Flying Squirrel

Initial Design Report

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Project Sponsor: Dr. Reza Razavian
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DISCLAIMER

This report was prepared by students as part of a university course requirement. While considerable effort has been put into the project, it is not the work of licensed engineers and has not undergone the extensive verification that is common in the profession. The information, data, conclusions, and content of this report should not be relied on or utilized without thorough, independent testing and verification. University faculty members may have been associated with this project as advisors, sponsors, or course instructors, but as such they are not responsible for the accuracy of results or conclusions.

EXECUTIVE SUMMARY

As of January 23,2025, team members John Avila-Copado, Ryan Donnellan, Justin Joy, Owen Kehl, and Joseph Mathews have been assigned to the Fly Squirrel project. The project sponsor, Dr Reza Razavian has provided the team with a description of the project, a budget, expectations and customer requirements. The team has participated in many meetings and projects since the project was assigned to discuss and progress with project requirements. Dr. Razavian has participated in all of the team's concept generation and current progression. All members of the team have contributed to the project through individual assignments and team assignments and meetings. As of the current date, March 9, 2025, the team is currently on schedule with all project requirements.

Shortly after the Flying Squirrel was assigned, the team quickly scheduled a meeting with all members to meet and get to know each other. The first meeting the team created ground rules and conflict resolution to follow throughout the project. During this time, the team scheduled its first client meeting to introduce themselves to Dr. Razavian. During the first client meeting, the team was tasked with their first concept generation so Dr. Razavian could get an idea of what each team members thoughts were toward the Flying Squirrel. The team scheduled another client meeting with Dr. Razavian the following week to review the concept generation. While Dr. Razavian liked some of the ideas the team presented, he introduced the direction he would like to see the project go with a cable driven design. The team was requested to complete another concept generation according to Dr. Razavian’s idea. During the following client meeting, issues were addressed that were discovered during second concept generation. Dr. Razavian requested the team to focus on specific issues for the third concept generation along with the first CAD model. The following week, the team had another client meeting to discuss what was requested the previous week. The next line of focus was mathematic models for drive cables and motor requirements. The last client meeting the team had at this period was to discuss the data the team developed to approach issues discussed during the previous client meeting.

In conjunction with client meetings, the team was also tasked with class assignments and presentations. This required the team to meet to complete tasks and develop team rules and resolutions for the project. The first team meeting was to discuss and complete a team charter that discusses the rules and conflict resolution that the team came up with and agreed on. The following task the team needed to complete was the first presentation. The first presentation was constructed to introduce the class to the Flying Squirrel. The presentation introduced the quality function deployment, engineering requirements, client requirements, relevant equations to the project, SOTA and literature reviews in respect to the project, and a Gantt chart to visualize the team's progress. The week following the presentation, the team was scheduled for a staff meeting with Professor Carson Pete. He discussed feedback from the presentation and followed up with the team's progress. The following task was an individual learning assignment for each member of the team. These assignments are aimed to improve and learn skills that are helpful towards the project. The most recent task completed by the team was the second presentation. The second presentation the team developed discusses concept generation, mathematical modeling and equations, the CAD model, and the team's progress in a Gantt chart.

The team's progression and growth with this project is reflected by the positive feedback from peers, clients, and professors. Every individual within the team has extended beyond the typical requirements assigned. The team meets very frequently to discuss next steps to ensure success for future assignments and a smooth completion of the research and development of the Flying Squirrel. The next steps for the project include prototyping and programming within the constraints of the project.

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1 BACKGROUND

In section 1.1 we will go over the project itself, what its main purpose is, and the various reasons for its existence while giving some reasons other options aren't adequate. Also, in this section we talk about our project's current budget and what we are looking at in terms of fundraising. In the next section, section 1.2, we go over several different deliverables that our client would like us to achieve by the end of our capstone. Lastly in section 1.3 we go over what success looks like for us and the Flying Squirrel using different success metrics to see if our end product is indeed successful.

1.1 Project Description

The Flying Squirrel is meant to be a therapeutic rehabilitation robot focusing on restoring the motor functions in the arms of a stroke victim. The Flying Squirrel is a spiritual successor of the Hamster, a capstone project from the past year. While the Hamster and the Flying Squirrel share the same purpose and idea, that being a relatively cheap alterative robot to what's out on the current market, where these diverge is the scope while the Hamster is locked into the 2D plane the Flying Squirrels goal is to expand into the 3rd dimension. Our project development budget is $3750; the current fundraising target is $300 which would put our budget over $4000 in total budget for this project. One of main reasons why this project is important aside from rehabilitating stoke victims to give them use in their arms, is to make this robot cheap because as it stands today on the current market there is almost no robot that delivers same function for below $10,000! The end goal vision is that a person can buy this robot and set it up with relative ease and begin the road towards rehabilitation in their own home without breaking the bank.

1.2 Deliverables

The main deliverable for this project is to produce a robot that is capable of moving in the X, Y and Z direction by the end of capstone. It also needs a system to track its position at all times and the amount of force it receives and produces, while also recording that information and sending it to a computer. Another deliverable that we need to carry out is an accurate and complete CAD model and drawings of the final design of the Flying Squirrel. All this will be accomplished while keeping up with the actual Capstone course deliverables such as presentation, reports and staff meetings.

