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Team 505: FPL Robotic Pole Inspection Collar

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Abstract

Due to an incident that occurred because of a faulty and outdated testing method, Florida Power and Light has come seeking a more accurate and objective solution to pole health examination. This project's objective is to create a robot that can climb wooden power poles and find out if the pole is safely climbable. This is a joint venture between mechanical and electrical engineering teams. The mechanical engineering team handles the design of the robot and its climbing and the electrical engineering team deals with the sensing. The current pole safety test is the hammer test. It relies on a line worker listening to the sound the pole makes when struck to decide the integrity. The Florida Power and Light Robotic Pole Inspection Collar will use ground penetrating radar. This sensor creates a more accurate test by studying the internal quality of the pole. Testing the robot on both healthy and unhealthy pole samples calibrated the ground penetrating radar. The robot conforms to the pole using a triangular prism shaped design. This design allows simplified mounting by being able to wrap around the pole. The robot relies on tension and its shape to keep contact with the pole's round surface. This design uses motors to cause vertical motion while its passive wheels help keep grip on the pole. The wheels of the robot were custom-made by using two cones to form an hourglass shape to provide improved grip on the poles by having two points of contact. The driven wheel also has a rubber coating with spikes to further increase grip. The robot houses the ground penetrating radar between the two triangles where it can contact the surface and send pulses to scan for flaws in the wood.

Keywords: ground penetrating radar, robot, climb, triangular prism

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We would like to thank Dr. Hooker for ordering the necessary components for our robot's final assembly.

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We would like to thank Eric Adams from the Florida State Innovation Hub. Without Mr. Adams and the massive array of 3D printers in his lab, there would have been no way we could

have rapid prototyped as quickly as we did. The initial prototyping was crucial for the success of this project and the resources at the Innovation Hub remained useful for the final design which contains multiple 3D printed parts that allow the robot to function properly.

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Notation

ABS	Acrylonitrile Butadiene Styrene
DC	Direct Current
FPL	Florida Power and Light
GPR	Ground Penetrating Radar
OSHA	Occupational Safety and Health Administration
PLA	Polylactic Acid
SCAMPER	Substitute Combine Adapt Modify Put to other use Eliminate Reuse

Chapter One: EML 4551C

1.1 Project Scope

Project Description

The objective of this project is to create a robot that can detect and report back the structural integrity of a power pole. Developing this mechanism will increase the safety of the linemen, decrease the error in pole testing, and increase the reliability of the electric utility. The robot will test the integrity of the pole and check for rotten wood. The pole inspection is crucial to the reliability of the utility and the safety of FPL's linemen.

Key Goals

The key goals for team Southern Pine are to aid FPL engineers and help keep linemen safe from compromised power poles. To do this a device will be designed to automate parts of the inspection process and to generate an accurate analysis of the safety of the poles by working alongside the linemen. The goals of the pole inspections are to detect rot and determine the integrity of the wood. To best aid the linemen in the inspection the device will have a means to interface with them, by sending the information to a screen to convey important information such as its determination of the stability and if it would be safe to attempt to climb the pole.

Market

The primary market would involve our sponsor, Florida Power and Light. This will also include other utility and energy companies who have to inspect the integrity of power poles and perform routine maintenance. The secondary market would be directed towards telecommunication companies such as Comcast and construction companies that would also need to perform routine inspections and maintenance on wooden poles.

Assumptions

To focus on scope development, T505 generated assumptions that will guide our project. We assume that the operator will have prior training completed before inspecting and working on poles. It is assumed that the lineman will be present while operating the device. The device will be used under normal working conditions. Normal being defined as safe conditions a crew would operate under, no inclement weather. It is assumed that the poles are wood and have a circular cross-section with a set range of diameters within 17.5 inches to 6.7 inches. The device will operate strictly above ground. The pole is assumed to be straight and flush surface.

Stakeholders

The stakeholders involved in the overall project range from individual professors/administrators to larger-scale Universities and companies. The main stakeholder in this project has been determined to be Florida Power and Light as the project directly benefits their company moving forward in the future. That said, the linemen working for Florida Power and Light will also be stakeholders as they will be in charge of operating the device. More stakeholders include the project sponsors Genese Augustin and Troy Lewis, who represent Florida Power and Light. In addition to Florida Power and Light, the FAMU-FSU College of Engineering is also a stakeholder in the project, since the joint University will be funding the project. Dean Gibson and Dr. Hellstrom are also stakeholders as the two head administrators for the FAMU-FSU College of Engineering. Dr. McConomy and Dr. Clark as class professor and project advisor respectively will serve as the main project guides for structure and aid throughout the design and production stages. Lastly, the repair personnel would also be deemed stakeholders as they will be performing maintenance on the device.

