Robotic Pole Inspection Collar

Team 505

"Team Southern Pine"

ME Team Introductions

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Design & Material Engineer

Carey Tarkinson
Mechatronics & Programming Engineer

Angelo Mainolfi
Project Engineer

Angelo Mainolfi

EE Team Introductions

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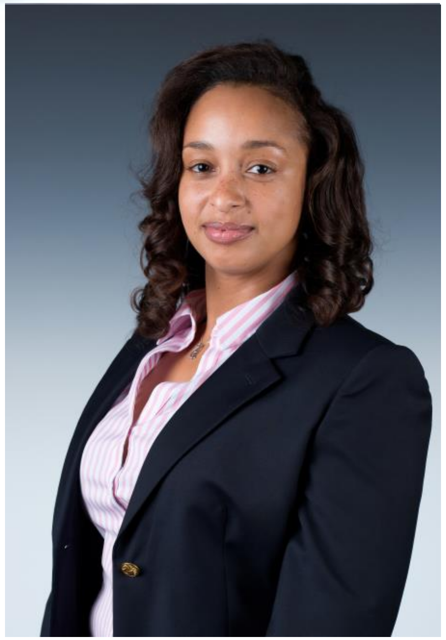
Thomas Williams
Hardware Engineer

Angelo Mainolfi

Sponsors and Advisors



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Engineering Professor
Shayne McConomy, Ph.D.
Teaching Faculty

Angelo Mainolfi

Objective

The objective is to design a mechanism that can climb a wooden utility pole and check its structural integrity

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Project Background

- FPL is Florida's largest utility company serving over 5 million customer accounts
- FPL's linemen interact with wooden utility poles daily to maintain reliability
- Checking the structural integrity is crucial to keeping linemen safe

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Problem

- Compromised utility poles pose hidden safety risks for utility workers
- An incident occurred over the summer of 2020
- Currently a hammer is used to check for rotten wood
- This test is certified by OSHA
- This mechanism is being created to replace outdated testing measures

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Project Guidelines

Key Goals

- Ascend and descend a wooden utility pole
- Interface the readings to the linemen
- Design to be a lightweight climber

Targets & Metrics

- Climb a minimum of 15 feet
- Interface readings within 60 seconds
- Keep the weight below 40 pounds

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Rapid Prototypes

Prototype 1

Prototype 1 used a bicycle frame structure

Prototype 2 used a simpler geometric frame

Prototype 2

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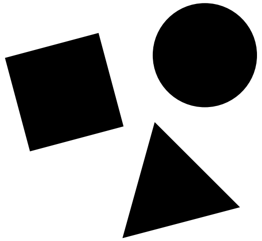
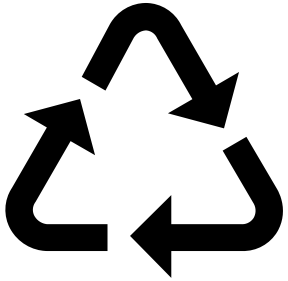
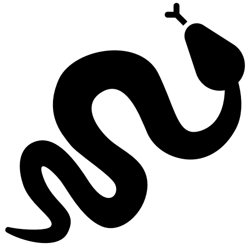
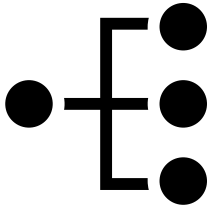
Concept Generation

- Crapshoot
- SCAMPER
- Biomimicry
- Morphological Chart









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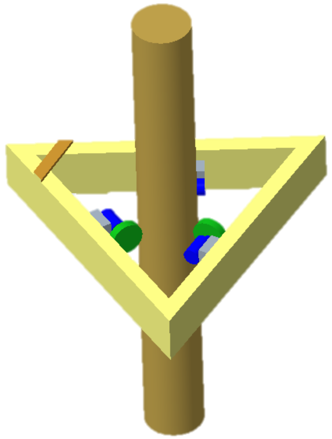
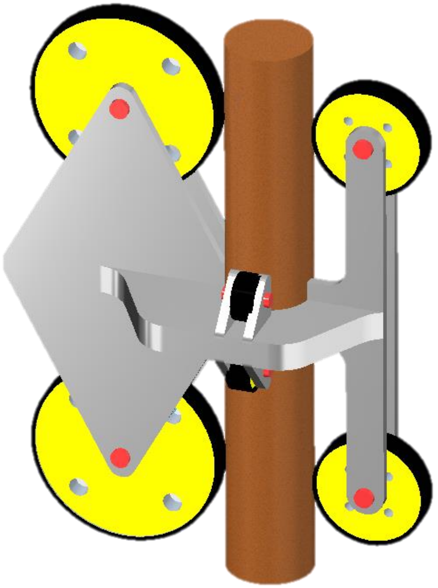
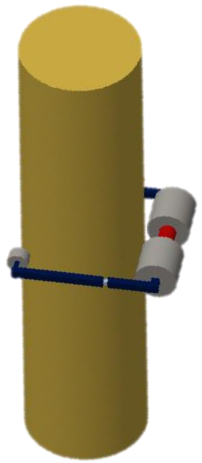
High Fidelity Concepts



Triangle Climber



Roller Coaster Gripper



Batmobile Climber

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Concept Selection

Binary Pairwise

Evaluation Criteria Hierarchy

1. Space for Sensors
2. Ability to Climb
3. OSHA Test Standards
4. Data Interface
5. Portability
6. Modularity

House of Quality

Engineering Characteristics

- ❖Stability
- ❖Safety
- ❖Maneuverability
- ❖Speed

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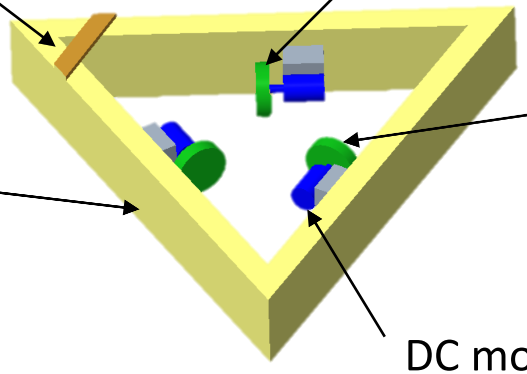
Winning Concept

Triangle Climber

- Modularity
- Stability
- Easy to use
- Variable climbing



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Prototype Three

Motorized Triangle Climber

Challenges Revealed:

- Pinching caused by poor wheel mounting
- Motors were grossly underpowered
- Wheels struggled to maintain contact to pole
- The model could not account for variable diameter poles