1.3 Success Metrics

For this project, the main measure of success is our ability to procure the necessary main deliverables while remaining fulfilling the proper requirements for our final product. These include the customer requirements, or the performance requisites expected by the user; and the engineering requirements, which refer to technical parameters defined by our sponsor. Each set of requirements will be explained further in section 2. Some simple conditions, such as the size of the robot in its inactive state, will be fulfilled in the course of its design. Other performance-related requirements will be validated through testing. We will attempt to ensure capabilities like force detection and position accuracy are present in our initial programming, but physical trials will likely be necessary to confirm their function.

2 REQUIREMENTS

In this section we will go over the different requirements that will be needed for the flying squirrel robot. Cover our customers' requirements ranging from affordability to ease of use for the customer. Also, in this section we will go over the engineering requirements associated best by meeting not only our clients' wants but the needs of the consumer that will be using the robot. Finally, there will be a Quality function deployment graph combining all the customer requirements and the engineering requirements to see how each induvial item correlates with one another.

2.1 Customer Requirements (CRs)

Below is a list of customer requirements and the reasons why they're important for the customer of the flying squirrel robot.

1. **Affordability:** The main obstacle right now to physical therapy is either the patient doesn't have the time to travel to physical therapy or the means or money to pay for extensive physical therapy. By making it as affordable as possible we can at least try to eliminate one of these problems.
2. **3rd dimensional movement:** A lot of physical therapy exercises for patients require 3D movements, like reaching for a glass of water and drinking it. By giving it access to the 3D the Flying Squirrel can access a whole host more exercises than the Hamster ever could.
3. **Precision and Accuracy:** It's important to have an accurate and precise robot so that any data that it produces is reliable and can be used to plan out the next steps of the patient's recovery.
4. **Size:** If the main goal is to have the Flying Squirrel in people's home it has to be a relatively small and compact size so that it can be stored when not in use.
5. **Cosmetics:** If the robot is hideous people would put off from buying it.
6. **User Friendliness:** when the Flying Squirrel is in people's homes it's imperative that it has a fast set up time and that it is easy to use so that people don't get discouraged from doing their therapy just because it's a hassle to set up.

2.2 Engineering Requirements (ERs)

The engineering requirements established by the team and our client are listed below. We have decided that these are the most important requirements we need to focus on over the course of this project.

1. **Range of motion**: Moving the hand in 3D space up to 1ft above the surface of a table.
2. **Size**: Fit within a box of 8"x8"x8".

3. **Speed**: The device must be able to “catch up” with users at a hand speed of up to 1 m/s in any direction.
4. **Force**: The device must be able to produce forces of up to 10 N to the hand in any direction.
5. **Sensing accuracy**: Position sensing accuracy: <0.1mm. Force sensing accuracy: <0.1N.
6. **Control accuracy**: position control with <0.5mm error. Force control <1N error.
7. **Production Cost**: The total “production” cost (bill of materials + manufacturing/labor cost) must be <$1000. (Though this has changed to be more flexible as we have done more research, a 3-axis force sensor would cost more than half the initial design cost.)

Commented [JA1]: Insert as one category into qfd?

2.3 House of Quality (HoQ)

		Technical Requirements							Competitive Analysis				
Customer Needs	Customer Weights (1-5)	Production Cost	Speed	Force	Position Tracking	Device Size	N/A	N/A	1 *Poor*	2	3 *Acceptable*	4	5 *Excellent*
Affordability	5	9			3	3			AB				C
3rd Dimension Movement	4	3	1	1		1			C				AB
Precision and Accuracy	3	3	9	9	9						C		AB
Size	4	3	1			9			B		A		C
Cosmetics	1	1				1				C	B		A
User Friendliness	5	3				9				A		B	C
Technical Requirement Units		Dollars ($)	Meters per Second (m/s)	Newtons (N)	Millimeters (mm)	Inches (in)							
Technical Requirement Targets		1000	1	10	0.1	8x8x8							
Absolute Technical Importance		93	35	31	42	100							
Relative Technical Importance		2	4	5	3	1							

Relationships:			
9	3	1	
Strong	Moderate	Weak	None

Legend:	
A	Armeo SpringPro
B	ArmMotus M2 Pro
C	The Hamster

Table 1: Quality Function Deployment (QFD)

3 Research Within Your Design Space

3.1 Benchmarking

- *Armeo SpringPro*

Figure 1: Armeo SpringPro

This device is an advanced motion rehabilitation machine designed to target the patient's arm. It provides a significant array of motion in three dimensions, and while in use fully supports the targeted limb according to [1]. However, due to its technical complexity, the product is both cumbersome and not realistically affordable to individual consumers.

- *ArmMotus M2 Pro*

Figure 2: ArmMotus M2 Pro

This system also aims to restore arm movement in patients, specifically those suffering from neurological and musculoskeletal disorders as stated in [2]. In addition to providing simple 3D motion, the system comes with a variety of game programs to exercise the patient's arm. While an impressive product, it suffers from largely the same drawbacks as the large and costly Armeo.

- *The Hamster*

Figure 3: The Hamster

Being the basis of our own project, this design addresses some of the issues present in the other two rehabilitation devices. Namely, it supplies arm movement in a more compact and affordable package. [3] states that it will eventually be programmed with exercise routines to facilitate the motor control of stroke victims. Its main drawback is that, while the omnidirectional wheels allow it to take any horizontal path on a surface, the Hamster lacks vertical movement.