1.2 Customer Needs

Needs and Specifications

The objective of this project is to design a robot that can traverse a wooden pole and test whether or not the pole is safe to climb. To obtain more information and define our project needs, we scheduled a meeting with our sponsors Genese Augustin and Troy Lewis, representatives of our customer, Florida Power and Light (FPL). During the meeting, we asked specific questions that would provide us with further insight into our robotic pole inspector project. In addition to the meeting with our sponsors, our team contacted Donnie St. John who is a member of the lineman union and was able to provide us with some valuable insight about the wooden poles our project is oriented around. Below in Table 1 is a list of questions that were asked by our team and the responses that were given by Genese Augustin, Troy Lewis, and Donnie St. John. Also included in the table is our interpreted need to the responses we received.

Customer Statements

Table 1 *Genese Augustin Statement*

Question	Statement	Interpreted Need
"What does the device have to incorporate in its test of the wood?"	"The device needs to incorporate a few steps of the OSHA wooden pole test, especially the hammer test. This would allow for less injury and more assessment of the utility asset."	The device adheres to OSHA standards of inspection.
"What should the device do with its findings?"	"The linemen should be able to control the robot with its test or have it report back the	The device can interface with the linemen and deliver data directly to them.

	findings of the pole's condition.”	
“At which height is the pole generally rotten?”	“The rot is usually found at ground level.”	The device can operate on the lower portion of the pole.

Table 2 *Troy Lewis Statement*

Question	Statement	Interpreted Need
“What is the intended mobility of the device?”	“The device needs to be able to ascend and descend the pole to perform its examination and test.”	The device can climb a wooden utility pole.
“What does the device need to test for?”	“It needs to test for rotten wood or voids in the wooden pole. This can seriously affect the structural integrity of the pole and is a huge safety issue.”	The sensors can determine the integrity of the wood.
“At what height or location is the pole bored?”	“Anywhere suspicious including above reach height.”	The device can examine the pole at various heights beyond operator reach.
“What is optimal for size and weight?”	“It can fit on the back of the utility truck and weighs under 30 lbs.”	The device is convenient to transport.
“What is the most common class of pole encountered?”	“The most common are class II and class III poles.”	The device works on poles of class II and III.
“What is the most common height of poles?”	“I would say 30’, 35’, and 40’. That should cover a good range of installs for this initial project while also focusing more on the types of poles that are usually encountered in the “rear of” and	The device works with a set range of diameters (derived from height to diameter relations)

	inaccessible locations where the crew will be required to physically climb instead of being able to use a bucket truck.”	

Table 3 *Donnie St. John Statement*

Question	Statement	Interpreted Need
“What would make the mechanism most effective in the field?”	“If the device tests with OSHA regulation or incorporates that into the design. This allows easy adoption and incorporation into a utility workers toolset.”	The device adheres to OSHA standards of inspection.
“What would you say would make the robot more appealing to use to you personally?”	“It would be helpful if it could determine its life if it is OSHA regulated, hip worn tool that is similar to a hammer, rechargeable. It would be best if it was user friendly.”	The device is convenient to use and portable.

Explanation of Results

The results above came from interview questions with our project sponsors and an electrical workers union. Genese and Troy are our Florida Power and Light sponsors, we meet every week. They are representing the consumer because the consumer cannot be directly communicated with. The consumer is the linemen of FPL, they are protected by Union rights and cannot speak directly to us. With these complications, we reached out to an electrical union in

Florida to gather some more information. The team reached out to Union 222 of the International Brotherhood of Electrical Workers and was connected to Donnie St. John. Donnie represents the union and answered some questions for us.

The overall purpose of the customer needs portion of the Senior Design project is crucial to developing a product with the consumer in mind. With our results, we can say that the product will adhere to OSHA standards when testing. OSHA testing requires the linemen to hit the pole with a hammer. The linemen are listening for a crisp rebound sound from the hammer, if the rebound is faint then the wood is rotten. The product can be convenient to use and weigh less than 30 lbs. The device operates within a range of diameters from 10.2 inches and 12.9 inches. It will ascend and descend the pole. The device will test wood integrity. The device will easily interface data to the linemen to show them the results of the test. These results will help guide the project to its desired result.

1.3 Functional Decomposition

Introduction

Functional decomposition is a common technique used to break down larger problems into smaller, finite components that make the process of solving a complex problem simpler. It is a helpful tool that emphasizes component breakdown that will facilitate a complex problem and make it easier to manage. It is important to note that functional decomposition does not directly point to a specific solution for a problem, but instead addresses the general functions that a solution will satisfy. The Robotic Pole Inspection Collar project was broken down into major systems that focus on individual aspects of the robot that need to be satisfied for the robot to operate as the customer wishes. These major systems include climb, detection, and communication. The major systems were broken down into sub-functions that will further address each element within the subcategory in a detailed manner.