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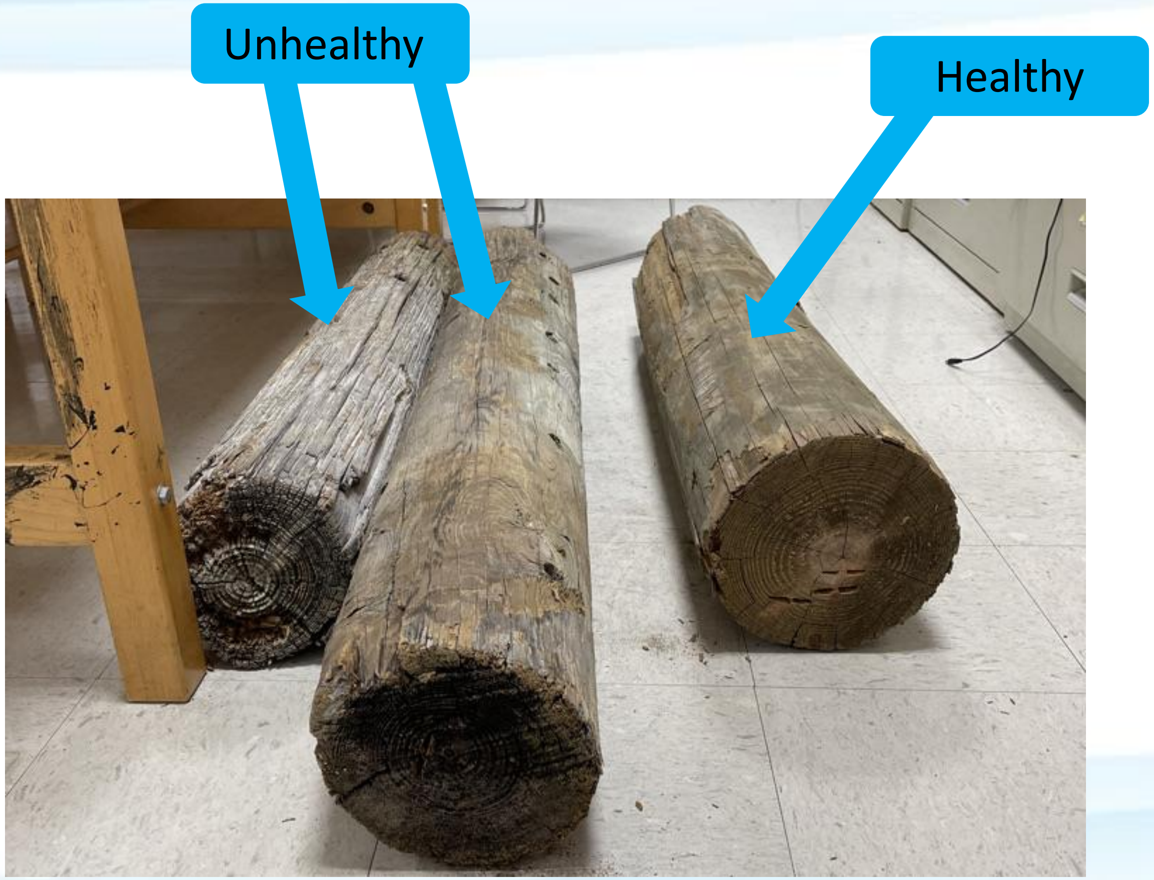
Pole Samples

- FPL provided us with three pole samples 4ft in length
- Previously we tested on live power poles
- These samples provide us with a safe testing measure
- The unhealthy sections are used by the Electrical Engineering team



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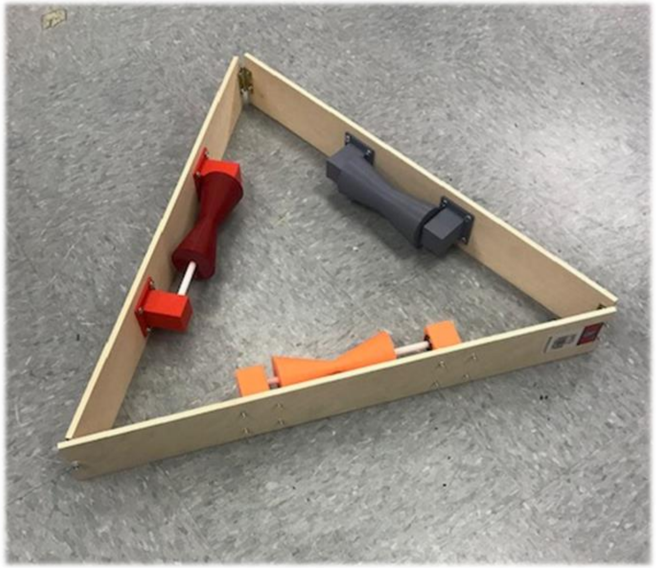
Prototype Four

- 3D printed hourglass wheels to increase contact area
- 3D printed bearing mounts that attach to the inside of the frame
- Skateboard bearings allow smooth rotation of acetal wheel shafts
- Long passive wheel shaft for diameter compliance



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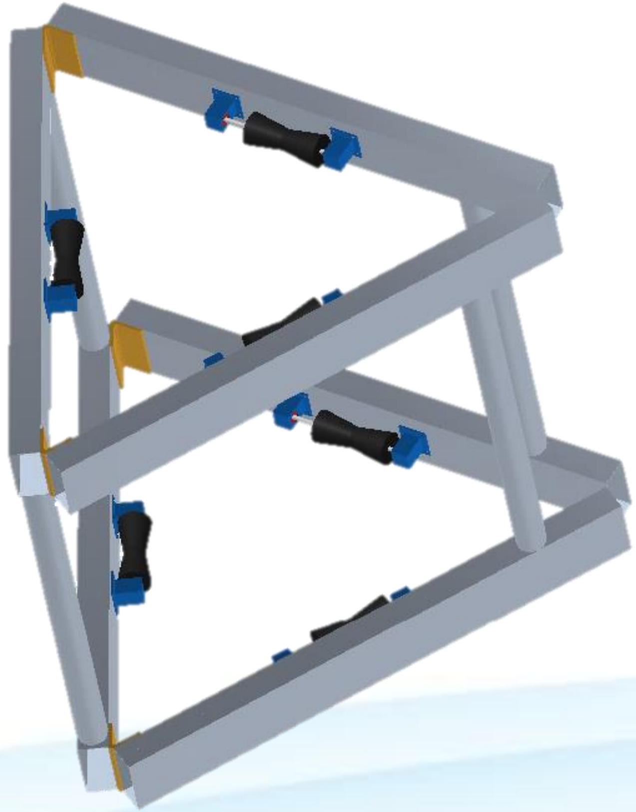
Design Five

- Utilized prototype four and incorporated a lower unit for extra stability
- Designed to eliminate pinching caused by motor torque
- Provides more area for ground penetrating radar



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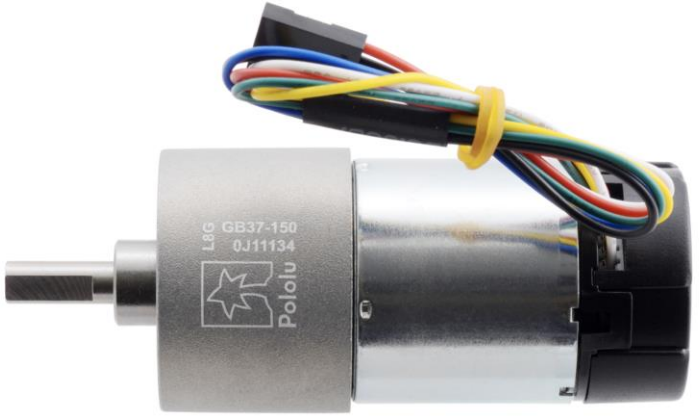
Motor Specification