3.2 Literature Review

- **3.2.1 Jonathan Avila**
  - *Rehabilitation Robotics: Technology and Application.* [4]
    - Rehabilitation Robotics gives an introduction and overview of different areas of rehabilitation robotics while also summarizing the different robot technologies and application of them. Seeing what kind of technology is already out there on the market gives us inspiration as to what alternative designs we can turn to during the concept generation portion of the project.
  - *Atlas of Orthoses and Assistive Devices.* [5]
    - The source detail various robots and more specifically medical devices in the medical field. This gives some examples of the do's and don'ts of what to do when creating a robot that has a better chance of succeeding.
  - *Wrench feasibility workspace analysis and adaptive rotation algorithm of cable-driven upper limb rehabilitation robot.* [6]
    - This source was useful in just seeing how it was possible to move a person around using cables though the main problem with this robot was that it was way too expensive and bulky to be really practical.
  - *Control of a large redundantly actuated cable-suspended parallel robot.* [7]
    - In building a cable driven robot learning some of the basics of moving around, a large cable robot seems imperative to create something that just focuses on moving just the one limb.
  - *String-man: A new wire robot for gait rehabilitation.* [8]
    - The same kind of robot mechanism and function but just built for different aspects of patient recovery, you couldn't dream for a source this similar for our project,
  - *Garrett Brown's skycam history.* [9]
    - This source specifically talks about the history of the process of the making of cable driven robot before they knew what they were actually end up making. Which is very useful when making a cable driven robot yourself to see what kind of struggles other people had along the way so that we can avoid some of those pit falls.
  - *How skycam works.* [10]
    - This explains some of the more in-depth mechanics as to how the sky cam works and being able to see how a cable driven robot can effort move in the XYZ plane effortlessly. Which helps us so that we aren't starting from scratch.
  - *Rehabilitation Robot - an overview.* [11]

        - This specific source is an overview of a wide variety of robots, more specifically the rehabilitation aspect of patient care. Which just gives us a frame of reference for what other robots did and what worked and became successful and what didn't.

- **3.2.2 Ryan Donnellan**
    - *Arduino Robotic Projects: Build Awesome and Complex Robots with the Power of Arduino*. [12]
        - This book covers the basics of Arduino, what is on an Arduino board, and how to use it. It gives examples of projects using Arduino to broaden the understanding of Arduino to the reader. It will be relevant to the project in the manner that the Flying Squirrel will be using Arduinos to control motors that control the movement of the robot.
    - *Raspberry Pi 3 Cookbook for Python Programmers: Unleash the Potential of Raspberry Pi 3 with over 100 Recipes.* [13]
        - This book gives an in-depth overview of how to use Raspberry Pis. It covers topics ranging from automating computer tasks to how to build a small robot. The content covered in this book will be used to set up the Raspberry Pi that is controlling the robot.
    - *Modeling cable-driven robot with hysteresis and cable–pulley network friction.* [14]
        - This article contains information on how to model the behavior of the cables that control a cable driven robot. It contains equations to calculate how much the cables will stretch while in use by the robot. This article could be applied to the project by helping to calculate the position in the event of the cables stretching.
    - *Permanent magnet DC motor control by using Arduino and Motor Drive Module BTS7960.* [15]
        - This article proposes a control system using pulse width modulation to control the output of a permanent magnet DC motor. This will be relevant to the project as the robot will be using pulse width modulation to control the motors that move the robot.
    - *Design and evaluation of a Bowden-cable-based remote actuation system for wearable robotics.* [16]
        - This article gives an example of a cable driven wearable robot that assists the motor function of the patient. It can help the team decide on what motors to use to drive the robot. It will help because the robot in the article has to support the weight of the arm, and the Flying Squirrel will not.
    - *Robot-assisted therapy in stroke rehabilitation.* [17]
        - This journal gives evidence as to what kind of robot works best and does not show evidence of working as a therapy device. It will help inform the design of the robot by improving upon what works and getting rid of what does not.

- *A novel cable-driven robotic training improves locomotor function in individuals post-stroke.* [18]
    - This article gives evidence on the success of cable-driven robots to improve the motor function of stroke victims. This article can help inform the design of the Flying Squirrel to incorporate what works best based on experiments that have already been done. It can also help by getting rid of what does not work based on the evidence presented in the article.
- *How to use Raspberry Pi and Arduino together.* [19]
    - This website gives an overview of how Raspberry Pi and Arduino work together. It tells you what hardware, software, and code you need to make the two work together. It will be relevant to the project because the Flying Squirrel will use a Raspberry Pi to change the input to the Arduino to control the motors.

