost two week to be give the price for the actuator.

Figure 3: S080D linear actuator

AMD L12 Linear Servo

Figure 4 shows the AMD L12 Linear Servo. This option offers equivalent force output in both tension and compression, which for the simulation of the effect of power tool use is ideal. In addition to equal force output the servo aspect of this option is intended for alternating between extending and contracting. Also the size of this option, compressed length of 12.5 cm, will allow for enough room to be left in the cage to be practical. The main drawback of this option are the low maximum speed of 25 mm/s which maybe too low to effectively modulate the intended motion. An additional drawback is that there is a limited range of input voltages only 4.5 - 7.5V which will limit the various velocities desired to test different scenarios.

Figure 4: AMD L12 Linear Servo

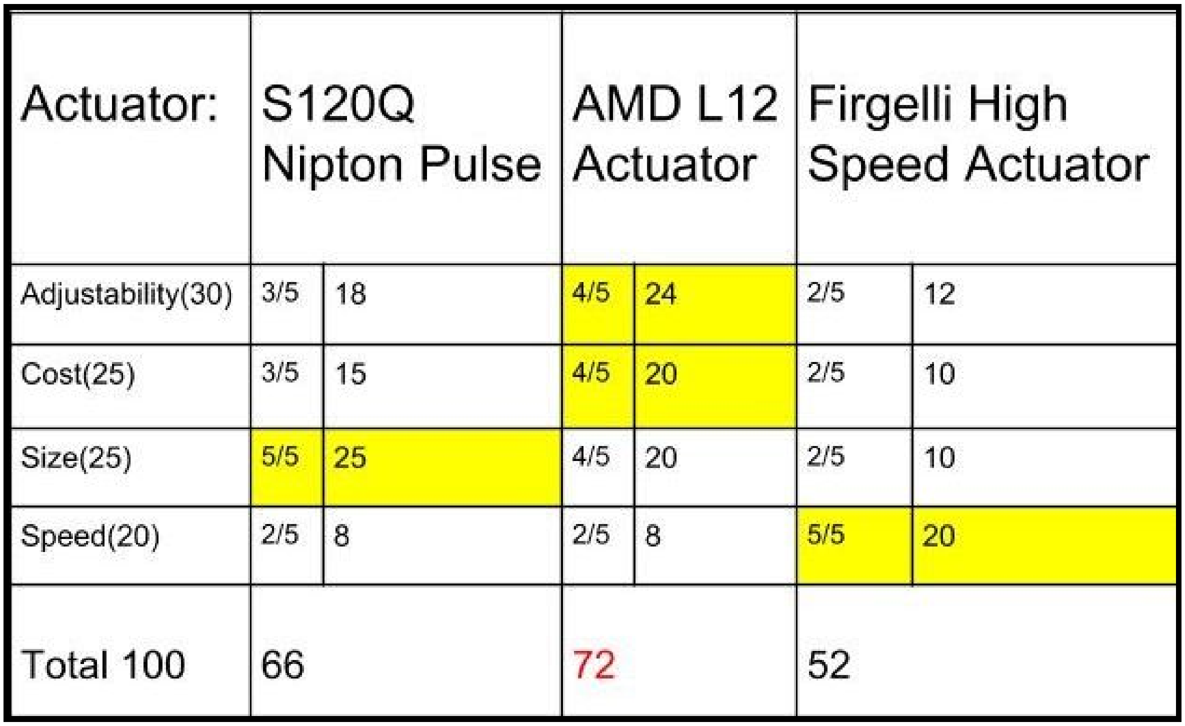
Firgelli high speed linear actuator

This option addresses the speed issues that may be required to effectively simulate the high speeds of power tool operation. This issue however is that this option is large, length of about 25 cm, which make it too large to fit in a rat cage comfortably. In addition to a concern with size the actuator requires an input of 12V of direct current making it unable to adjust the speed of the actuator.

Figure 5: Firgelli high speed linear actuator

Preliminary Design Evaluation

Design Matrix



Actuator:	S120Q Nipton Pulse		AMD L12 Actuator		Firgelli High Speed Actuator	
Adjustability(30)	3/5	18	4/5	24	2/5	12
Cost(25)	3/5	15	4/5	20	2/5	10
Size(25)	5/5	25	4/5	20	2/5	10
Speed(20)	2/5	8	2/5	8	5/5	20
Total 100	66		72		52	

Figure 2 - Design Matrix: This design matrix compares 3 possible linear actuators.