- To spec a motor, we needed to determine minimum torque necessary to overcome gravity
- The radius of the wheel was taken as an average of the major and minor diameters of the hourglass wheel
- The torque was calculated with a mass of 18 kg and a moment arm of 25 mm



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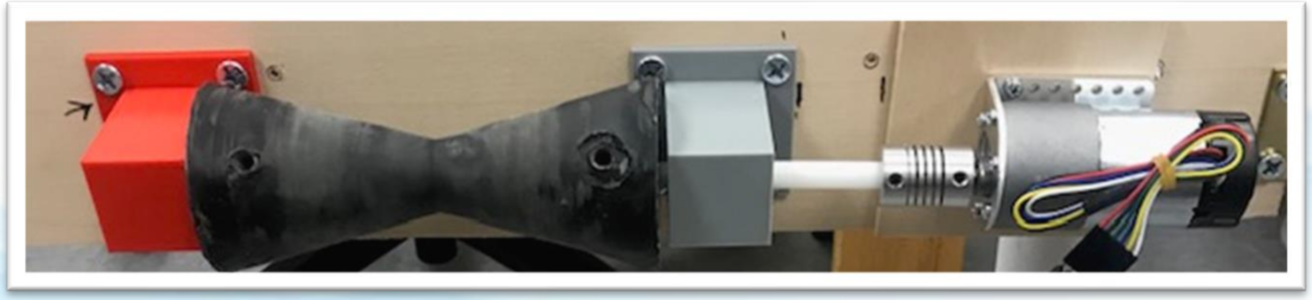
Shaft Mounting

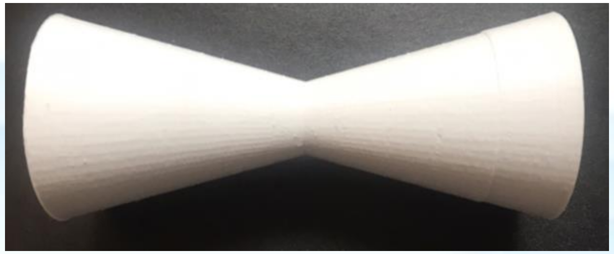
- The hourglass wheel’s unconventional design posed a problem with easily mounting to a motor shaft
- To remedy this, holes were created on each side of the hourglass wheel where setscrews will be installed to keep the hourglass wheel mounted to the shaft

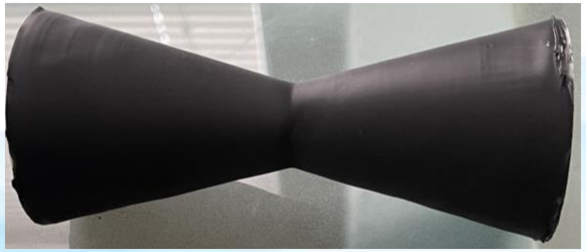


John Flournoy

Wheel Friction Method

- The more friction the driver wheel produces, the less tension will be needed from the strap
- The coefficient of friction must be increased as high as possible so the robot will not neutralize on the pole
- A rubber coating was applied to the 3D printed driver wheel
- Coefficient of rubber on wood is about 0.95





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Prototype Five

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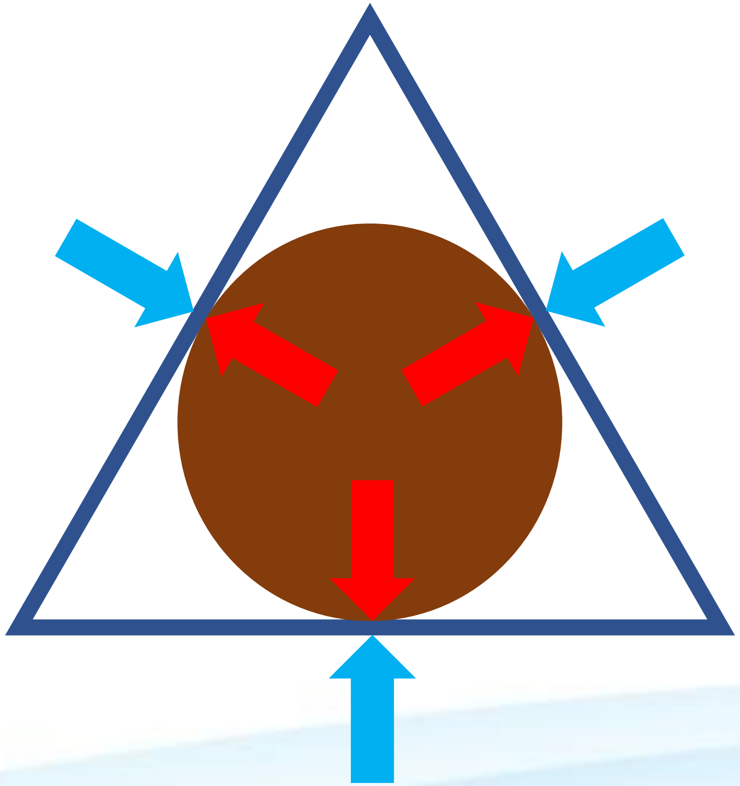
Strap Positioning Ideas

- Tension around the robot increases the normal force on the driven wheel
- This generates the friction needed to translate the collar up
- A ratcheting strap provides the tension needed to push the wheel into the pole