- **3.2.3 Justin Joy**
  - *Encyclopedia of Smart Materials* [20]
    - This book covers materials that have one or more properties that can be significantly changed in a controlled manner. It provides information on fundamental and recent developments for design and applications. The applications include robotics which is relevant to the Flying Squirrel.
  - *Chapter 5 - Robotics and Rehabilitation: The Role of Robot-mediated Therapy Post Stroke* [21]
    - The chapter discusses the importance of exercise-based intervention for stroke patients. It then justifies how robotics can play a role in the therapy of stroke victims. The chapter reviews research of work done to implement robotics in stroke therapy
  - *Upper Limb Robot Mediated Stroke Therapy—GENTLE/s Approach* [22]
    - The article discusses how early therapy can enhance stroke recovery. Robots and VR-based systems encourage patients to exercise for longer periods of time. It is also quickly available at home.
  - *Multi-sensor Fusion for Body Sensor Network in Medical Human–robot Interaction Scenario* [23]
    - The article discusses how multi-sensor integration is important for data collection in real time. It is also important to collect data from the user for medical purposes. Multi-sensor fusion methods can improve the communication of data.
  - *Development of an Integrated Haptic Sensor System for Multimodal Human–Computer Interaction Using Ultrasonic Array and Cable Robot* [24]
    - The article connects human interaction with cable drive robotic sensors and motors. The subsystems and sensors invoke realistic stimulation. The device uses a novel haptic sensor system.
  - *Adaptive Robot-Assisted Feeding: An Online Learning Framework for Acquiring Previously Unseen Food Items* [25]
    - A feeding robot is programmed to adapt to different food preferences under

uncertain conditions. Different manipulation strategies are used for successful bite acquisitions. These methods can be used to manipulate different user inputs.

- *Adaptive Assistive Robotics: A Framework for Triadic Collaboration Between Humans and Robots* [26]
  - Framework is given to provide a combination of biomechanical modeling and weighted multi-objective optimization. This allows for fine tuning of robot behaviors. The framework is illustrated in the article showing the benefits of the triadic approach.
- *A State-of-the-Art Review on Robots and Medical Devices Using Smart Fluids and Shape Memory Alloys* [27]
  - Various robots in this article use smart materials to activate functions. These smart materials include electro-rheological fluids, magneto-rheological fluids, and shape memory alloys. Specific types of mechanism in robots are investigated in medical devices and rehabilitation systems.

- **3.2.4 Owen Kehl**
  - *Chapter 6 - Robotics in Rehabilitation Medicine: Prosthetics, Exoskeletons, All Else in Rehabilitation Medicine*. [28]
    - This chapter talks about similar robotic rehabilitation equipment, as well as how it is used in the physical therapy sphere. Given the nature of this project, material related to rehabilatation and robotics helps with benchmarking.
  - *Chapter 3 – Sensors and Transducers*. [29]
    - In this chapter, the author discusses the different types of sensors used in bio mechatronics and writes a little about how the technology works. This information is good for deciding what sensors will work in our own design.
  - *Forces and Moments Generated by the Human Arm: Variability and Control.* [30]
    - This study examines arm movements in response to forces exerted on the hand. Such data helps us to understand how people will respond to a moving handle, which our project may be crudely defined as.
  - *Force Control and Degree of Motor Impairments in Chronic Stroke.* [31]
    - The focus of this study is to compare force application control in the fingers and wrists of stroke victims versus control subjects of a similar age. This helps us to get an idea of how users will interact with the Flying Squirrel.
  - *A Low-Dimensional Representation of Arm Movements and Hand Grip Forces in Post-Stroke Individuals.* [32]
    - This investigation aims to observe how motor control is affected by a stroke, studying data from both stroke victims and a control group. Like the previous source, the data helps us to understand the arm motions of patients.
  - *Human Body Mass Distribution.* [33]
    - Taken from a larger study, this table provides an idea of mass represented by different parts of the human body. This includes the arm and hand, which helps to understand the weight and moment applied by a person's extended arm.
  - *Understanding Force Sensors: How They Work and Measure Force.* [34]
    - This page explains the mechanisms behind force sensors and the different types available. It is important that we understand how this technology works and what

type of sensor should be used for our purposes.

- *Accurate Tracking: A Look at Position and Distance Sensors.* [35]
  - Similarly, this page discusses the different types of force sensors and their uses. Our final product needs to detect forces and its own position, so an understanding of position tracking is necessary.

- **3.2.5 Joey Mathews**
  - *Raspberry Pi Robotic Projects* [36]
    - This book starts with an overview and tutorial on how to use a Raspberry Pi. Each chapter after that focuses on applying a Raspberry Pi for different robots that each perform different tasks, and several sections within the chapters explain how to set up and use various components, such as servo motors and cameras. This book will be useful for us because it will help us understand how to integrate electronic components with a Raspberry Pi that we will be using.
  - *Hands-on robotics programming with C++ : leverage raspberry pi 3 and C++ libraries to build intelligent robotics applications.* [37]
    - This book is similar to the previous source, as it introduces and explores how a Raspberry Pi works and what functions it is capable of. A larger portion of the book is dedicated to this than the previous source. It then explores different applications for the Raspberry Pi in robotics and has tutorials on how to build and program different types of robots. This source is beneficial for our group because it goes into further detail about how to set up and program different electronic components and how to use them for robotics applications.
  - *ToF 3D Vision Algorithms in C++ for Robotic Applications* [38]
    - This article primarily focuses on different algorithms that can be used with a Raspberry Pi, and what kinds of algorithms the author used for their thesis work, and how these algorithms were applied. Again, this article will be beneficial for us because it goes further in depth on programming with Raspberry Pis for robotics applications.
  - *Gesture Control Robot with Arduino* [39]
    - This article focuses on the creation of a robot that can be controlled by gestures. We've been tasked with adding a load cell into the Flying Squirrel, so when the user applies force, the robot will respond to it. While the connection is weak, I think it may still be useful in integrating these types of controls with the load cell.
  - *Path Following System for Cooperative Mobile Robots* [40]
    - This paper describes the path following system utilized by the robots described in the paper. It explains the equations utilized by the robots' programming to track its movements. This source will be useful for us as it will help us understand and develop our own path following system along the cables.
  - *Wire Robots Part I: Kinematics, Analysis & Design* [41]
    - This paper focuses on robots controlled by cables and wires. The details it provides on how those robots are controlled will be useful in the development of our cable system.
  - *Robot dynamics and control* [42]