Matrix Criteria

Adjustability is the ability of our design to conform to the range of peak forces and ramp times entered by our client. We weighted adjustability at 30 as it is the most important aspect of our design to our client. We objectively measured adjustability for each linear actuator by comparing the range of voltages over which the linear actuator can operate as this relates to the range of speeds the linear actuator can operate over which allows us to control how much force we apply to the rat. While the S120Q had a range from 10-240V, L12 won in this category as it had the largest operating range that was within our range of voltages we could apply with the power supply available to us.

Cost is important to our design as the components we are considering are very expensive and we need to ensure that the linear actuator we purchase is within our budget as the force sensor and amplifier alone come out to nearly $800. The L12, while pricy, was the most affordable out of the three actuators.

Size is defined as the ability of the actuator to fit into the dimensions of the space available for us to work in. Because the the total depth, width, and length we have to work with are set parameters we want to minimize the space the linear actuator takes up in order to ensure we have space for the rest of the components of our design. The S120Q won in this category as its fully extended length was shorter

Speed is defined as the maximum speed at which the linear actuator can move. This is important to our design as it correlates to the max force we can apply to the rats arm. We can always slow down the actuators speed using pulse width modulation from our microcontroller, however we can not increase the max speed. The Firgelli actuator won in this category with a max speed of 23 cm/s.

Proposed Final Design

Based upon our matrix evaluation we believe the L12 actuator will be most appropriate to use because it minimizes cost while still providing the adjustability and force necessary.

Fabrication & Development

Materials

Our design will consist of a FUTEK LSB200 load cell as the force sensing element in our design. We will also have a CSG110 amplifier in order to increase the resolution of the signal coming from our sensor as the forces we are working with are very small. The signal coming out of the amplifier will then be sent to an Arduino microcontroller which will process the signal and determine if the linear actuator needs to be extended or retracted. The microcontroller will control the linear actuator via an H-Bridge circuit by allowing the microcontroller to switch the polarity of the voltage being applied to the L12 linear actuator. The H-Bridge circuit will also prevent excessive current from going through the microcontroller.

Methods

We will create our final design by following this simplified procedure. We will first calibrate our force sensor. We will then directly attach our force sensor to the arm of the linear actuator so that the axis of the load on the force sensor would be in line with the axis of the linear actuators arm movement. We will then connect the Linear actuator to the H-Bridge and the force sensor to the amplifier. The H-Bridge will then be connected to a PWM output of the microcontroller and the amplifier to the analog input to complete the circuit.

Testing

We plan to evaluate two aspects of our design during the testing phase of our project. We plan to evaluate the force application of our device by using a spring of known spring constant to model the rats pull on our device. We will measure the displacement over time to ensure that the force being applied to the rats arm ramps in accordance to the parameters entered into the code. We also plan to evaluate the user input aspect of our design with the previous method by ensuring that the ramp time and peak force entered by the client are utilized properly by the code to increase the force applied to the rats arm to the peak force over any ramp time entered.

Discussion

Implications

If our design is successful in modeling repetitive motion injuries in rats our clients can then study the effects of these injuries on the rats' muscle tissue. Rat are model organisms for human beings in many aspects of biology and physiology therefore by better understanding these injures in the rat our client would be able to make connections to the progression of these injuries in humans. This research could eventually lead to a better understanding of the effects and pathways of repetitive motion injuries and help to create more comprehensive guidelines for heavy machinery operation.

Considerations

Some considerations to keep in mind as we progress in the project are that we need to ensure that our product actually does what our client wants it to, and if we need to compromise on some aspects of our design, our client needs to know exactly how this affects their research. Because our clients research has implications on human health, any deviation from what our client thinks our product is capable of vs what it actually does could lead to incorrect conclusions being drawn n have an adverse effect on health policies.

Conclusion

Findings

Our client is aiming to model repetitive motion injuries in rats. Currently the esign our client is using does not apply any force to the rats arm as it is pulling. Our client would like us to create product which applies a dynamic load to the rats arm which will increase over a time period (set by our client) to a peak force (also set by our client). From our previous work on the project we found that the best way to do this is by using a linear actuator controlled by a microcontroller to pull back on the rats arm and apply a force.

Future Work

In the future we plan to build our actuator to load cell connection, wire the actuator and load cell to the H-Bridge and amplifier respectively, and wire both the amplifier and H-Bridge to the microcontroller. We plan to calibrate our load cell using known weights and plan to test our design using springs of known spring constant. Once our design passes our tests we plan to build a housing for it in order to ship it to our client in one complete neat package and make installation easier.