Explanation of Results

The systems of climbing, detecting, and communicating, are from our customer needs statement. These needs form the functions of the project to accomplish the customer's goals. The major functions of the project are shown below, there are two figures of flow diagrams. Below in Figure 1, it displays the Detection Flow Diagram

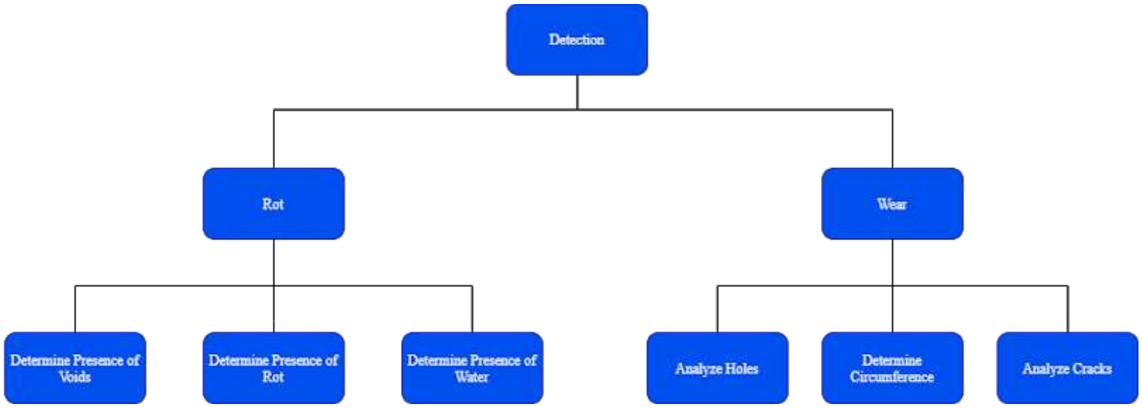


Figure 1 Function flow diagram.

The Flow diagram was split to provide a clear view of each system and function. Below in Figure 2, the climbing and communication systems are displayed.

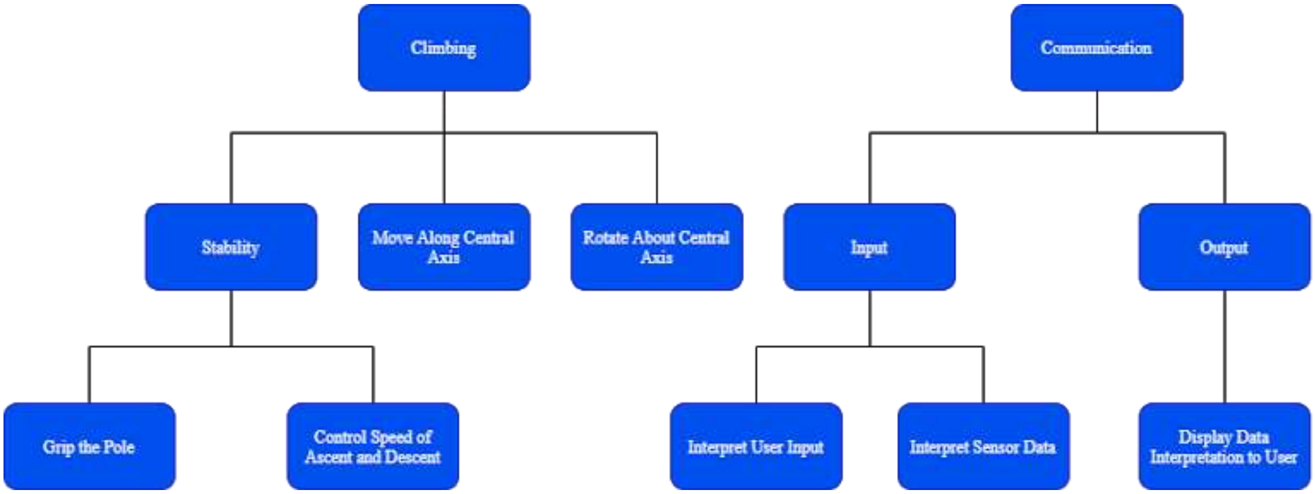


Figure 2 Climbing and communication flow diagram

With our major functions defined and our sub-functions below them, we developed a table to cross-reference the functions with one another. Below in Table 1 shows the major functions and subsections cross-reference table. This cross-reference table shows us what functions have a relation to one another.

