Flying Squirrel

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Project Description

SPONSOR

- Dr. Razavian
- Raz Labs

CUSTOMER NEEDS

- Therapeutic stroke patient device
  - Table-top cable-driven robot
- At home, easy and fast to setup, inexpensive
  - Less than $1000
  - Less than 1 minute for setup
- Next generation of "Hamster"
  - Improved from 2D movement to 3D
  - Smaller in size

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Background & Benchmarking

Armeo SpringPro

Image 1: Armeo SpringPro

- Works in x,y,z planes
- Full arm support
- Large footprint
- Complex 3D motion
- Very expensive

ArmMotus M2 Pro

Image 2: ArmMotus M2 Pro

- Works in x,y,z planes
- Forearm support
- Very large footprint
- Simple 3D motion
- Very expensive

The Hamster

Image 3: The Hamster

- Works in x,y planes
- No arm support
- Compact footprint
- Simple 2D motion
- Inexpensive

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Customer Requirements

Client Specified Requirements

- Affordable
- Smaller size for storage
- Lifting mechanism
- Simple and efficient setup
- Movement using wires
- Able to track position and force
- No movement when winch motors are locked
- Capable to add force sensors
- Screen Interface

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Engineering Requirements

Functional Requirements

- Production cost
- Speed of the robot
- Amount of force the robot needs to be able withstand
- Accurate position tracking
- Device needs to be relatively small for practical use and storage

Technical Requirement Targets

- The finished cost should not exceed $1000
- The robot must be able to reach 1 m/s
- The robot must be able to withstand and provide 10 Newtons of force
- While in use the robot must be able to report is position with a .1 mm margin of error
- The device needs to be compact so that it can be easily stored and used in a short amount of time.

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QFD

Quality Function Deployment

Project title:	Flying Squirrel
Project leader:	Owen Khel
Date:	2/3/2025

Relationships:

9	3	1	
Strong	Moderate	Weak	None

	Customer importance rating (1: low, 5: high)	Desired direction of improvement (↑,0,↓) / Functional Requirements (How's) → / Customer Requirements - (What's) ↓	Production Cost	Speed	Force	Postion Tracking	Device Size	Weighted Score
1	5	Affordability	9			3	3	75
2	4	3rd dimension movement	3	1	1		1	24
3	3	Precision and Accuracy	3	9	9	9		90
4	4	Size	3	1			9	52
	1	Cosmetics	1				1	2
5	5	User Friendliness	3				9	60
		Technical importance score	93	35	31	42	100	303
		Importance %	31%	12%	10%	14%	33%	99%
		Priorities rank	2	4	5	3	1	
		Techincal Requirment Units	Dollars($)	m/s)	Newtons (N)	Millmeters	inches	
		Techincal Requirments Targets	1000	1	10	0.1	8x8x8	

Table 1: QFD

Important Benchmarks

- A production cost of 1000$
- Capable of 10 Newtons of force
- A device size concentrate of 8x8x8 inches
- Accurate position tracking with a tolerance of 0.1 mm

Literature Review

Books, Chapters, and Articles

Books/Chapters

- Rehabilitation Robotics: Technology and Application
- Atlas of Orthoses and Assistive Devices

Papers/Journals

- Wrench feasibility workspace analysis and adaptive rotation algorithm of cable-driven upper limb rehabilitation robot
- Control of a large redundantly actuated cable-suspended parallel robot
- String-man: A new wire robot for gait rehabilitation

Other Resouces

Online Articles

- Rehabilitation robot," Rehabilitation Robot - an overview
- Garrett Brown's skycam history
- Fish Line Strength Charts
- "How skycam works,"

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Literature Review

Books, Chapters, and Articles

Books/Chapters

- Arduino robotic projects: build awesome and complex robots with the power of Arduino
- Raspberry Pi 3 cookbook for Python programmers : unleash the potential of Raspberry Pi 3 with over 100 recipes

Articles

- Modeling Cable-Driven Robot With Hysteresis and Cable-Pulley Network Friction
- Permanent magnet DC motor control by using arduino and motor drive module BTS7960
- Design and Evaluation of a Bowden-Cable-Based Remote Actuation System for Wearable Robotics

Other Resouces

Online/Conferences/Gov.

