Power Tool Operation- Rat Model

BME 200/300

12/10/2018

Client:

Professor Radwin - Industrial and Systems Engineering

Advisor:

Professor Tompkins - Biomedical Engineering

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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.

Introduction

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[1]. 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 pulls the rat hand 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.

This device is meant to model power tool operation by humans, through the use of a rat model. This device is necessary because the repetitive motion due to long term, consistent use of power tool operation can lead to muscle weakness, fatigue, and joint problems. This device will allow the researchers to test these effects on rats, in order to gain an understanding of the effects on the limbs of rats. This is the first step in understanding the effects on humans; workers in the industrial setting who are consistently using power tools will benefit greatly from these findings. Safety regulations could be put in place and new technology could be developed to protect these workers and make a safer workplace. Current guidelines require power tools to be fitted with guards and safety switches (Hand and Power Tools), and new guidelines for new safety mechanisms may be researched once there is more information available.

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.

Figure 1. Vulintus Mototrak

Our clients Prof. Radwin and the research team at Temple University hope to improve the current study by implementing a handle that provides a reaction force to the rats' effort. The current study conducted at Temple University utilizes a static handle that the rat pulls linearly to obtain its food pellet reward. The proposed design solution intends to integrate a dynamic handle that provides a reaction force to simulate power tool operation. The significant data points that guide the proposed design solution are the 1.5 cm distance from chamber window to the handle, the mean reach force of 1.44 N, and the mean reach duration of 150 msec[3]. Additional design specifications are (See Appendix PDS).

The design team investigated servo motors and linear actuators as potential reaction force providers. We found that although servo motors were low-cost, it would be difficult to achieve the desired speed, measure forces and integrate a negative feedback system for this design project[4]. Solenoids or motorized linear actuators were slightly more costly, however their application was more practical for providing the desired reaction forces, speeds, and control systems[3].

Preliminary Designs

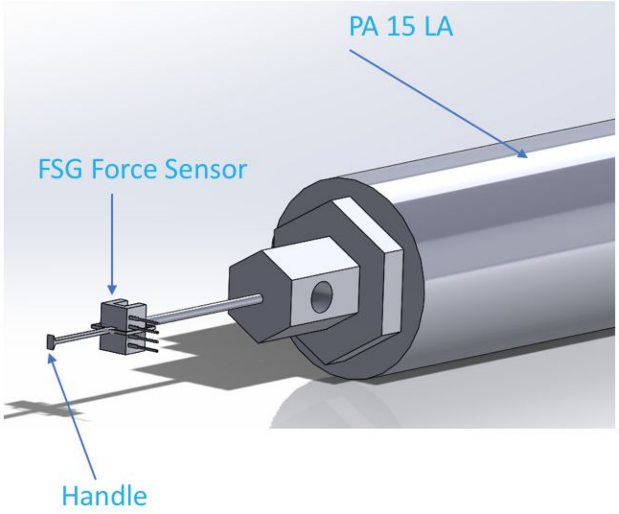

Figure 2. Progressive Automation Linear Actuator-15 with an FSG Force Sensor attached to the handle.

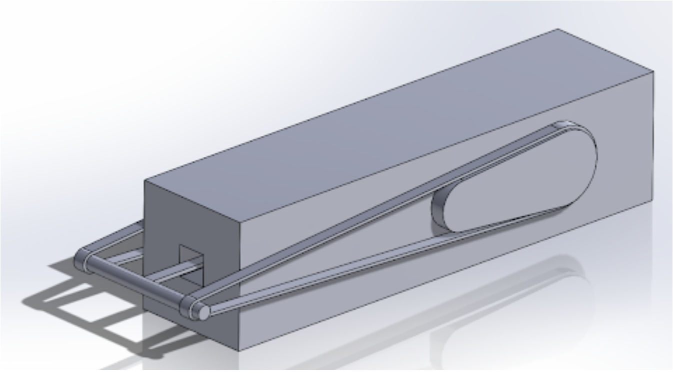

Figure 3. Rubber Band Design uses bands of various tensions to apply varying resistive loads on the rat.