Table 4 *Major Functions and Subsections Cross-Reference Table*

Functional Decomposition Cross Reference Table			
Sub-function:	Climb	Detection	Communicate
Grip the Pole	X		
Control Speed of Ascent and Descent	X		X
Rotate About Center Axis	X		
Move Along Central Axis	X		

Interpret User Input			X
Interpret Sensor Data			X
Display Data Interpretation to User			X
Determine Presence of Void		X	X
Determine Presence of Rot		X	X
Determine Presence of Water		X	X
Analyze Holes		X	X
Determine Circumference	X	X	X
Analyze Cracks		X	X

Every system has a function that breaks down what is needed from that system. In the climbing system, three functions help accomplish our goals. The climbing functions are: stability, rotation about a central axis, and ascend and descend along an axis. Stability is needed so the mechanism can safely ascend and descend without crashing into wires or slamming into the ground. The mechanism will have to stay attached to the pole which will act as an axis which it will move along. The sensors on the robot will have to test around the circumference of the pole, so when the robot climbs there will be an ability to rotate the sensor around. Within the communication function, there are two functions, input and output. The input is responsible for interpreting the user input and the sensors input. The output displays the interpreted data to the user. The communication system is important to provide the data to the user and intake data from its surroundings. A detection system is a large part of the mechanism, it needs to determine the wood's condition. The detection function has two sub-functions, rot, and wear. The function of the robot will be to detect the rot within the wooden pole along with wear. Wear indication would be from visual appearance. Rot detection will include voids, rotten wood, and water.

The information for functional decomposition was obtained by first identifying preliminary customer needs and then creating a project scope based on those needs. After confirming the customer needs and creating the guidelines for the project scope, the main functions for functional decomposition were decided by our team. These functions are paramount to meet the required customer needs and fit within the project scope that was predetermined.

Smart Integration

Several sub functions are contributing to other major functions outside of their own. For example, the robot's ability to determine the circumference of the pole will assist not only for the system of detection, but stability for climbing and provide data to communicate as well. Other sub-functions can also be integrated, such as everything in the detection system into the communication as the detection sub-functions provide the sensor inputs to be interpreted and displayed for the user. As the robot becomes more “integrated”, the systems can support each other and become more efficient as one process can fulfill multiple functions.

Action and Outcome

For the robot to work successfully, the robot must apply a force to the wooden pole. This force will subsequently be applied specifically to allow for mounting and dismounting from the pole. This will supply the necessary friction for the robot to stay on the pole until the operator wishes to detach it. Next, to maintain adhesion to the pole, the robot must continuously be applied and adjusted depending on the variable diameters. This will allow the robot to have the necessary grip that will keep it engaged and supported to where it will not fail. For the desired outcome, the robot will use its sensor array to check for voids while ascending the pole. The sensor array will rotate around the pole as it moves up to different altitudes of the pole. The data from the detection system is communicated to the user. This data will be interfaced with the user, explaining information found and determining the integrity.

Functional Resolution

Once the robot is complete it will be capable of traversing a wooden pole vertically as well as rotate around the pole while being operated by a human user. There will also be a device mounted to the robot that can determine if there is any indication of pole rotting and then convey important information such as if the pole is safe to climb to a lineman through an interface. The project will ultimately result in a robot that can grip the pole, control speed of ascent and descent up/down the pole, move around central axis, rotate around central axis, interpret user input, interpret sensor data, display data interpretation to the user, determine presence of void, determine presence of rot, determine presence of water, analyze holes, determine circumference, and analyze cracks.

1.4 Target Summary

The target values were assigned for all the low-level functions seen in the functional decomposition chart. All the functions laid out in the catalog are followed by an individualized metric that can be used to validate the use of said functions. Through constant communication with our sponsors at Florida Power & Light as well as guidance from our academic advisors, Team Southern Pine developed a complete set of targets and metrics, allowing numerical values to be placed on functions. Out of all the functions, a smaller group of critical targets and metrics were established to emphasize the most important functions for the design. The most critical targets and metrics are displayed below in Table 1: Critical Targets & Metrics. The comprehensive list of targets and metrics can be found in the appendix labeled as Table A-1: All Targets & Metrics.

1.5 Concept Generation

To generate concepts, the team used four systematic methods: morphological analysis, crapshoot, SCAMPER, and biomimicry. This was done to assure that the ideas were creative and considered different aspects of the problem. For the morphological analysis, a chart was built to divide the design into four different aspects of the design. The team took turns suggesting ideas to solve each of these issues. Then, solutions for each issue were combined in different ways and were consolidated to form a more cohesive concept. This process begins with the morphological chart, below in Table 1.

Table 5 *Morphological Chart*

Body Material	**Climbing Method**	**Frame Type**	**Sensory Equipment**
Aluminum	Wheels	Serpentine Climber	Ground Penetrating Radar
Stainless Steel	Claws	Counterweight system	Tomography
Wood	Mechanical Grip	Climbing Car	Mechanical Hammer with acoustic mic sounding
Fiberglass	Adhesion	Triangular climber	
		Animal (Armed/Legged) Climber	

The Morphological chart theoretically could provide us with 192 ideas; Even though this morphological chart would satisfy the goal of 100 concepts, the team opted to consider other methods to achieve this goal.