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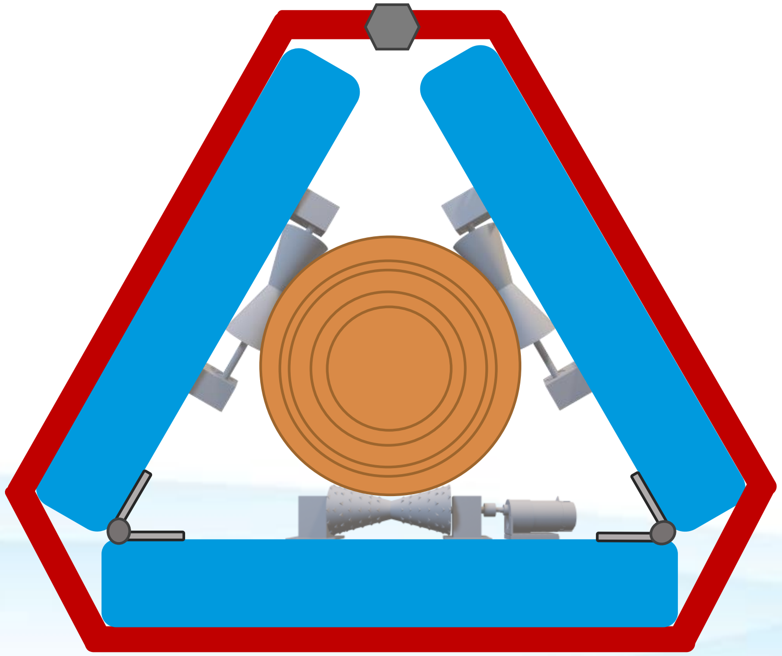
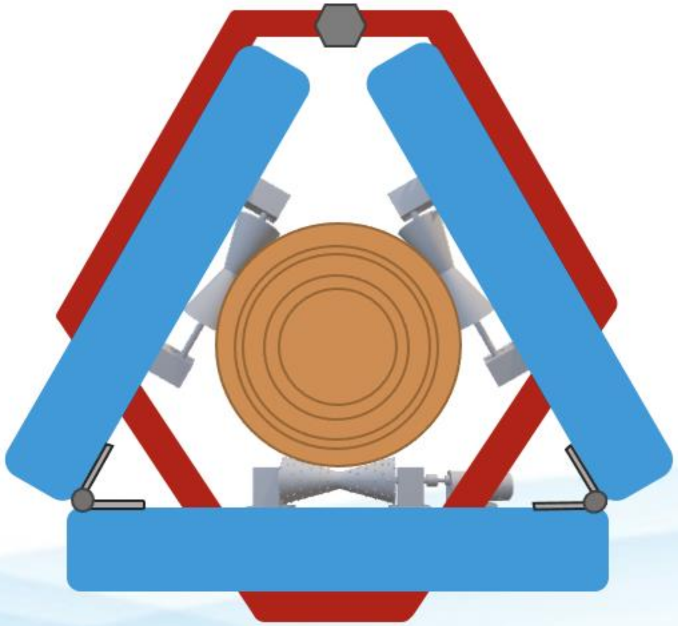
Tension Strap Path Ideas

Perimeter wrap



Weave wrap



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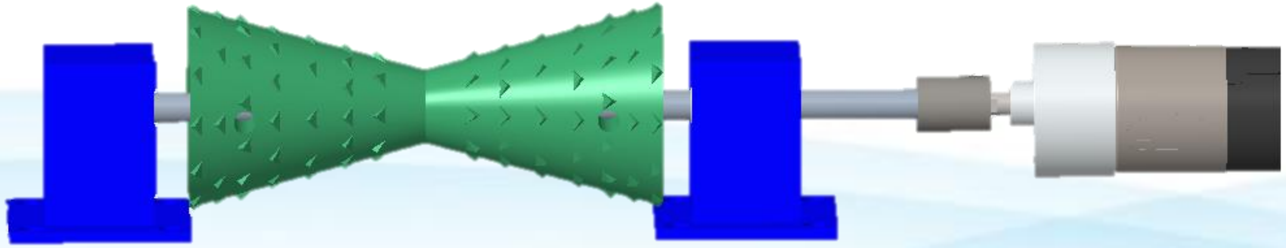
Wheel Design Modifications

- Ridges and a rubber coating were added to the hourglass wheel to provide better grip
- A spiked wheel design was also considered in the case the ridged wheel failed



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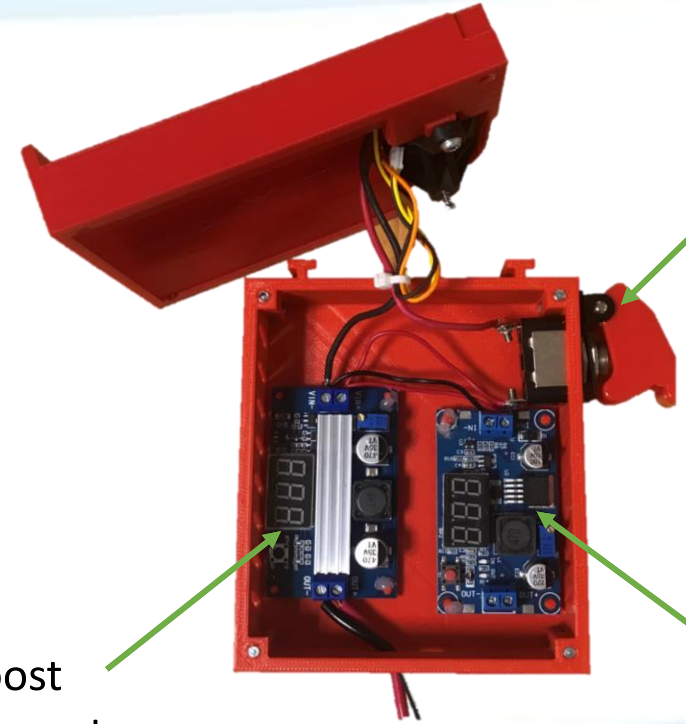
Power Supply

- To best accommodate FPL lineman, the battery powering the robot is an FPL issued drill battery
- The battery can deliver 21.6 V at 5.2 Ah
- The battery adapter and cargo box is modeled similarly to a commercial grade battery charger

John Flournoy

Power Supply

- Within the cargo box are the DC-to-DC converters necessary to distribute power accordingly
- The buck converter is used to downgrade the output battery voltage for the microcontroller
- The boost converter increase the battery voltage to 24 Volts to supply the rated voltage to the motor



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Prototype Six

- This robot utilized the weaved strap design, rubber coated wheel with printed ridges, and a ratchet strap
- The ratchet strap supplied the tension needed to create contact between the pole and the driven wheel
- The collar successfully climbed without additional support