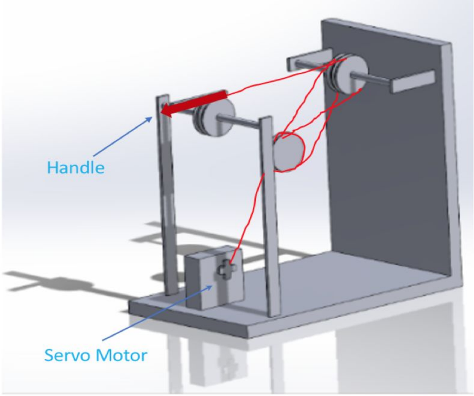

Figure 4. Servo-Pulley Design uses the servo motor to provide the resistive force and the pulley to redirect the rotational force to a linear force.

Figure 2 is our linear actuator design. It includes a linear actuator that is wired to an arduino microcontroller. A force sensor is attached between the rat handle and the tip of the linear actuator rod. The FSG force sensor provides a negative feedback to the arduino microcontroller. The arduino code (See Appendix Arduino Code) provides the logic that will monitor the force being applied on the handle and direct the linear actuator to extend or retract the rod. When the rat begins to pull on the handle, the linear actuator will begin to move in the opposite direction of the rats pull. If the rat releases the handle before reaching threshold forces and durations the food pellet will not be dispensed. However, if the rat has applied the target force over the target duration, food pellet will be released to the rat. At the end of each attempt the linear actuator will reset to its default extended position.

Figure 3 is the Servo-Pulley design. The servo motor provides the intended resistive force as a rotational force. Then cross-shaped gear attached to the rod of the servo is connected to a system of pulleys that redirect the initial rotational force to a linear force on the handle bar. This linear force on the handle bar would ultimately be the reaction force to the rats pull. The motor is controlled by an arduino microcontroller. This model requires a tensile force sensor to provide negative feedback to the microcontroller. The sensor and microcontroller would the able to sense and control when the rat starts to pull, how much force the rat pulls with, and how much force to apply in reaction.

Figure 4 is our rubber band design. There are two rubber bands that are latched onto either side of a small box, and onto either side of the handle. The handle is then attached to a sensor inside of the box. When the rat pulls on the handle, the rubber band automatically provides the reaction force. The sensor would then serve the purpose of determining if the rat has pulled on the handle, and how much force it has pulled with.

Preliminary Design Matrix

Design:	Rubber Band		Servo-Pulley		Linear Actuator	
Adjustability(25)	3/5	15	4/5	20	4/5	20
Consistency(25)	2/5	10	3/5	15	5/5	25
Feasibility(25)	4/5	20	3/5	15	2/5	10
Ease of Integration(20)	3/5	12	3/5	12	2/5	8
Cost(5)	5/5	5	3/5	3	3/5	3
Total 100	**62**		**65**		**66**	

Our five criteria are adjustability, consistency, feasibility, ease of integration, and cost. Our linear actuator design received the highest score for adjustability because it will be controlled by a microcontroller which will allow the client to control the force through their software. Our linear actuator also received our highest score for consistency because the reaction forces provided by the linear actuator will not have to be translated or converted. Additionally, all parts of the linear actuator are rigid and ideal for applying accurate forces on the rats over multiple trials. Our rubber band design received the highest scores for ease of integration, feasibility and cost. The rubber band design is the easiest to integrate because it can be be finalized as one final part that can then be integrated into the existing model. Unlike the linear actuator and servo-pulley designs, the rubber band design will only require putting a rubber band onto the knobs. The rubber band design is our most feasible design because we will most easily be able to complete the design and produce the final product within the given time period. All we would need to produce this design are rubber bands and some plywood to build the body. The rubber band design is also the most cost efficient, as rubber bands are much cheaper compared to linear actuators or motors and pulleys.