Continuing from the morphological chart and transitioning to the “crapshoot” procedure, where we started by considering the customer, Florida Power & Light, specific request, as well as the markets. With those ideas in mind, our spontaneously generated ideas were documented. The concepts generated were thought of quickly and documented to maximize creative and abstract solutions. This method of brainstorming produced some unique and interesting results, but not the most practical.

During the SCAMPER procedure, we considered the ideas that were conceived previously and how we could adapt or modify certain aspects of these ideas to make them better. SCAMPER ended up producing relevant results with its combination of the morphological analysis and the crapshoot methods. This allowed for more than one idea from each column in the table to be included in a concept.

Lastly, we had a list that identified several biomimicry concepts. This is where we observed animal behavior such as monkey, koala, and spider abilities to climb up surfaces. This allowed us to explore additional possible solutions for our problem that we could adapt to our concepts.

Out of the 100 total concepts generated, the team selected 8 concepts based on their abilities to find a solution to the problem at hand. The complete list of 100 concepts can be found in Appendix A. The following concepts listed are numbered based on the concept order that depends on the conceptual method that was used.

Medium Fidelity Concepts

Concept 46: Variable Arm Climber - The Variable arm climber was chosen as a medium-fidelity concept because of its ability to adapt to any size pole. The climber uses 6 wheels mounted in pairs to ascend the pole, 2 on the backside of the pole and 4 on the front, 2 above and 2 below. The back wheels are attached to a variable arm that compresses to shorten the arm length till the wheels are snug against the pole. A linear actuator would be used to perform that collapsing action. This allows the robot to adapt to any size pole. The cost of a linear actuator and implementing it so the robot can quickly adapt poses a challenge. This concept would also use a tomograph to sense the poles rot.

Concept 20: Bicycle Climber – This design utilizes a counterweight system and a single driven wheel with two follower wheels. The counterweight system allows the device to not have to fully encompass the pole but at the cost of increased length. The design was inspired by a system that was designed to scale palm trees, utilizing a bicycle system to power it and the weight of the mounted operator, and a spring between two sides of the frame, to maintain tension on the tree. The device would be modular with a ground-penetrating radar by default and have room for more sensor arrays to be implemented in the future. The frame would need to be a lightweight metal like aluminum and features a very simple means to mount as it is open on one side.

Concept 83: Counterweight Triangle Hybrid– Combination of the basic concept of the triangle climber’s platform and the climbing apparatus of the “Bicycle” Counterweight Climber. The attachment process would be similar to that of the Bicycle Climber with an extra step to open the outer shell, most likely with a hinge. The shape of the outer shell would likely be circular or triangular with a hinge to allow it to open and close. The shell would exist to allow a sensor array to move about the pole without needing to rotate the actual robot.

Concept 16: Serpent robot - This design is manifested in the form of a snake with several aluminum wheels that are evenly spaced out and connected to a serpent spine. Since this robot wraps around the pole, the wheels are angled and rotate in harmony. This allows the robot to traverse up and down the pole. This robot would support an x-ray system that would be attached to the spin to determine the health of the pole.

Concept 76: Hybrid bike design– This hybrid design piggybacks off the bike design, but with an additional feature. The bike design incorporates 3 hourglass wheels that will be slid onto a wooden pole and a counterweight on the opposing side that will create a bending moment and supply the necessary weight that will append the robot to the pole. Two of the wheels will be on one side of the pole (passive wheel), while the other will be on the direct opposite (active wheel). There will be a frame attached to the robot that will support all necessary equipment to determine the health of the pole. The extra feature included on the hybrid bike is a linear actuator that will control the distance between the passive arms. The greater the distance between the arms, the greater the stabilization and traction to the pole. This new addition will also allow for easier mounting and unmounting for the user.

High Fidelity Concepts

Concept 24: Triangle Climber – The Triangular climber is a high-fidelity concept because of the numerous advantages of its frame. The three-piece design can accompany different pole diameters. The triple wheel design provides stability while the robot traverses the pole. The frame will be composed of a lightweight material such as aluminum which offers plenty of space for mounting the sensor array, motors, and motor drivers. The frame even offers the availability to be modular in adding more sensors. needed once the electric motors apply torque to climb. Ground-penetrating radar sensors will scan for wood rot. One arm of the triangle will be able to hinge open and close to allow mounting and dismounting. The frame also offers rigidity which is rot and degradation. The data will be displayed on the robot with an LCD screen.