John Flournoy

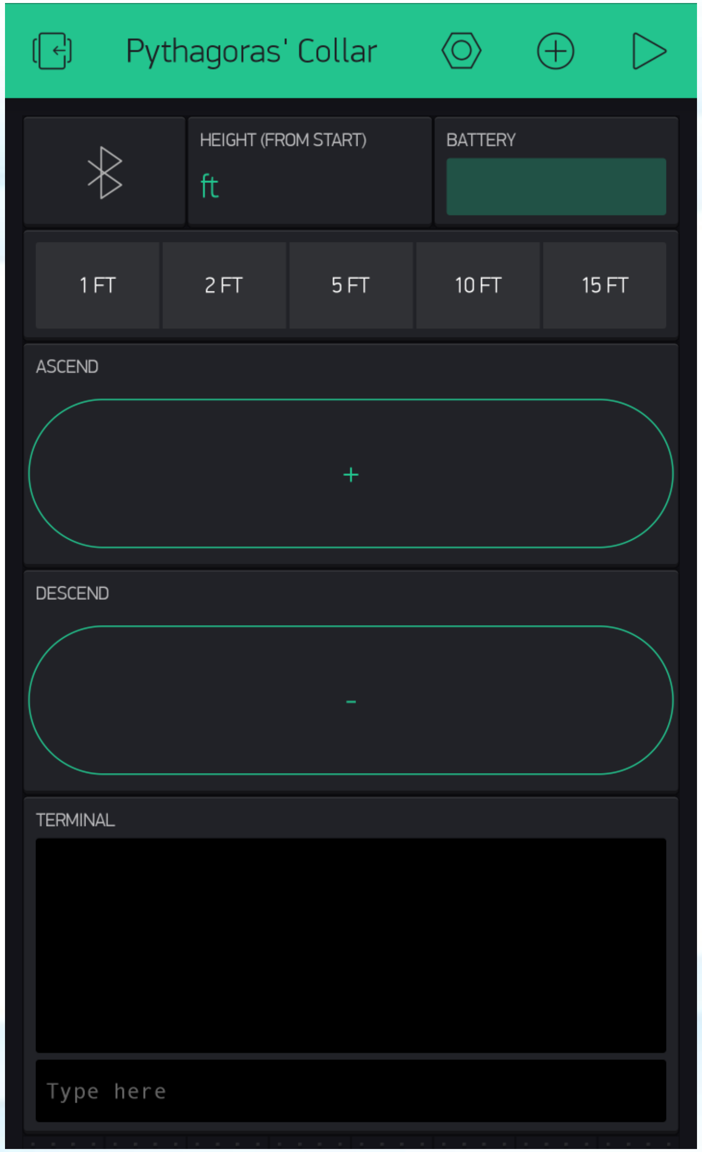
Prototype Six Climbing

- The prototype successfully carried a weight of 25 pounds
- The weaved strap design implemented the tension in the correct manner

John Flournoy

Controls and Interface

- Blynk will be used to wirelessly control robot with a smart phone via Bluetooth
- The user interface will display various measures to the operator
- Buttons will be used to control the ascent and descent of robot



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Backup Control

- Due to hardware-software incompatibility we moved to an IR sensor
- The remote can direct the robot up and down the pole

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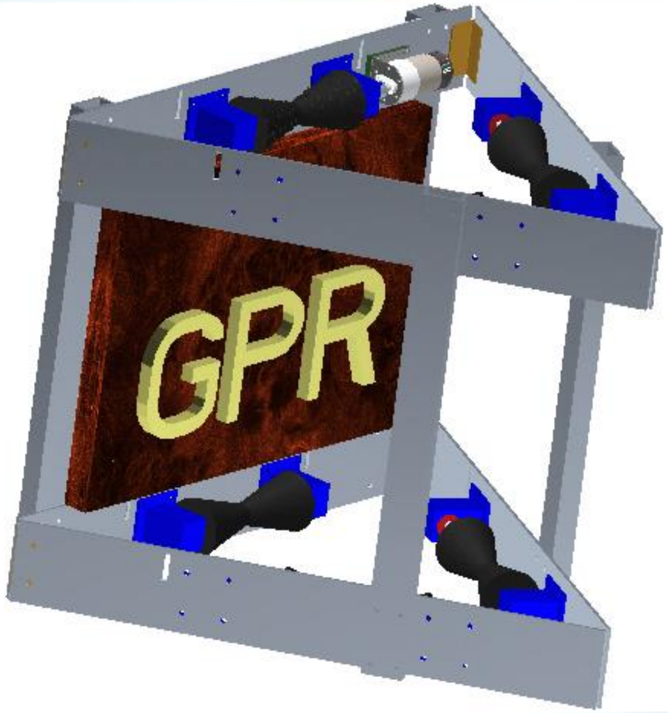
Final Design

- 1/8” thick aluminum segments will be used to take advantage of the metal plates’ flexibility
- The final design only weighs 10 pounds
- It can support a payload for our sensor and associated parts



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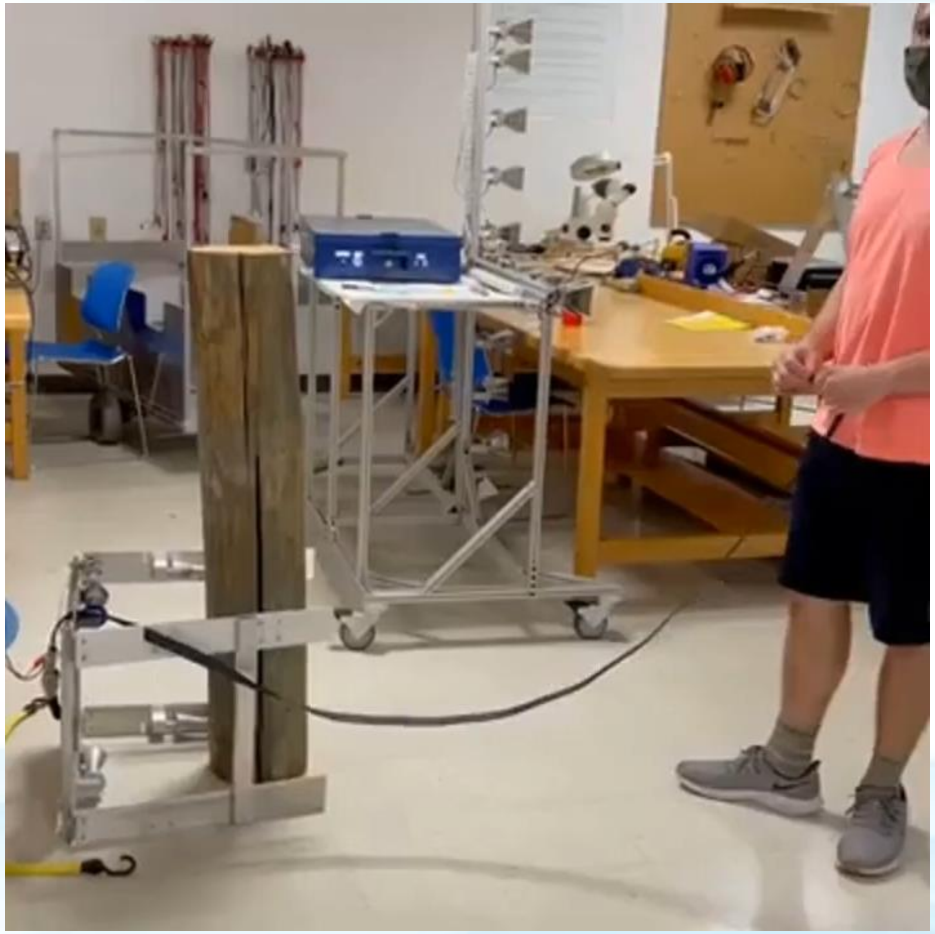
Climbing Action