        - This book focuses on the physics and dynamics of robots, control systems, and how the two are related. There are many different aspects within the control system sections that will help us with the development of our programming. The sections regarding force control, trajectory and path planning, and velocity kinematics will likely be the most useful sections for us.
    - *Controlling Tensegrity Robots through Evolution* [43]
        - This source is very similar to 41, and the reasoning is also similar. It focuses on how cable driven robots work, and the information it provides may be useful to the development of the Flying Squirrel.

3.3 Mathematical Modeling

Equations pulled from prior classes so no citations needed.

3.3.1 Attachment Cable and Motor System

- **Wire Tension-Jonathan A. and Justin J.**
    - $\sum MA = 0$
- **Maximum Motor Torque Estimates-Joey M. and Justin J.**
    - $\tau = F*r$
- **Wire Max Stress-Jonathan A.**
    - $S = (F*nf) / A = (T*nf)/ A$

3.3.2 Battery

- **Total Battery Capacity Required-Ryan D.**
    - $Ah = I * h$

3.3.3 Lifting System

- **Necessary Lifting Strength-Owen K.**

- $M = MP_{hm}g(L(1-0.5P_{hl})) + MP_{fm}g(L(0.5P_{fl}+P_{al})) + MP_{am}g(L(0.5P_{al}))$

- **Downward Force from Wires-Owen K.**
  - $F_y = F_t * \cos(\theta)$

3.3.4 Position and Motion Tracking

- **Vector Analysis for Motion and Angle Tracking-Joey M. and Ryan D.**
  - $\theta = \arctan(y / x)$
- Engineering Tools
  - Matlab/Python/C++

Calculations Table

Equation	How it's applicable.	What requirements these equations meet.	How we validated the answers obtained.
$t = I * Ah$	Calculating minimum battery required to achieve desired run time.	Minimum run time of 30 minutes.	Obtained average power draw from online sources and used those to calculate time
$\theta = \arctan(y / x)$	Calculating position of robot as it moves closer to boundary	Position accuracy of 0.1mm	Solved equations by hand and used scale model to test angles
$S=(F*nf) / A = (T*nf)/ A$	Calculates the minimum amount of stress our cable needs to able to withstand	To be able to withstand 10 N of Force	By finding the amount stress induced we can select an appropriate wire
$\sum MA=0$	Calculates the minimum amount of tension in cables	Minimum tension needs to be 2.2lbs or nearly 10 N	Using structural analysis, the equation can be solved by hand

$\tau = F*r$	Calculates the estimated maximum applied torque	Finding a motor that can output the required 10 N of force	Using a MATLAB script to calculate the torques at all positions the robot could be at
$\tau_{adjusted} = F.O.S. * \tau$	Calculates the estimated maximum applied torque using the factor of safety	Finding a motor that can output the required 10 N of force accounting for a factor of safety	Using a MATLAB script to calculate the torques at all positions the robot could be at
$M= MP_{hm}g(L(1-0.5P_{hl}))+ MP_{fm}g(L(0.5P_{fl}+P_{al}))+ MP_{am}g(L(0.5P_{al}))$	Calculates net upward force needed to move an extended arm	Moving user's hand with an upward force of 10 newtons	Used human body mass percentages and solved by hand
$F_y= F_t*\cos(\theta)$	Calculates downward force due to wire tension	Applying 10N force in horizontal and vertical directions	Solved by hand using force diagrams and position assumptions

Table 2: Calculations Table

4 Design Concepts

4.1 Functional Decomposition

Black Box

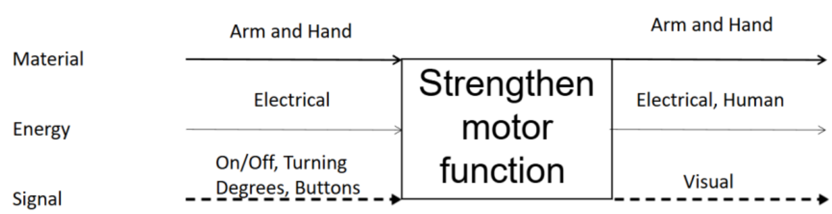


Figure 4: Black Box Diagram

This model shows the different inputs and outputs of our system, in addition to its main function.