Fabrication/Development Process

Materials

The final design consisted of Progressive Automation's 15 Linear Actuator (PA 15 LA), an FSG Series force sensor, an arduino microcontroller, and an H-Bridge MOSFET circuit. The H-Bridge MOSFET circuit consisted of:

1. 2 p channel mosfet transistor
2. 2 n channel mosfet transistor
3. 2 npn transistors
4. 4 10k Ohm resistors
5. 2 2k Ohm resistors

The PA 15 LA provides the linear reaction force that is applied to the rats arm. The FSG force sensor sends input values to the arduino microcontroller, which in turn controls the actions of the linear actuator with the provided negative feedback loop. The H-Bridge MOSFET is the circuitry that allows the extension and retraction of the rod in the linear actuator by switching the polarity in the leads. For additional materials used (See Appendix Materials).

We created an h-bridge mosfet circuit in order to control the direction of current at the two leads attached to the pa-15 linear actuator. We are able to switch the polarity of the output leads by running the circuit with multiple digital output pins on the arduino(7). The reason we needed to be able to control the polarity of our leads was due to the fact that in order to change the direction of the linear actuator we need to be able to provide a positive and negative voltage. For an LTSpice generate circuit diagram (See Appendix Circuitry).

The FSG Series force sensor is a compressive load sensor that requires a mechanism to redirect the tensile forces of the system to compressive forces that can be read by the sensor. To achieve this we created a cage which had columns affixed to its base. The base would be attached to the handle which the rat is pulling on. The top of the cage would slide freely along the columns with minimal resistance and would be attached to the linear actuator. The orientation of the top and base plate would be such that when tension is applied on the rat handle the space between the cage would decrease. The force sensor occupies the space between the two plates and therefore experiences compressive forces when the handle is pulled.

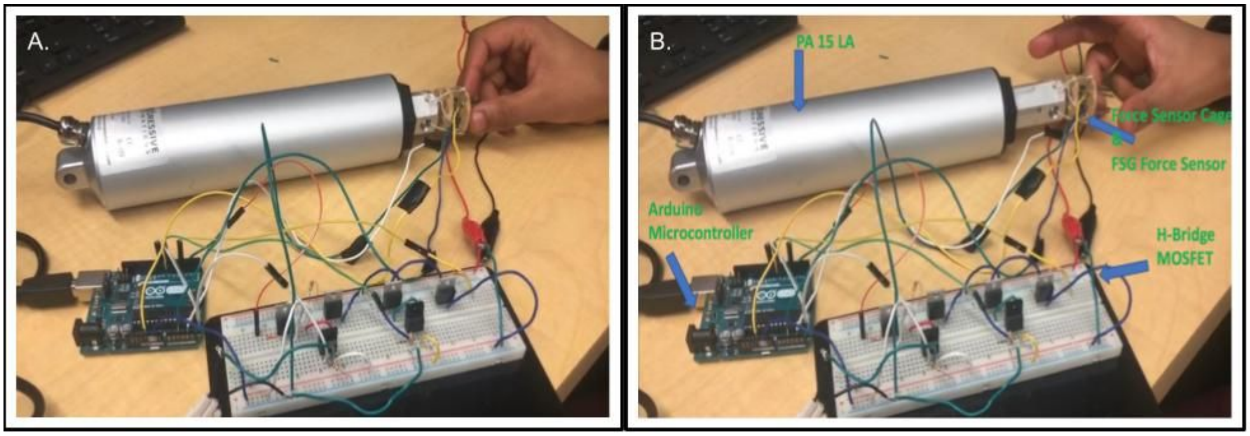

Figure 5: This is a labeled photograph of the final prototype. For a video of the design in action follow the link below:

https://youtu.be/sUe_xbdiCz8

Testing

Calibration testing - we know from the datasheet for the force sensor that the voltage potential measured across pin 2 and 4 will change linearly, with very little linearity error (+ or - 0.5%)[5], as force applied to the sensor changes. The calibration results of applied force vs ADC values are shown in the graph below. We extrapolated the linear equation derived from this calibration to determine forces being applied to the handle based on the ADC value being read into the arduino.