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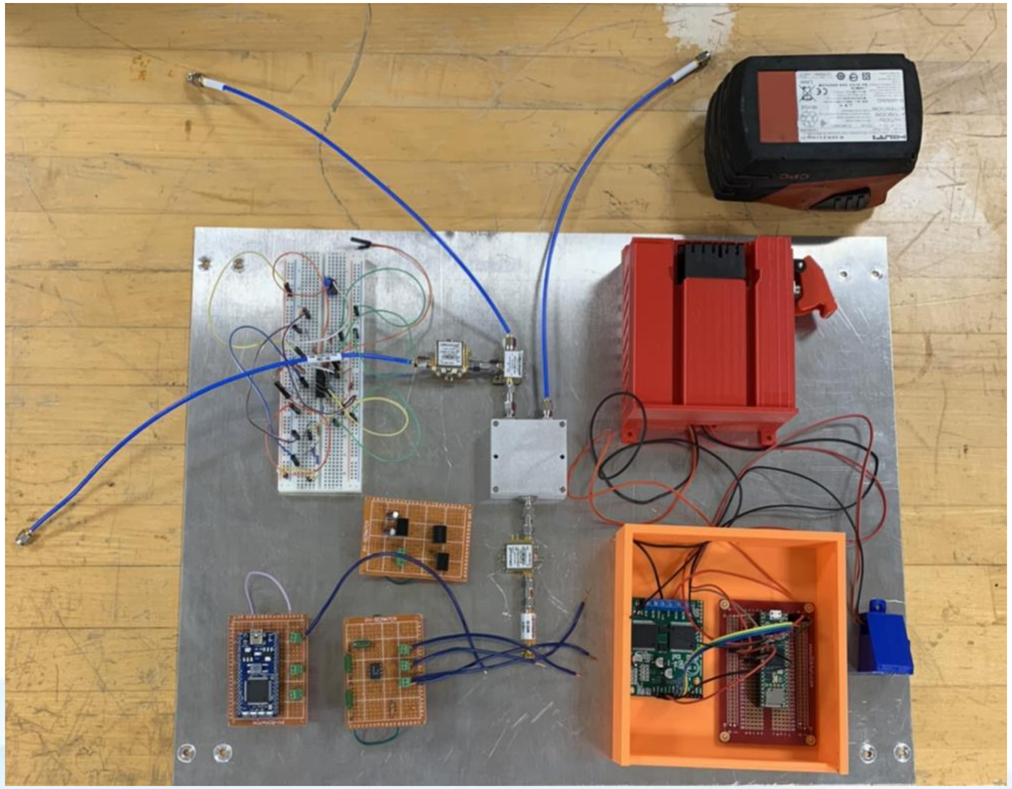
Electrical Component Layout



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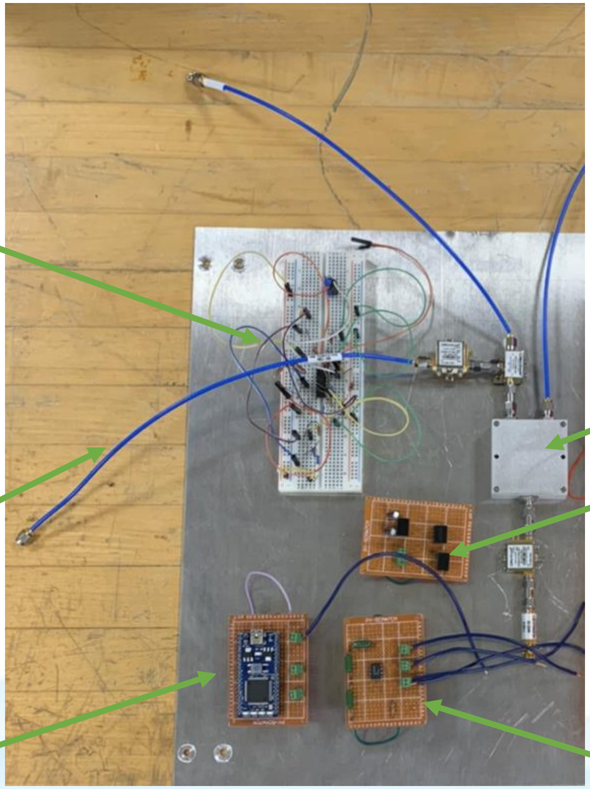
GPR Components

Low Pass Filter/
Wiring

Antenna x3

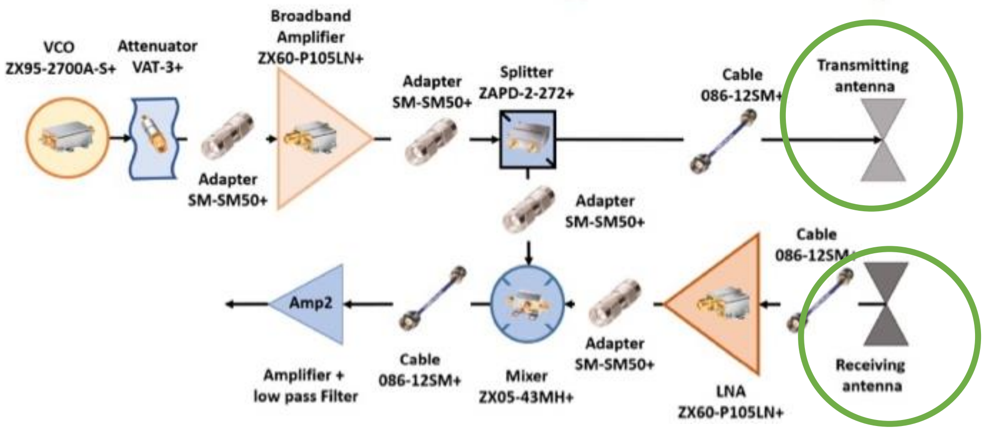
Controller



Splitter

DC to DC Converter

Amplifier



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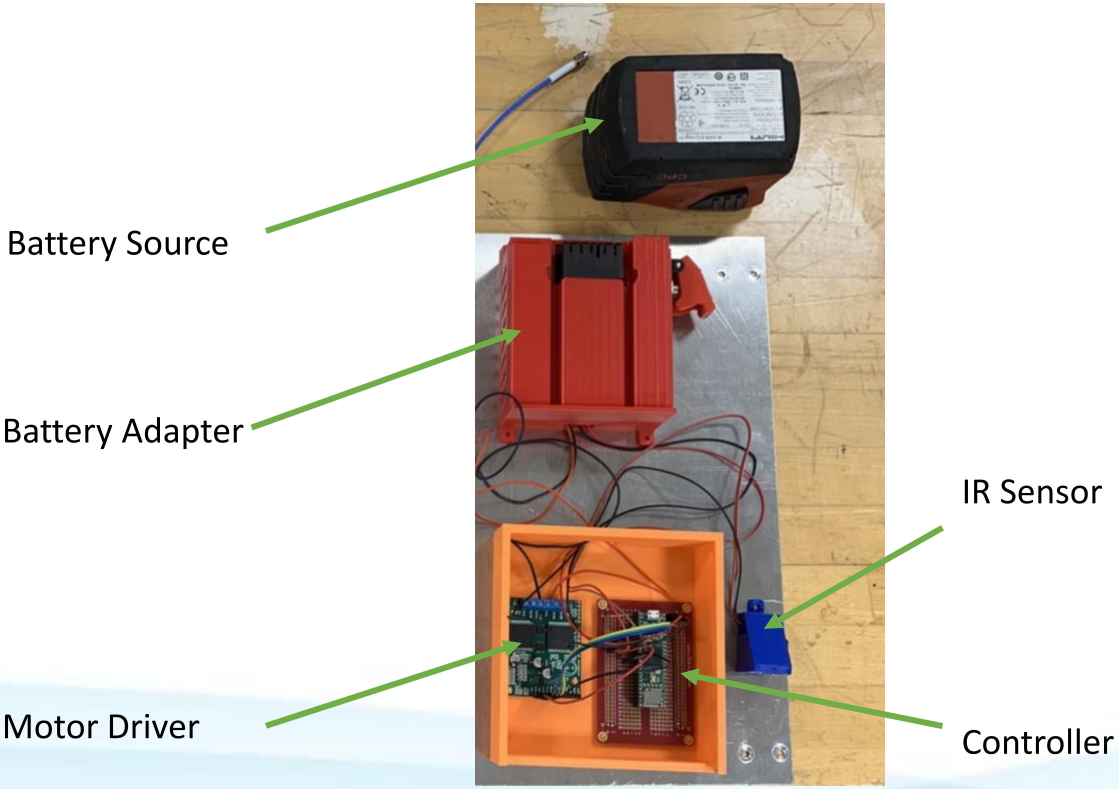
Battery and Controller