- Robot-assisted Therapy in Stroke Rehabilitation
- A novel cable-driven robotic training improves locomotor function in individuals post-stroke
- How to Use Raspberry Pi and Arduino Together

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Literature Review

Books, Chapters, and Articles

Books/Chapters

- Encyclopedia of Smart Materials
- Chapter 5 - Robotics and rehabilitation: the role of robot-mediated therapy post stroke

Articles

- Upper Limb Robot Mediated Stroke Therapy—GENTLE/s Approach
- Multi-sensor fusion for body sensor network in medical human–robot interaction scenario
- Development of an Integrated Haptic Sensor System for Multimodal Human–Computer Interaction Using Ultrasonic Array and Cable Robot

Other Resouces

Online/Conferences/Gov.

- Adaptive Robot-Assisted Feeding: An Online Learning Framework for Acquiring Previously Unseen Food Items
- Adaptive assistive robotics: a framework for triadic collaboration between humans and robots
- A State-of-the-Art Review on Robots and Medical Devices Using Smart Fluids and Shape Memory Alloys

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Literature Review

Books, Chapters, and Articles

Books/Chapters

- Chapter 6 - Robotics in Rehabilitation Medicine: Prosthetics, Exoskeletons, All Else in Rehabilitation Medicine
- Chapter 3 – Sensors and Transducers

Articles

- Forces and Moments Generated by the Human Arm: Variability and Control
- Force Control and Degree of Motor Impairments in Chronic Stroke
- A Low-Dimensional Representation of Arm Movements and Hand Grip Forces in Post-Stroke Individuals

Other Resources

Online Sources

- Human Body Mass Distribution
- Understanding Force Sensors: How They Work and Measure Force
- Accurate Tracking: A Look at Position and Distance Sensors

Literature Review

Books, Chapters, and Articles

Books/Chapters

1. Raspberry Pi Robotic Projects
2. Hands-on robotics programming with C++ : leverage raspberry pi 3 and C++ libraries to build intelligent robotics applications.

Articles

1. ToF 3D Vision Algorithms in C++ for Robotic Applications
2. Gesture Control Robot with Arduino
3. Path Following System for Cooperative Mobile Robots

Other Resources

Online Sources

1. Wire Robots Part I: Kinematics, Analysis & Design
2. Robot dynamics and control
3. Controlling Tensegrity Robots through Evolution

Mathematical Modeling

Wire Tension

Explanation

Though with our robot design it won't be enduring it max stress, we still test it at what a worst-case scenario could be.

That would be if all ten newtons were acting on a single wire.

T=10N

In addition, we added a factor of safety of nf=1.2, diameter of the selected wire being .022mm

Equation

Stress = (F*nf) / A = (T*nf) * A

A=((pi) d ^ 2) / 4= 3.801*10^-6

Stress = 3,157 Kilopascal

Engineering Tools

- Engineering Toolbox
- Shigley's Mechanical Engineering Design, 11th Edition
- Fish Line Strength Charts

Mathematical Modeling

Total Battery Capacity Required

Components

- 4 motors at 2-amp draw
- 4 motor controllers at 0.25-amp draw
- 1 Raspberry Pi at 0.35-amp draw
- 1 Arduino at 0.1-amp draw
- 1 Display at 0.5-amp draw
- Position sensors and inverters negligible amp draw