References

[1] United States Department of Labor, "PREVENTION OF WORK-RELATED MUSCULOSKELETAL DISORDERS," 2014. [Online]. Available: https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_id=4481&p_table=UNIFIED_AGENDA. [Accessed: 26-Feb-2019].

[2] L. Foss et al., "The Impact of Workplace Risk Factors on Long-term Musculoskeletal Sickness Absence," J. Occup. Environ. Med., vol. 53, no. 12, pp. 1478–1482, Dec. 2011.

[3] V. S. Massicotte et al., "Prolonged performance of a high repetition low force task induces bone adaptation in young adult rats, but loss in mature rats," 2015.

[4] S. A. Hays et al., "The isometric pull task: A novel automated method for quantifying forelimb force generation in rats," J. Neurosci. Methods, vol. 212, pp. 329–337, 2013.

[5] Occupational Safety and Health Administration, "Ergonomics." [Online]. Available: https://www.osha.gov/SLTC/ergonomics/. [Accessed: 27-Feb-2019].

[6] J. O. Green, S. Nagaraja, T. Diab, B. Vidakovic, and R. E. Guldberg, "Age-related changes in human trabecular bone: Relationship between microstructural stress and strain and damage morphology," 2011.

[7] B. J. Amorim et al., "Low sensitivity of three-phase bone scintigraphy for the diagnosis of repetitive strain injury," Sao Paulo Med. J., vol. 124, no. 3, pp. 145–149, 2006.

Images

Figure 3: http://www.nipponpulse.com/catalog/parts/search/motors-linear-servo/part_id:15

Figure 4: https://www.servocity.com/100-mm-stroke-4-lb-thrust-light-duty-linear-servo

Figure 5: https://www.firgelliauto.com/products/high-speed-actuator

List of Appendices

Appendix A - Preliminary PDS

A rat model for studying hazards in industrial power tool operation, Team Rat_Model

Product Design Specification (PDS)

Clients: Prof. Radwin, UW-Madison & Prof. Mary Barbe, Temple University
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Date: February 07, 2019

Function

Power hand tool operation in factories and service facilities, including threaded fastener tools (i.e. screwdrivers and nut drivers), present hazardous hand loads resulting in repetitive motion injuries. The rapidly rising impulse loads transmitted to the hands while operating tools often produce stressful eccentric muscle contractions, which exceed the operator's capacity to hold the tool stationary and stretch muscle fibers and tendons, resulting in chronic injuries due to repetitive loading. The objective of this research is to conduct animal studies leading to an understanding of the pathophysiology associated with repetitive tool operation.

This project proposes to develop a device that contains a handle that a rat can be trained to pull which initiates a controlled rapid impulse force in the opposite direction that results in eccentric muscle contractions in the rat's arms, simulating repetitive power hand tool operation. The investigators intend to train rats to repetitively pull on the handle using sufficient force to activate a motor that then pulls the rat’s limb in the opposite direction in order to receive a food pellet. The device will need to fit inside a cage-mounted device of similar dimensions that currently controls passive pull force. The force provided must be enough to strain the rat, but not to exceed the load that it can bear.

Client Requirements

- A device which provides an opposing force to the rat’s pull
- Force and reach duration thresholds should be adjustable
- Opposing force should begin immediately once the rat begins to pull on the handle
- The rat must retain it’s grasp on the handle for a given amount of time in order to receive it’s food (the food should not fall out immediately once the rat pulls on the handle).
    - Threshold reach duration from 25 to 250ms (rat should hold on until force threshold is reached

- Force applied to the rat should be around the target 1.44 N (the average force of a rat's pull)

Design Requirements

1. **Physical Characteristics**
    a. Performance Requirements
        i. Dimensions/Data
            1. Distance from window to handlebar: 1.5cm
            2. Mean Max Grip Force: 163 gf
            3. Threshold Force: 0.15(163) = 24.45gf
            4. Mean Reach Force(from data) = 146.75gf or 1.439N
            5. Mean Reach Duration(from data) = 0.1463sec
            6. Threshold Reach Duration: 0.05sec
            7. Loading Pattern:
                a. 4 reaches/min * 30 min/session * 4 session/day
                b. 480 reaches per day