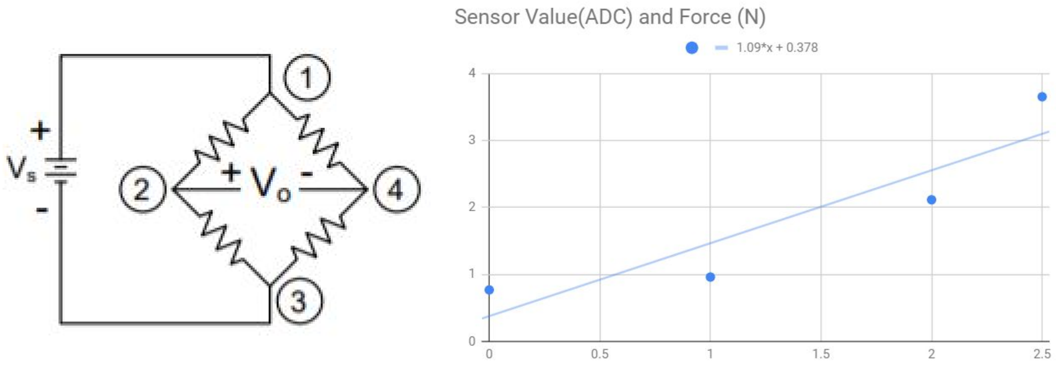

Figure 6. A diagram of the working principles of the FSG force sensor and our calibration plot.

Due to the sensitivity and fragility of the sensor we found that the force sensor was damaged before we were able to perform numerical tests after calibration. However, we planned on testing the device by pulling on the handle with springs of varying spring constants so that we may compare the force being measured with the force associated with the displacement of the spring.

We expect that the results of the test would display accurately recorded applied forces and a properly functioning negative feedback control. Depending on the threshold forces declared in the arduino code we expect that the control loop will properly extend and retract rod.

Results

While the sensor was still functional, we ran an arduino code with a threshold force of 0.05 N, and found that as soon as we began to pull on the handel the rod began to retract. When we let go of the handle and the sensed force was below 0.5 N the rod began to extend. For a demonstration of these actions visit the following link: https://youtu.be/sUe_xbdiCz8

Discussion

The two successes of our project were that we were able to pullback at a rate comparable to the average pull speed of the rats, and that we were able to measure force applied by the linear actuator throughout the duration of the pull.

These successes carry multiple implications. The client can now model muscle damage due to long term repetitive motion injuries on the majority of rats, and can eventually scale the results of this project up to understand long term repetitive motion muscle injuries for humans. We are also able to ensure that we are actually applying a force to the rat and that it is greater than the reference ramp force, and because the resolution of the force sensor is so fine it allows us to detect the exact moment at which the rat begin to pull on the handle.

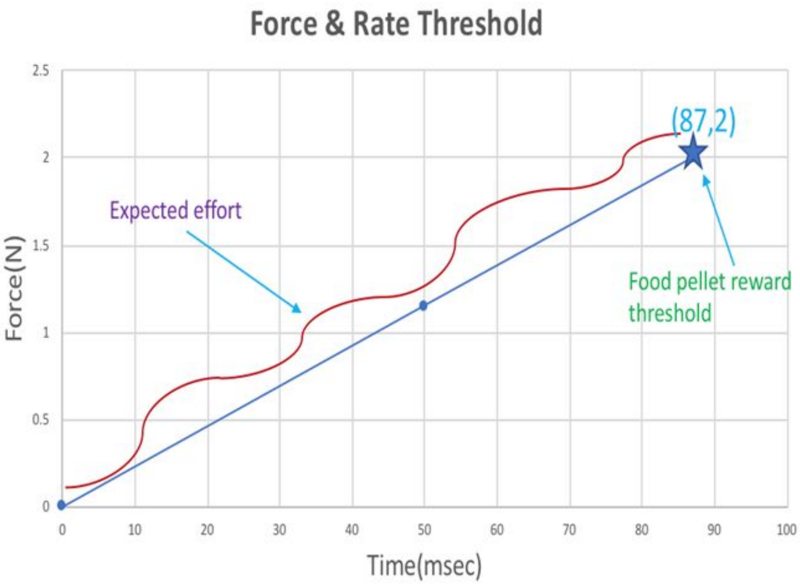

Figure 7. Force and Rate Threshold plot based on average reach forces and durations.