Functional Decomposition

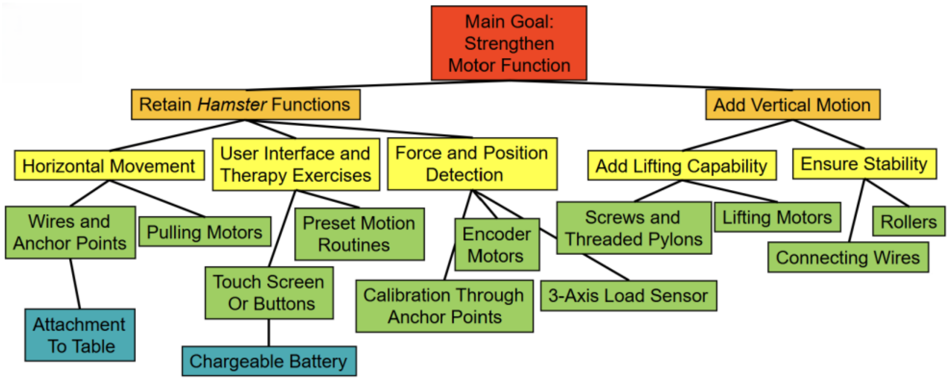
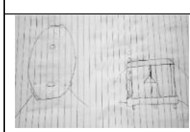
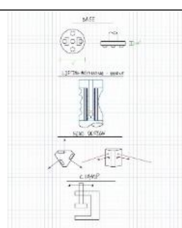
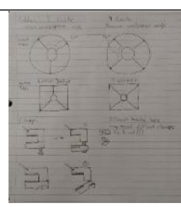
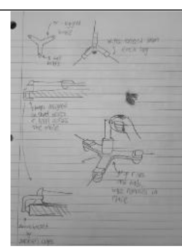
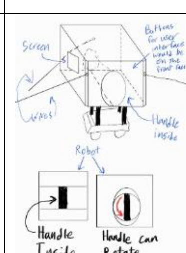


Figure 5: Functional Decomposition

The main function is expanded upon in the above figure. It is divided into two major functions in orange, those being to capture the capabilities of the Hamster design and add vertical motion. Each major function is split into several yellow sub-functions. Green boxes indicate the components or systems necessary to realize the functions. Some of these include teal sub-components that are crucial for their design. This breakdown of functions was important to identifying the necessary hardware that our robot would have to host. Additionally, knowing the required functions and components helped to focus our efforts during concept generation phases.

4.2 Concept Generation

After our first round of concept generation, Dr. Razavian broached the idea of a cable-driven robot. It was decided that this concept would be the basis for all future ideas going forward. From there, another round of generation based on the cable-anchor idea took place. Larger images of this phase's designs can be found in Appendix B. Designs from the initial concept generation can be found in Appendix A

Design 1-Jonathan	**Design 2-Ryan**	**Design 3-Justin**	**Design 4-Owen**	**Design 5-Joey**
				
Pros: Robust lifting system, flexible handle,	**Pros:** Ergonomic, stable clamp design	**Pros:** Different wire/anchor configurations,	**Pros:** Adjustable handle, different clamp options	**Pros:** Arm support, stable lifting system

stable design		adaptable clamps		
Cons:	**Cons:** Rigid handle	**Cons:**	**Cons:** Prone to tipping	**Cons:** Potentially bulky

Table 3: Concept Generation

4.3 Selection Criteria

The way we went about establishing our selection criteria was different from a normal concept generation and selection process. Dr. Razavian had already come up with an idea that he wanted to use for this project, so when we got to the stage to select what concepts to use, we ended up selecting pieces from each of the concepts we had generated that Dr. Razavian had liked, and incorporated those concepts into our next design until we had generated a design that was satisfactory and we moved forward from there.

4.4 Concept Selection

Pugh Chart

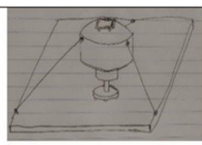
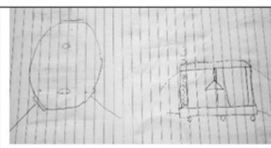
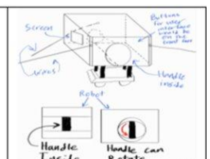
Criteria			
Design	1	2	3
Production cost	+ Smaller device	S	Datum
Speed of the Robot	-It has a smaller base to work with	+The base and double wire allow for fast accurate movement	Datum
Device Size	+ It has a small frame	+ it is more compact than the Datum	Datum
Position Tracking	S	S	Datum
Force	-Smaller base to account from moment	S	Datum
User Friendliness	-Setup difficulties from base size and user touchscreen.	+It has a fast and easy set up with a screen	Datum
Total +	2	3	
Total S	1	3	
Total -	3	0	

Table 4: Pugh Chart

CAD Model

Below is the current CAD model we have. This model is based on design 2 from the Pugh Chart. Dr. Razavian had requested a rough draft CAD model as a next step to the concept design process. The purpose of this was to create a rough design that he could review and provide feedback on.