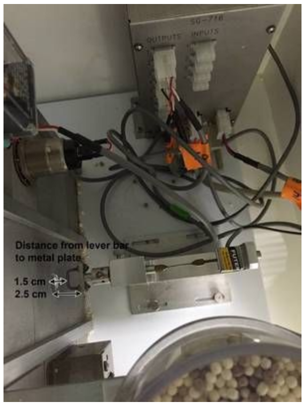


Figure 1: Picture of current system, handlebar will be 2.5 cm from the slot in the cage wall

b. Safety

i. The design must be free of pinch points and fire hazards

ii. If the product is damaged, exposed wires could cause electric shock, this should be noted somewhere on the setup.

c. Accuracy and Reliability

i. Resistive force should be able to ramp up to 1.2 N (average pull force of rat) with a resolution of at least 0.1 N (1.2/12 =0.1) giving at least 12 different force settings

d. Life in Service

i. The experiment will be run over 6-12 weeks and the device should last for multiple trials

e. Shelf Life

i. The apparatus should be stored at approximately 25 degrees Celsius.

ii. The apparatus should be able to last at least three years on the shelf while maintaining functionality

f. Operating Environment

i. The materials used will be put under stress by the pull of the rat. This is not a very significant amount of force (about 1.5 Newtons), but it will stress materials over a long amount of time. While the experiment is only being run for 6-12 weeks, preferably the device will be able to last for longer than that, in case it is needed for further research. The lab could become humid during the summer months, however the device will likely always be operating at room temperature plus or minus a few degrees celsius. Dirt and dust could certainly collect, so the device should be cleaned twice weekly to avoid this causing issues it’s functioning.

g. Ergonomics

i.The handle must be small enough to be gripped by a rat. It must be strong enough to not become weak or deformed under the force of the rat pulling on it. The handle needs to be located approximately 8.5 cm above the level of the rat (in order to fit the current model), and it must be located about 1.5 cm from the hole that the rat has to reach through. The force applied in reaction to the rat’s pull should not exceed 2.5 N in the case that this could instantaneously injure the rat.

h. Size

i. The product must be able to fit within the rest of the current model. The box that rats are held in is 31.8 cm tall. The handle is 8.5 cm from the bottom of the box.

i. Weight

i. Once our product is installed to the rest of the machine, it will not move. That being said, it needs to be light enough to handled by the average person (50 lbs). Apart from that, there are no weight limitations.

j. Materials

i. The PA-15 Linear Actuator was used to create a linear reaction force. 2 p and 2 n channel mosfet transistors, 2 npn transistors, 4 10k Ohm resistors, and 2 2k Ohm resistors were used in the circuitry for the device. A force sensor was used to detect the pull of the rat. The force sensor was required to pick up forces between 0 and 5 N due to the small forces of the rat.

k. Aesthetics, Appearance, and Finish

i. Because it is being used to research with rats, the functionality is the only concern for our product. Appearance is not important.

2. Production Characteristics

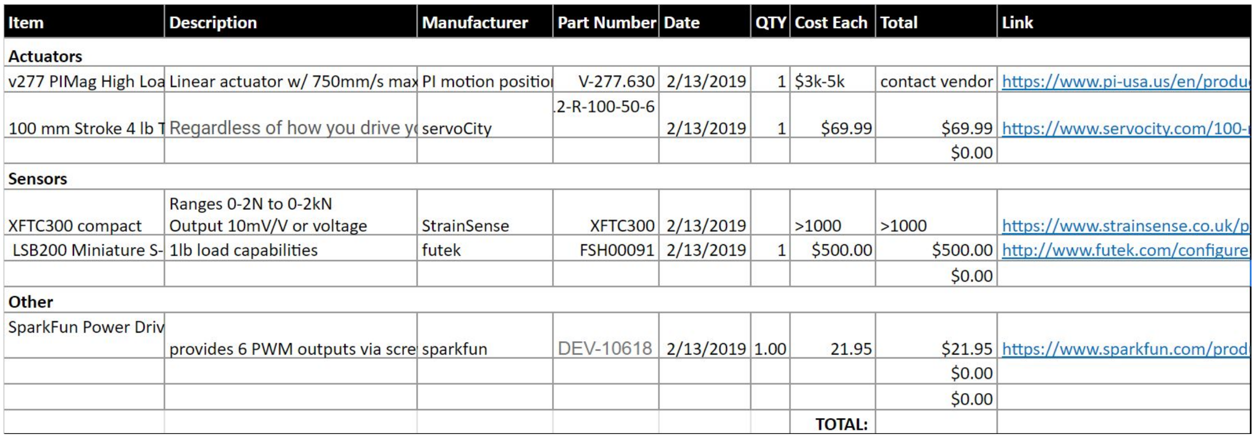
a. Quantity
    i. One device to be built
b. Target Product Cost
    i. It should cost less than the Vulintus Mototrak which costs $3520. Our client did not specify a certain budget, but would like the product to be produced for under $500.