The only testing we carried out throughout the duration of this research was the force sensor calibration, in which we used this plot in order to find an equation to convert ADC values to force values in newtons. In this testing there weren't any ethical considerations to take into account. However for the ultimate use of this device researchers at Temple University will be using this design and testing it on rats. They will have to ensure that they follow The APA guidelines for ethical conduct in the care and use of nonhuman animals in research.

We need to use a force sensor which has a higher max force rating because 5N is a very small force and it is very easy to exceed the max force rating of 15N, and doing so causes permanent damage to the device. We also need a better method to hold the force sensor so that it measures force purely applied by the rat. Some improvements we could make to the current cage would include using machined parts for a smoother movement of the top plate along the columns, reducing the number of support columns, and using more flexible wires to connect the sensor to the power supply and arduino to minimize their contribution to the force being measured.

Conclusion

Industrial workers commonly suffer long term muscle fatigue and damage due to large loadings on muscles. The final design involves a linear actuator connected to an arduino microcontroller and a force sensor. The sensor will detect when the rat is pulling on the lever, and then instruct the linear actuator to retract, providing a reaction force for the rat. Our initial design involved a pulley system connected to a servo motor and an arduino microcontroller. This design provided many challenges, including trying to incorporate a force sensor. After that, we invested more money into our parts, and purchased a linear actuator. Our refined design worked much better, and could incorporate the force sensor. One of our major future directions includes increasing our adjustability and precision. At the moment, the device runs at the fixed pulling rate of an average size and strength rat.[2] This can be improved by allowing the researchers to adjust this through the use of Pulse Width Modulation. A PWM with a higher frequency rate will allow for higher resolution.[4] Displacement control is another aspect of the design that can be improved. This is amount of control the researchers have over the distance that the rat will pull the lever. This can be improved through the use of a more precise linear actuator. While researching for a linear actuator, we found a high precision actuator with a force sensor built-in. This part costs $3-5,000, so we went with a cheaper version, and this high precision actuator can be incorporated into a future design. Our prototype testing is limited to using a spring, as our client's research lab is set up at Temple University. In the near future, this design may also be used for research testing with actual rats. Finally, the application of this research done on rats will lead the researchers to gain more information on the effect of repetitive hand motion on the limbs. This can then be analyzed to derive human scalability and to help improve health and safety regulations to avoid injuries in the workplace.

Appendix

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

Product Design Specification (PDS)

Client: Prof. Radwin
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Date: December 11, 2018

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 pulls the rat hand 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

- Needs a device which provides an opposing force to the rat’s pull
- Forces applied to the rats as well as reach duration should be able to be changed by the researcher
- 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)

<u>Design Requirements</u>

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 8: 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 is 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.