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Future Work

- Integrate the sensor and test with linemen in real world scenarios
- Consult with OSHA to propose this new test standard
- Upgrade the user interface from IR sensor and remote to the Bluetooth application, Blynk
- Determining the battery lifespan of the entire integrated robot

John Flournoy

Lessons Learned

- Rapid prototyping was extremely helpful
- Testing the prototypes early was crucial for success
- Integration between climbing and detection should have taken place earlier to fine tune the collaboration
- We quicky adapted to new learning environments during a pandemic

Mathew Crespo

Summary

- The robotic pole inspection collar is a beneficial device that provides additional safety for utility workers
- This inspection collar has the potential to replace the OSHA standard tests
- Simple geometry allows for an easy assembly and high stability
- Our climber can scale utility poles and provide the power and modularity for a ground penetrating radar

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Roadmap To Our Final Design

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Appendix

- The following slides have supporting information

Roadmap To Our Final Design

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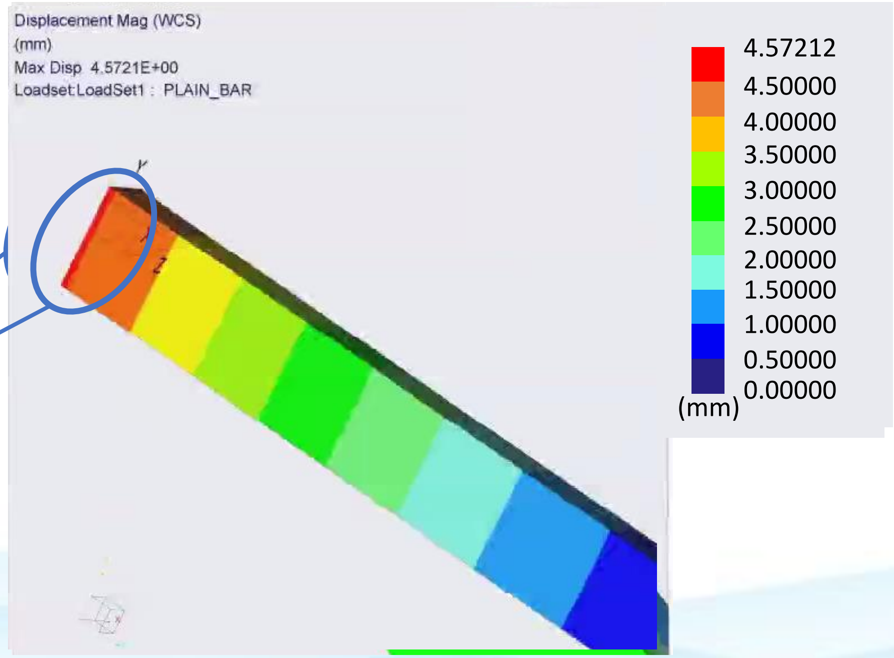
Sources

- https://www.slunglow.org/event/new-show-cap-pie/
- https://journalnow.com/archive/so-metal-the-world-of-metal-detecting-is-changing-and-north-carolina-is-home-to/article_7bb241c8-ecac-11e6-a1f4-7f1a74729de1.html
- https://www.onlinewebfonts.com/icon/546768
- https://www.flaticon.com
- https://devmesh.intel.com/projects/blynk

Perimeter Wrap FEA

60lbs tension



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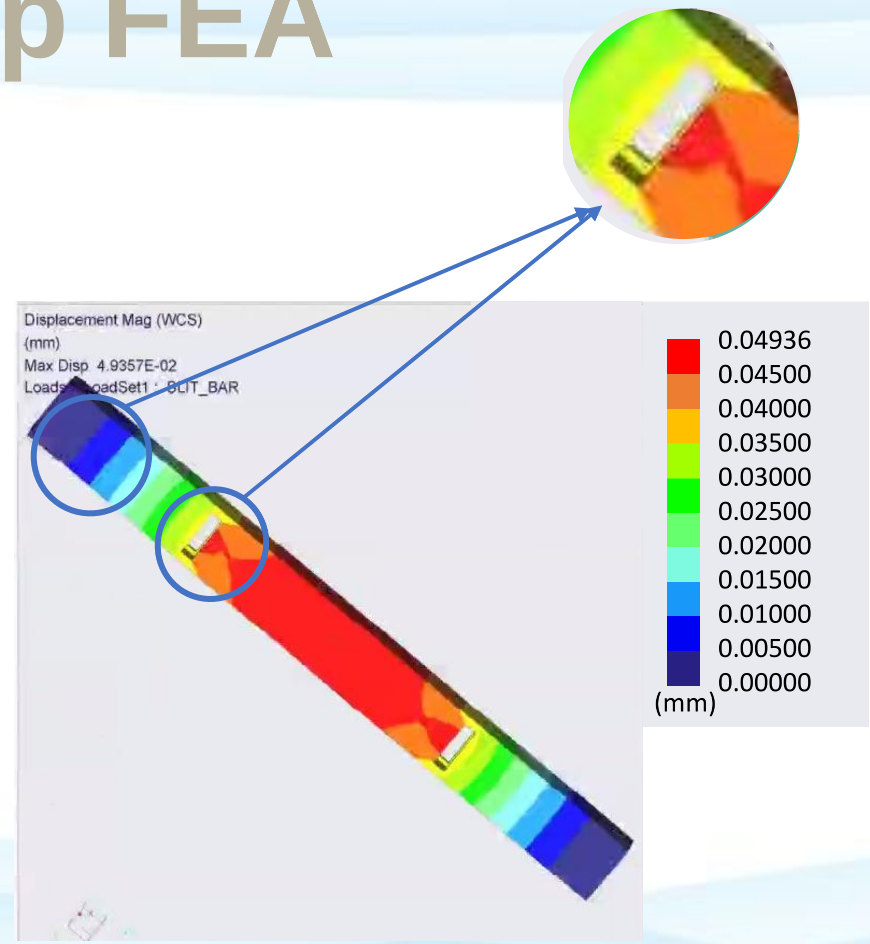
Weave Wrap FEA