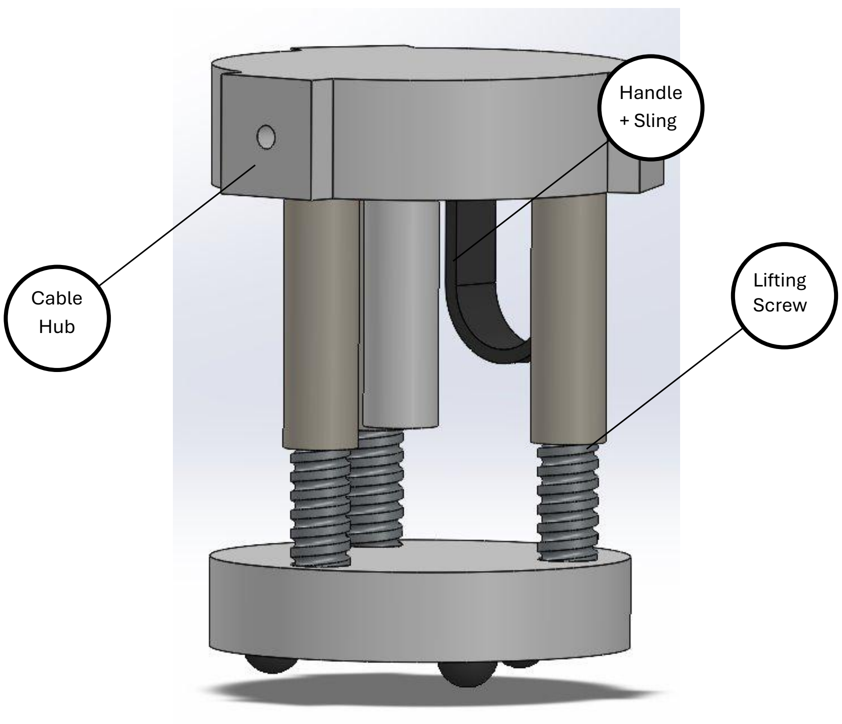


Figure 5: CAD Model

Hybrid Clamp Design

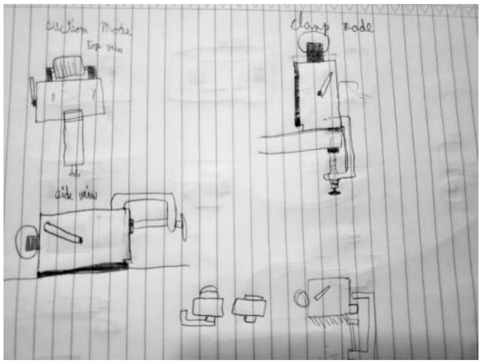


Figure 6: Hybrid Clamp

5 CONCLUSIONS

So far, we have been able to examine the purpose of this project, take the customer and engineering requirements into account, and make good progress in developing a solution. In addition to the information provided by our sponsor, we have also compiled a good list of relevant sources to draw upon and equations to calculate necessary quantities. Through design generation and meetings with Dr. Razavian, we have been able to narrow down possible designs and converge upon our current wire-driven design. Further concept generation and selection has allowed us to select a final design and construct a tentative CAD model of it. If we continue at this rate, we are confident that our team will produce a capable design that is able to produce 10 Newtons in any direction, lift 1 foot off its work surface, detect force and position with great accuracy, fit within 8^3 cubic inches of space, and cost little more than $1000 to produce. Ultimately, our final product will improve upon the Hamster design and provide efficient and affordable rehabilitation assistance to stroke patients.

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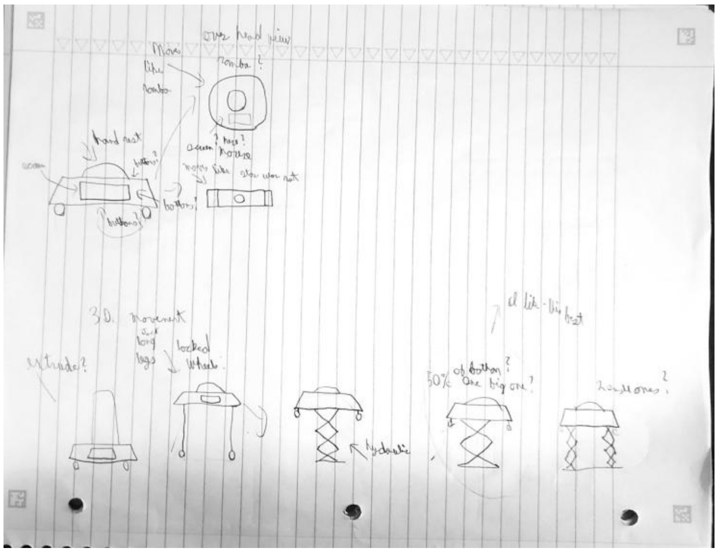
7 APPENDICES

7.1 Appendix A: 1st Concept Generation



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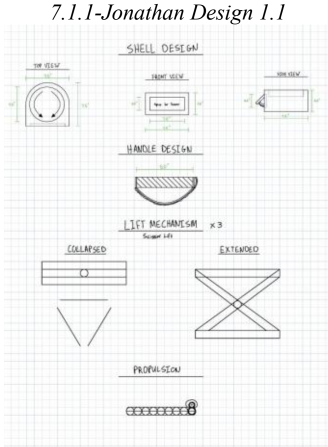

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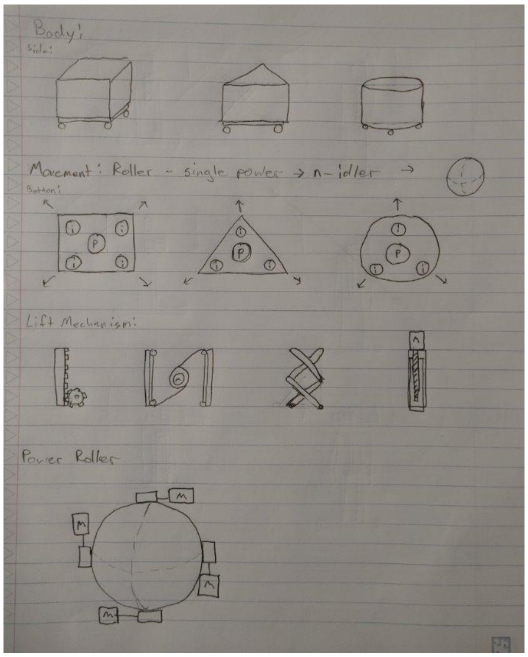