Concept 70: Rollercoaster Gripper– This design is inspired by an inverted roller coaster mounting apparatus that grips and maintains the multiple trains (roller coaster sections) to the railings at all times. It consists of three sides, all of which have two wheels that attach to the pole. Out of all the 6 wheels attached to the pole, 4 are passive and 2 are active. The passive wheels provide greater stabilization on the railing (pole in this case) while the active wheels would allow for vertical traversal of the pole.

Concept 72: Batmobile – This concept uses a car climbing structure with wheels to traverse up and down the pole. The design will integrate a ground-penetrating radar to sense for voids and detect the health of the pole. The material selected will likely feature a finished aluminum frame to carry the load while still being able to be lightweight and move at an ideal speed.

Table 6 *List of 100 Ideas*

Number	Concept
	Morphological Analysis
1	Wooden, Wheeled, Serpentine Climber with Hammer
2	Fiberglass, Adhesive, Animal Climber with Ground Penetrating Radar
3	Wooden, Wheeled, Counterweight System with Tomograph
4	Wooden, Clawed, Animal Climber with Ground Penetrating Radar
5	Fiberglass, Wheeled, Climbing Car with Tomograph
6	Wooden, Wheeled, Triangle Climber with Hammer
7	Fiberglass, Wheeled, Serpentine Climber with Ground Penetrating Radar
8	Wooden, Mechanical Grip, Triangle Climber with Hammer

9	Fiberglass, Adhesive, Serpentine Climber with Tomograph
10	Wooden, Clawed, Serpentine Climber with Ground Penetrating Radar
11	Fiberglass, Mechanical Grip, Climbing Car with Tomograph
12	Wooden, Wheeled, Counterweight System with Hammer
13	Fiberglass, Clawed, Animal Climber with Ground Penetrating Radar
14	Wooden, Adhesive, Serpentine Climber with Tomograph
15	Fiberglass, Wheeled, Climbing Car with Hammer
16	Aluminum body, serpentine climber with wheels while utilizing ground penetrating radar to sense
17	Aluminum body, serpentine climber with wheels while utilizing tomography to sense
18	Aluminum body, serpentine climber with wheels while utilizing a mechanical hammer with acoustic mic to sense

19	Aluminum body, serpentine climber with wheels while utilizing tomography to sense
20	Aluminum body, counterweight system to climb with wheels while utilizing ground penetrating radar to sense
21	Aluminum body, counterweight system to climb with wheels while utilizing tomography to sense
22	Aluminum body, counterweight system to climb with claws while utilizing ground penetrating radar to sense
23	Aluminum body, counterweight system to climb with adhesion while utilizing ground penetrating radar to sense
24	Aluminum body, triangular climber with wheels while utilizing ground penetrating radar to sense
25	Aluminum body, triangular climber with mechanical grip while utilizing ground penetrating radar to sense
26	Aluminum body, triangular climber with mechanical grip while utilizing tomography to sense
27	Aluminum body, triangular climber with adhesion while utilizing tomography to sense
28	Aluminum body, triangular climber with claws while utilizing ground penetrating radar to sense

29	Aluminum body, climbing car with wheels while utilizing tomography to sense
30	Aluminum body, climbing car with wheels while utilizing ground penetrating radar to sense
31	Aluminum body, climbing car with claws while utilizing ground penetrating radar to sense
32	Aluminum body, climbing car with adhesion while utilizing tomography to sense
33	Aluminum body, climbing car with mechanical grip while utilizing tomography to sense
34	Stainless Steel body, wheeled, counterweight system using tomography
35	Stainless Steel body, Wheeled, serpentine Climber using Ground Penetrating Radar
36	Stainless Steel body, clawed, climbing car, using mechanical hammer
37	Stainless Steel body, mechanical grip, Animal climber, using Ground Penetrating radar
38	Stainless Steel body, adhesion, serpentine climber, using tomography

39	Stainless Steel body, wheeled, triangular climber, utilizing ground penetrating radar
40	Stainless Steel body, clawed, animal climber utilizing tomography
41	Stainless Steel body, adhesion, counterweight system, utilizing mechanical hammer
42	Stainless Steel body, clawed triangular climber utilizing tomography
43	Stainless Steel body, wheeled, animal climber, utilizing mechanical hammer
44	Stainless Steel body, mechanical grip, counterweight system utilizing ground penetrating radar
45	Stainless Steel body, clawed serpentine climber using tomography
46	Stainless steel, wheeled, linear actuating climber using tomography
47	3D printed wheeled climbing robot using tomography

48	Composite wheeled robot using ground penetrating radar
49	Composite wheeled robot using ground tomography
50	3D printed wheeled climbing robot using ground penetrating radar
	Crapshoot
51	Dual track climber that uses ultrasonic sensors
52	Inchworm clamp climber with ground penetrating radar
53	Propeller climber with ground penetrating radar
54	Wheeled climber with screwdriver scraper to reveal below surface rot
55	Triangle climber with drill and scope
56	Coiled robot that uses shigomotry to test wood
57	Jumping robot that uses mechanical hammer to test wood