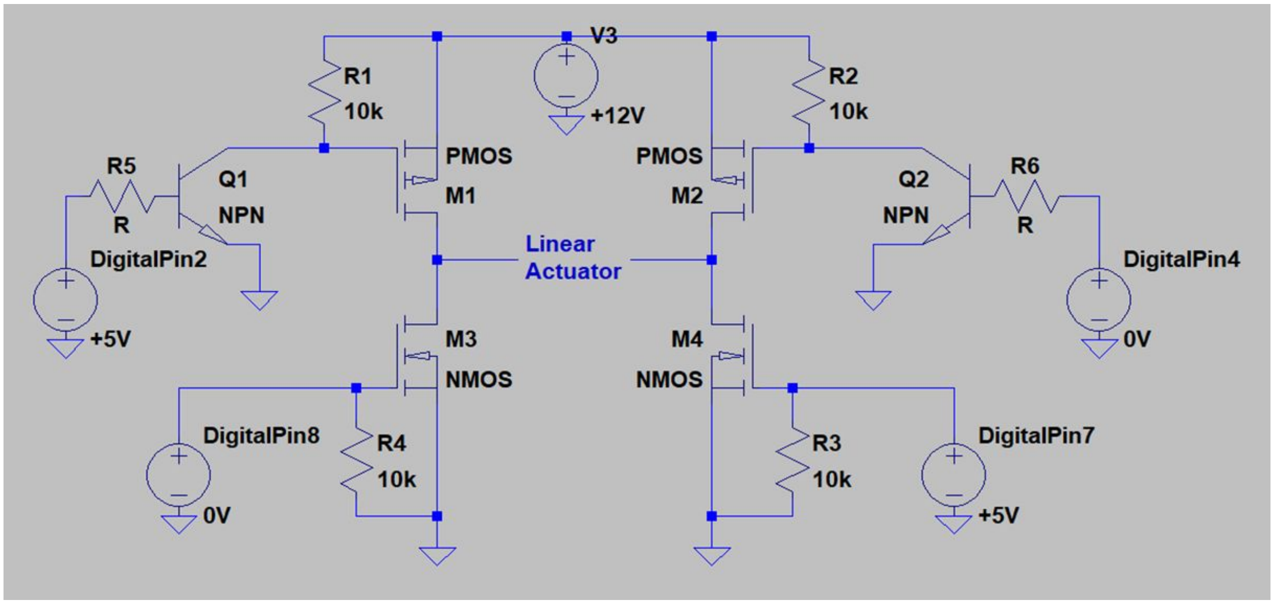
3. Miscellaneous

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. It features a static handle, not a dynamic handle. No patents were found on the device.

Materials

Description	Supplier	Part/Model #	Date	QTY	Cost Each	Total	Link
FEETECH FS90R (2 Pack) - 360° Rotation | Continuous Rotation Robotic Servo	Amazon	**FS90R**	10/17/2018	1	$11.94	$11.94	https://www.amazon.com/gp/product/B074BFQC3Q/ref=ox_sc_act_title_3?smid=AV7P08MNXGUP7&psc=1
5x 83010mm Nylon Round Pulley U Groove Track Roller Bearing,double Shielde 608zz Bearing Inside by Preamer	Amazon	N/A	10/17/2018	1	$8.84	$8.84	https://www.amazon.com/dp/B014884ZYG/ref=psdc_511408_t1_B014ER3QKK
eBoot 260m 150D 1 mm Leather Sewing Waxed Thread Cord for Leather Craft DIY (Beige)	Amazon	N/A	10/17/2018	1	$7.99	$7.99	https://www.amazon.com/dp/B01N0ZDPAG/ref=sspa_dk_detail_3?psc=1
SENSORFORCE SENSING RES0-5N	Honeywell Sensing and Productivity Solution	**480-5692-ND**	11/30/2018	1	$167.06	$167.06	https://www.digikey.com/product-detail/en/honeywell-sensing-and-productivity-solutions/FSG005WNPB/480-5692-ND/3884046
HIGH SPEED ACTUATOR	Actuator Zone	**SKU:PA-15**	11/30/2018	1	$145.00	$145.00	https://www.actuatorzone.com/high-speed-actuator

Circuitry


V3
+12V
R1
10k
R2
10k
PMOS
M1
PMOS
M2
R5
R
Q1
NPN
DigitalPin2
+5V
Q2
NPN
R6
R
DigitalPin4
0V
Linear
Actuator
M3
NMOS
M4
NMOS
DigitalPin8
0V
R4
10k
R3
10k
DigitalPin7
+5V

Arduino Code

```
int V2 = 2;
//int V4 = 4;
//int V7 = 7;
//int V8 = 8;
//int V2in = A2;
//int V4in = A4;
//
//void setup() {
//  Serial.begin(9600);
//
//  pinMode(V2, OUTPUT);
//  pinMode(V4, OUTPUT);
//  pinMode(V7, OUTPUT);
//  pinMode(V8, OUTPUT);
//
//  pinMode(V2in, INPUT);
//  pinMode(V4in, INPUT);
//}
//void loop() {
//float Sensed = (analogRead(V4in)-analogRead(V2in));
//float FSensed = 0.111*Sensed + 0.0385;
//
//
////Serial.println(FSensed);
//if(FSensed>0.05){
//  digitalWrite(V2, HIGH);
//  digitalWrite(V4, LOW);
//  digitalWrite(V7, HIGH);
//  digitalWrite(V8, LOW);
//}
//if(FSensed<0.05){
//  digitalWrite(V2, LOW);
//  digitalWrite(V4, HIGH);
//  digitalWrite(V7, LOW);
//  digitalWrite(V8, HIGH);
//}
```

References

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