60lbs tension



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Spike Wheel Design

- To produce the most traction, ¼ inch track spikes were imbedded into the hourglass wheel
- The spikes are minimally invasive and allow the robot to traverse with ease

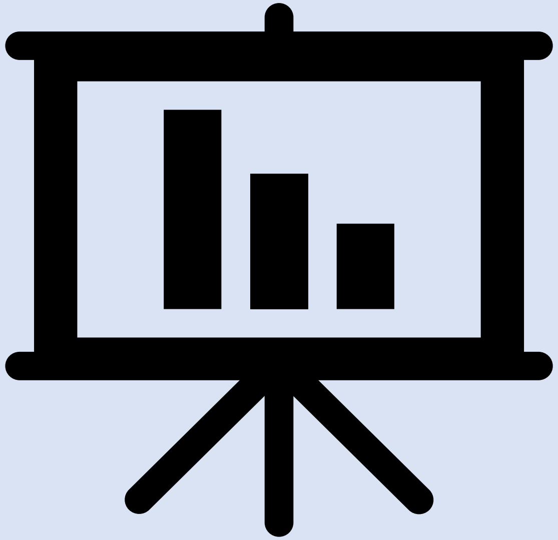
John Flournoy

Material properties

Mechanical Properties			
Hardness, Brinell	95	95	AA; Typical; 500 g load; 10 mm ball
Hardness, Knoop	120	120	Converted from Brinell Hardness Value
Hardness, Rockwell A	40	40	Converted from Brinell Hardness Value
Hardness, Rockwell B	60	60	Converted from Brinell Hardness Value
Hardness, Vickers	107	107	Converted from Brinell Hardness Value
Ultimate Tensile Strength	310 MPa	45000 psi	AA; Typical
Tensile Yield Strength	276 MPa	40000 psi	AA; Typical
Elongation at Break	12 %	12 %	AA; Typical; 1/16 in. (1.6 mm) Thickness
Elongation at Break	17 %	17 %	AA; Typical; 1/2 in. (12.7 mm) Diameter
Modulus of Elasticity	68.9 GPa	10000 ksi	AA; Typical; Average of tension and compression. Compression modulus is about 2% greater than tensile modulus.
Notched Tensile Strength	324 MPa	47000 psi	2.5 cm width x 0.16 cm thick side-notched specimen, K_t = 17.
Ultimate Bearing Strength	607 MPa	88000 psi	Edge distance/pin diameter = 2.0
Bearing Yield Strength	386 MPa	56000 psi	Edge distance/pin diameter = 2.0
Poisson's Ratio	0.33	0.33	Estimated from trends in similar Al alloys.
Fatigue Strength	96.5 MPa	14000 psi	AA; 500,000,000 cycles completely reversed stress; RR Moore machine/specimen
Fracture Toughness	29 MPa-m½	26.4 ksi-in½	K_{IC}; TL orientation.
Machinability	50 %	50 %	0-100 Scale of Aluminum Alloys
Shear Modulus	26 GPa	3770 ksi	Estimated from similar Al alloys.
Shear Strength	207 MPa	30000 psi	AA; Typical

Analytical Hierarchy Process - AHP

- Pairwise Matrix
- Normalized Pairwise Matrix
- Criteria Weights
- Weighed Sum Vector
- Consistency Vector



AHP Chart

Table 1: Analytical Hierarchy Process

Pairwise Comparison							
Customer Needs	Ability to Climb	Rot Detection	Data Interface	Portability	OSHA Test Standards	Modularity	**Total**
Ability to Climb	-	0	1	1	1	1	**4**
Rot Detection	1	-	1	1	1	1	**5**
Data Interface	0	0	-	1	0	1	**2**
Portability	0	0	0	-	0	1	**1**
OSHA Test Standards	0	0	1	1	-	1	**3**
Modularity	0	0	0	0	0	-	**0**
Total	1	0	3	4	2	5	

AHP 2

Table 2: Normalized Analytical Hierarchy Process

Normalized Pairwise Comparison							
Customer Needs	Ability to Climb	Rot Detection	Data Interface	Portability	OSHA Test Standards	Modularity	**Weight**
Ability to Climb	-	0	0.33	0.25	0.5	0.2	**1.28**
Rot Detection	1	-	0.33	0.25	0.5	0.2	**2.28**
Data Interface	0	0	-	0.25	0	0.2	**0.45**
Portability	0	0	0	-	0	0.2	**0.20**
OSHA Test Standards	0	0	0.33	0.25	-	0.2	**0.78**
Modularity	0	0	0	0	0	-	**0**
Total	1	0	1	1	1	1	

HOC

Table 3: House of Quality Relationship Matrix

Relationship Matrix between Engineering Characteristics and Customer Needs							
		Engineering Characteristics					
Improvement Direction		↓	↑	↑	↑	↓	↑
Units		lb.	ft/s	N/A	N/A	s	N/A
Customer Needs	**Importance Weight Factor**	Weight	Speed	Stability	Safety	Ease of Mounting	Maneuverability
Ability to climb	**5**	9	7	9	8	5	7
Rot Detection	**5**	4	5	8	9	4	8
Data Interface	**4**	2	9	9	8	3	5
Portability	**3**	9	3	5	3	9	8
OSHA Test Standards	**5**	3	2	7	8	5	5
Modularity	**2**	4	1	2	4	6	4
Raw Score (887)		123	142	175	174	121	152
Relative Weight %		13.9	16.0	19.7	19.6	13.6	17.1
Rank Order		5	4	1	2	6	3

Pugh Chart 1

Table 4: Initial Pugh Chart

Selection Criteria	**Datum**	Variable Arm Climber	Rollercoaster Gripper	Counter-Weight Triangle Hybrid	Serpent Robot	Hybrid Bike Design	Triangle Climber	Batmobile Climber
Vertical Traversal Speed	**Bike Climber**	-	+	-	-	-	-	+
Stability		S	+	S	+	+	+	-
Weight		-	-	-	-	-	+	+
Ease of Mounting		-	-	-	-	-	-	+
Portability		S	-	-	-	-	+	+
Modularity		S	+	+	-	S	+	-
Simplicity		-	-	-	-	-	-	-
Number of Pluses		0	3	1	1	1	4	4
Number Minuses		4	4	5	6	5	3	3
Number of S's		3	0	1	0	1	0	0

Pugh Chart 2

Table 5: Second Pugh Chart

Selection Criteria	Datum	Triangle Climber	Batmobile Climber	Variable Arm Climber
Vertical Traversal Speed	Roller Coaster Gripper	+	+	-
Stability		+	-	S
Weight		+	+	+
Ease of Mounting		+	+	+
Portability		S	+	-
Modularity		+	-	S
Simplicity		+	+	-
Number of Pluses		6	5	2
Number Minuses		0	2	3
Number of S's		1	0	2

Project Management

Backup Slides

Tinker's Workshop