Equations

Combined amperes = $\sum A$

$(4 \cdot 2) + (4 \cdot 0.25) + 0.35 + 0.1 + 0.5 = 9.95$ amperes

Assumed average efficiency = $\eta = 0.85$

Total amperes required = $A_{tot} = \sum A/\eta = 9.95 / 0.85 = 11.7$ amperes

Required run time = $t = 0.5$ hours

Minimum amp-hours required = $A_{tot} \cdot t = 11.7 \cdot 0.5 = 5.85$ A-h

Engineering Tools

- MakerBot Print (MakerBot's slicing software)
- Engineering Toolbox: Material Properties
- Fusion360 or Onshape
- Python and C++

Image 4: 18650 Battery

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Mathematical Modeling

Torque

Torque Equations:

- T = f*FsinƟ (F*r)
- $T_{out} = T_{in} * (N_{out} / N_{in})$

Importance:

- Velocity control
- Motor/Gearing selection
- Working in boundary conditions

Example:

- $T_{out} = 10 * (20 / 10)$
  - $T_{out} = 20$ (F*r)
- 20 = r * 10 sin 90
  - r = 10 (r)

T – Torque
r – Radius
F – Force
N – Number of gear teeth

Engineering Tools

- Onshape, Fusion360, Sketchup, Solidworks
- Engineering toolbox
  - Material properties
- "Mechanical Engineering Design, 11th edition"
- "Applied Mechanics Dynamics"

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Mathematical Modeling

Necessary Lifting Strength

Quantities:

- M= Total body mass
- L= Total arm reach (Shoulder to knuckles)
- g= Acceleration due to gravity ($9.81 m/s^2$)
- P_{hm}, P_{fm}, P_{am}= Percentages of body mass occupied by the hand, forearm, and arm
- P_{hl}, P_{fl}, P_{al}= Percentages of reach occupied by the same
- F= Net upward force produced by FS

Equation:

$F= M[P_{hm}g(1-0.5P_{hl})+P_{fm}g(0.5P_{fl}+P_{al})+P_{am}g(0.5P_{al})]$

Rough approximation for M= 70kg and L= 0.6096m

F= 14.5N

Engineering Tools:

- ANSYS
- Matlab

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Mathematical Modeling

Vector Analysis for Motion and Motion Tracking

Example Equation:
Wire 1 starting position: (0, 0, 7) (inches)
Wire 1 Anchor position: (24, 42, 0) (inches)

$$\theta_{xy} = \tan^{-1}\left(\frac{42}{24}\right) = 60.3°$$

$$L_{xy} = \sqrt{24^2 + 42^2} = 48.4\ in$$

$$\theta_{xyz} = \tan^{-1}\left(\frac{48.4}{7}\right) = 81.8°$$

$$L_{xyz} = \sqrt{48.4^2 + 7^2} = 48.9\ in$$

If Wire 1 is supposed to then end up at (11, 7, 12) (inches):

$$\theta_{xy2} = \tan^{-1}\left(\frac{(42-7)}{(24-11)}\right) = 69.6°$$

$$L_{xy2} = \sqrt{(42-7)^2 + (24-11)^2} = 37.3\ in$$

$$\theta_{xyz2} = \tan^{-1}\left(\frac{37.3}{12}\right) = 72.2°$$

$$L_{xyz2} = \sqrt{37.3^2 + 12^2} = 39.2\ in$$

Then, knowing the diameter of the winch, the robot would calculate how many rotations it would need to move the wire 9.7 inches.
The elevation mechanism is separate, but the change in elevation would affect the change in the length of the wire.

$$\Delta L = L_{xyz} - L_{xyz2} = 48.9 - 39.2 = 9.7\ in$$

Engineering Tools:

MATLAB/Python for Vector Tracking and Modelling and Fusion360 for parametric modelling