58	Collar robot with tank tread and ground penetrating radar
59	Triangle climber with tomography probed wheels
60	End effector climber with shigometer sensors
61	Scissor lift robot that uses ground penetrating radar
62	Ultrasonic hammer that can detect rot
63	Handheld probe that uses shigometry
64	Square climber with roller wheels and Xray scanner
65	Tank track climber with ultrasonic sensor
66	Digging collar robot with drill and probe
67	Bending moment bike robot with ultrasonic sensor
68	Triangular robot with adhesive wheels and probe
69	Extension robot with ultrasonic sensors

70	Rubber band tension robot with ground penetrating radar
71	Magnetic tension robot with ultrasonic sensors
72	Batman 4 wheeled robotic climber with compression arms using ground penetrating radar
73	Collar climber using wheels and ground penetrating radar
74	Reverse pull up climber that utilizes claws to pull from the back side
	SCAMPER
75	Rollercoaster Gripper
76	Hybrid Bike Design
77	Circular wheeled climber
78	Robotic bike with drill climber
79	Vacuum fan climber
80	Variable arm and wheel climber

81	Angled wheel climber with linear actuator
82	Shigometer bird pecker
83	Carey’s Counterweight Triangle Hybrid
84	Wheeled sensor array with manual elevation
85	Robotic Screwdriver plunge
86	Robotic bird probe
87	Drilling robot with drill bit claws
	Biomimicry
88	Koala styled climbing that uses claws to reach above and pull itself up
89	Monkey oriented climbing that allows the robot to traverse vertically as well as swing circumferentially around the pole
90	Design will provide spider type movement as it features legs that climb simultaneously
91	Snake styled robot that will wrap around the pole and carry an ultrasonic sensor

92	Panda robot that will use libs to climb up the pole with x-ray system
93	Monkey robot with clawed hands and ultrasonic sensor
94	Frog robot (adhesive limbs) with ultrasonic sensor
95	Squirrel climbing robot with ground penetrating radar
96	Lizard robot with tailed used for stability while climbing with ultrasonic sensor
97	Adhesion snail robot that uses ultrasonic sensors
98	Spider robot with tomography probe fingers
99	Lizard climbing robot with tomography sensor on tail
100	Serpentine climber with adhesion rollers using X-ray sensors

1.6 Concept Selection

Concept Selection Tools

To successfully select a concept, many concept selection tools were utilized. First an analytical hierarchy process was used to compare our customer needs against one another to determine importance rating. Below in table 1 shows our analytical hierarchy chart comparing our customer needs against themselves. It was concluded that the most important customer need was rot detection and the ability to climb. These two functions were heavily emphasized by the customer and project sponsor.

Table 7 *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	

The analytical hierarchy table was then normalized to emphasize the value of the customer needs. The normalization sets up the bottom row, so no value is bigger than 1. The normalized table is shown below in table 2.

Table 8 *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	

As shown above in table 2, the robot will need to have a very big emphasis on the ability to detect rot. This value is exceptionally important because without detecting rot, the project objective is lost. The robot needs to detect rot to be successful with its objective and purpose.

Modularity has a value of zero because the need of modularity did not surpass any other need on the table. The weight values from the table play an important role in concept selection.

After the analytical hierarchy process, we developed a house of quality relationship. This table compares the customer needs to different engineering characteristics the product should possess. The purpose of this table is to give value to the engineering characteristics. Seen below in table 3 is the house of quality relationship matrix.

Table 9 *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

As seen above, the stability and safety of the robot scored very high against other characteristics. The stability of the robot is intertwined with all of its systems including climbing, sensing and interfacing. Stability in reference to climbing would be defined as how well its transverses without slip and fall. Stability in reference to rot detection would refer to how stable the robot will be when the sensors are scanning the wood. Then stability in reference to the data interfacing would be defined as how strong the signal is and how consistent the results are displayed. Safety is also a high scoring characteristic because this project is proposed for safety enhancement.

The team also made use of Pugh charts to compare the selected concepts with the prototype bike climber concept as we had basic data from it. After this initial comparison, one competently performing concept was selected as the datum and, after removing the worst performers, the other concepts were compared against it. The purpose of this methodology is to determine which three concepts can be considered high-fidelity. In these charts, a ‘+’ represents an improvement over the datum, a ‘-’ represents a deficiency compared to the datum, and an ‘S’ represents similar performance to the datum. The first Pugh chart can be seen in Table 4. After performing this comparison, the team decided to eliminate the “Counter-Weight Triangle Hybrid”, the “Serpent Robot”, and the “Hybrid Bike Design” due to their low number of pluses and relatively high number of minuses. The team also decided to establish the “Batmobile Climber” concept as the new datum. This was done because this concept showed a competitive number of plusses and a high number of minuses, which contributes to a fair comparison in the next chart.