3. Miscellaneous

a. Standards and Specifications
    i. Because we are building this for the specific use of a client, and not a marketable product, there are no formalized standards; FDA approval is not needed.
b. Client
    i. Our client, Professor Radwin, wants to incorporate a linear actuator in our design.
c. Patient-related Concerns
    i. Because the device is technically being used by rats each day, there are no patient-related concerns.
d. Competition

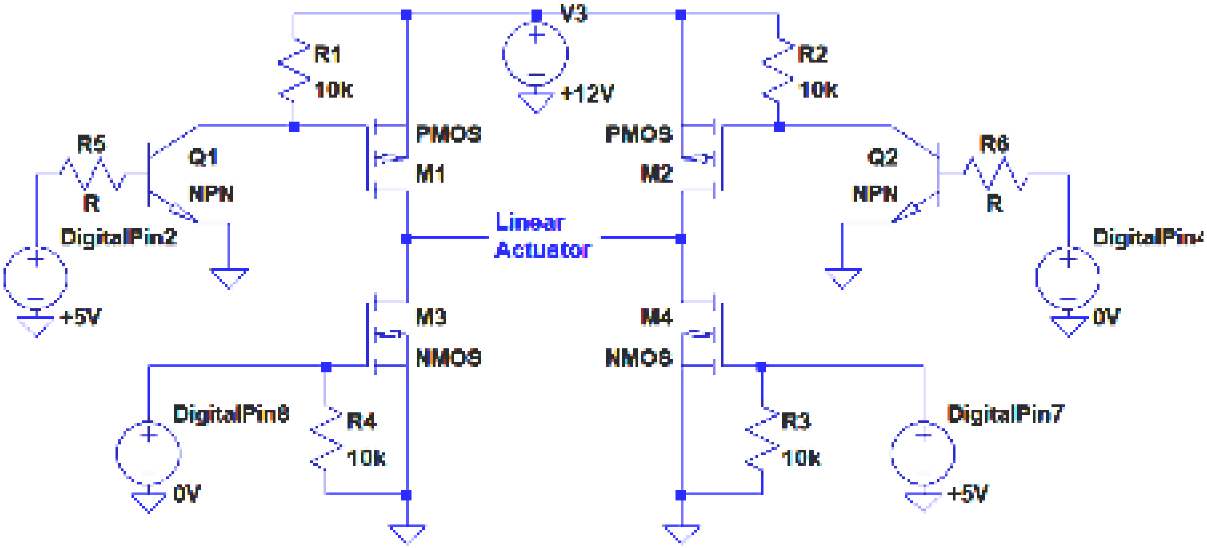
i. The Vulintus Mototrak is very similar to the product we are developing. However, it features a static handle, not a dynamic handle.

Appendix B List of Materials



Item	Description	Manufacturer	Part Number	Date	QTY	Cost Each	Total	Link
Actuators								
v277 PIMag High Loa	Linear actuator w/ 750mm/s max	PI motion positio	V-277.630	2/13/2019	1	$3k-5k	contact vendor	https://www.pi-usa.us/en/produ
100 mm Stroke 4 lb T	Regardless of how you drive y	servoCity	2-R-100-50-6	2/13/2019	1	$69.99	$69.99	https://www.servocity.com/100-
							$0.00	
Sensors								
XFTC300 compact	Ranges 0-2N to 0-2kN Output 10mV/V or voltage	StrainSense	XFTC300	2/13/2019		>1000	>1000	https://www.strainsense.co.uk/p
LSB200 Miniature S-	1lb load capabilities	futek	FSH00091	2/13/2019	1	$500.00	$500.00	http://www.futek.com/configure
							$0.00	
Other								
SparkFun Power Driv	provides 6 PWM outputs via scre	sparkfun	DEV-10618	2/13/2019	1.00	21.95	$21.95	https://www.sparkfun.com/prod
							$0.00	
							$0.00	
						TOTAL:		

Appendix C Previous Circuitry



H-Bridge Circuit Simulation (LT-Spice)