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Project Schedule

Milestone description	Category	Assigned to	Progress	Start	Days
February+					
Presentation 1	On Track	All	80%	2/2/2025	9
First Client Meeting	Milestone	All	100%	1/30/2025	1
Second Client Meeting	Milestone	All	100%	2/7/2025	1
2nd Staff Meeting	Milestone	All	0%	2/10/2025	1
Third Client Meeting (New Concept Generation)	Low Risk	All	0%	2/13/2025	2
3rd Staff Meeting	Milestone	All	0%	2/17/2025	1
Fourth Client Meeting	Low Risk	All	0%	2/20/2025	2
Self Learning Homework	Low Risk	All	0%	2/21/2025	7
Presentation 2	Med Risk	All	0%	2/25/2025	7

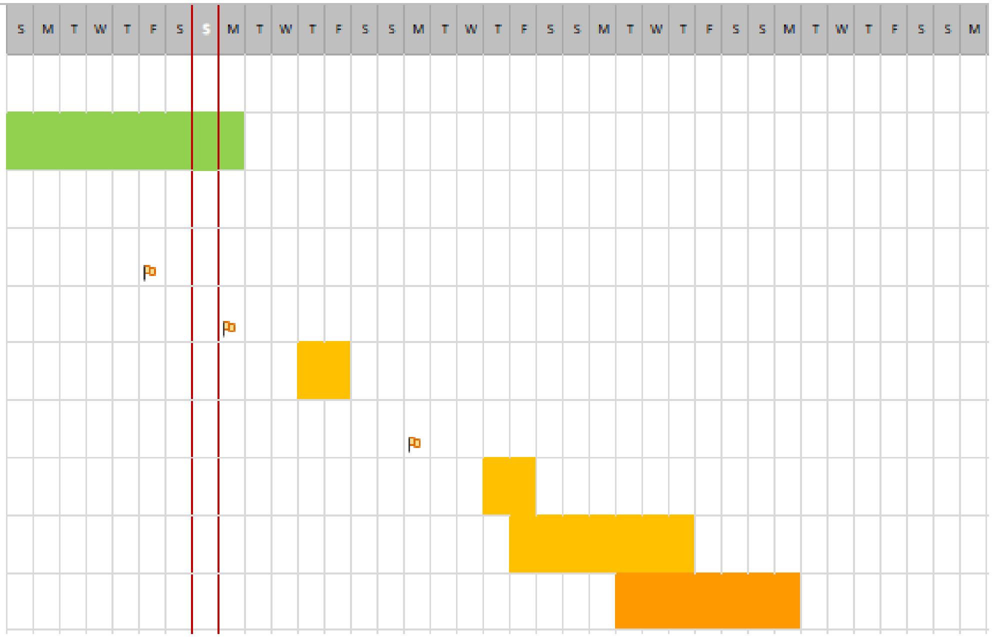

Table 2: *Gantt Chart for February*

- Most salient tasks are meetings with the client and concept generation
- Initial phase of concept generation is complete
- Next concepts to be completed before third weekly client meeting
- No high level risk tasks

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Budget & Expenses

	Current Expenses	Anticipated Expenses
Project Budget	+$3,750	+$3,750
Building Materials	$0	-3x$150 ($450)
Part Manufacturing	$0	-3x$150 ($450)
Machinery and Electronics	$0	-3x$400 ($1,200)
Research Material	$0	-$100
Fundraising	$0	+$375
Balance	$3,375	$1,550

Table 3: Budget & Expenses

- No expenses incurred yet
- Accounts for three models with $700 production cost
- Some funds set aside for manuals or trainings
- Each team member will contribute at least $75 to fundraising

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Conclusion & Moving Forward

Conclusion

- Dr. Razavian has asked us to construct a cable-driven robot to be used as a therapy device for stroke victims.
- The robot must be compact, easy to set up, affordable, and precise in its movements.
- We have a budget of $3750 as well as an addition $375 that is to be fundraised by the team to construct this robot.

Moving Forward

- Begin cable-driven robot concept selection and SolidWorks designing
- Begin building Bill of Materials using mathematical modeling data.
- Begin putting together code to power motors using sources in Lit. Review

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Thank you!

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