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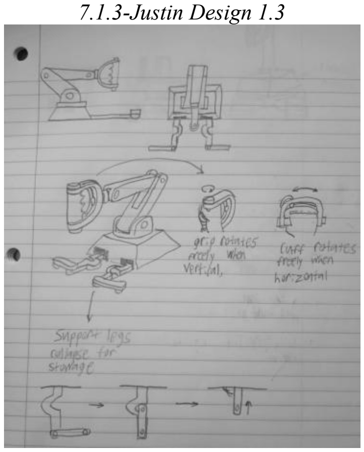

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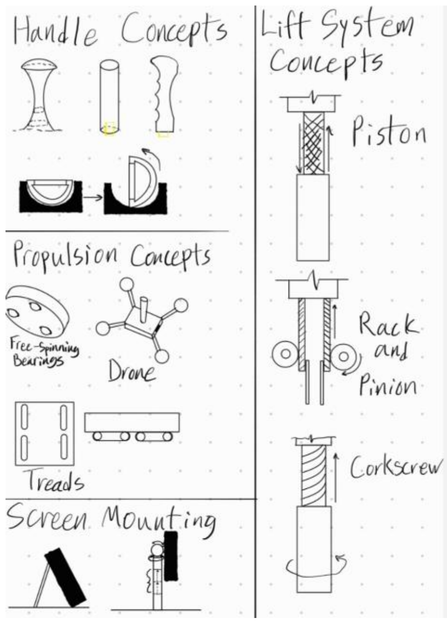
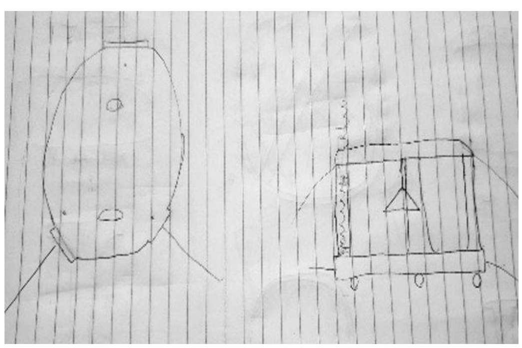


7.1.5-Joey Design 1.5

7.2 Appendix B: 2nd Concept Generation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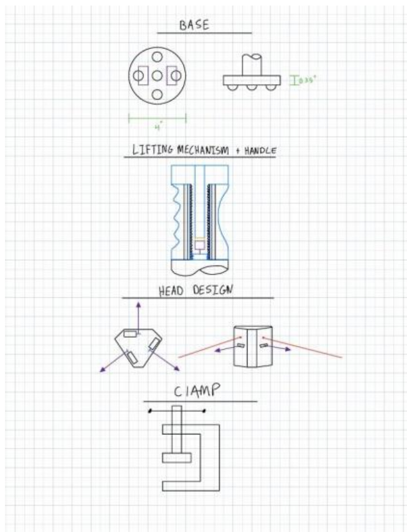

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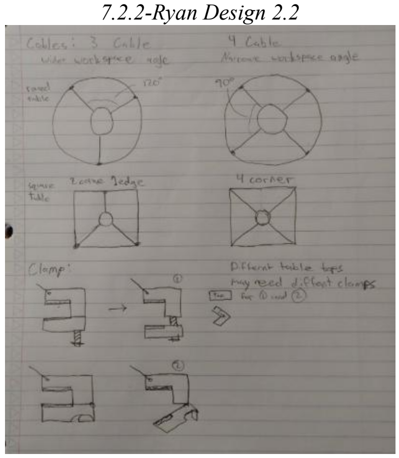

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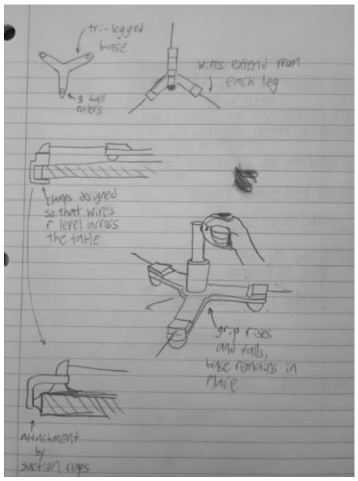

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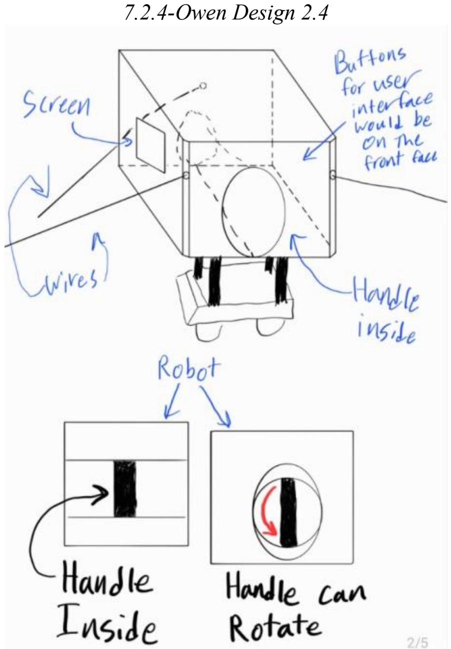

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