Table 10 *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

Another Pugh chart was developed in order to eliminate concepts, determine the three concepts that can be determined as high-fidelity concepts, and select the final solution. The second Pugh chart can be seen in Table 5. It was concluded from this table that the “Variable Arm Climber” concept must be eliminated because it has the highest number of minuses. From this chart, it was also decided that the “Batmobile Climber”, the “Roller Coaster Gripper”, and “Triangle Climber” were the high-fidelity concepts with the “Triangle Climber” was to be the best solution due to its overall performance compared to the datum and the other concepts.

Table 11 *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

Selected Concept

After an extensive process of sorting through 100 ideas and using multiple tools and methods to objectively determine the best possible solution, the triangle climber with ground penetrating radar (concept 24). The triangular climber was chosen because of numerous advantages of its frame. After performing an analytical hierarchy process (Tables 1 &2) and the house of quality (Table 3) to determine the aspects that took the most precedence. Afterwards, two Pugh charts (Tables 4 & 5) were conducted to compare several concepts with the respected aspects. In the end, the triangle robot was selected, this was due to the importance of modularity. It had a marginal win over the batmobile robot. The triangle robot had a high rating for modularity, while the batmobile robot had none. Moreover, the triangular three-piece design makes it easier to accompany different pole diameters. The triple wheel design provides stability while the robot traverses the pole. The frame will be composed of a lightweight material such as aluminum which offers plenty of space for mounting sensor arrays, motors, and motor drivers. The large frame will offer greater modularity for adding additional sensors. One arm of the triangle will be able to hinge open and close to allow mounting and dismounting. Shown below in Figure 1 is a rough sketch of the final design, prone to slight modifications and tweaks as all robotics deem necessary.

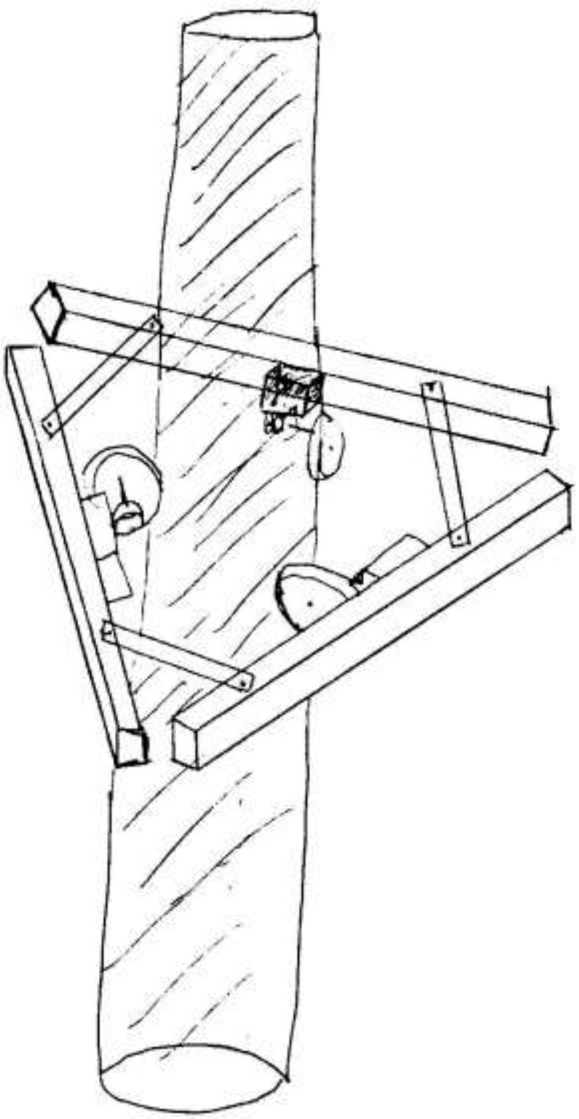


Figure 3 Rough sketch of final design.

1.7 Spring Project Plan

T505's spring project plan is as follows

- Finalize design by January 31st

- Submit order for components by February 28th
- Have Final assembly finished by March 15th
- Begin Testing March 20th
- Integrate systems by March 27th
- Present Final Design April 8th

Chapter Two: EML 4552C

2.1 Project Definition and Scope

Project Description

The objective of this project is to create a robot that can measure and report back the structural integrity of a power pole. Developing this mechanism will increase the safety of the linemen, decrease the error in pole testing, and increase the reliability of the electric utility. The robot will test the integrity of the pole and check for rotten wood. The pole inspection is crucial to the reliability of the utility and the safety of FPL’s linemen.

Key Goals

The key goals for team Southern Pine are to aid FPL engineers and help keep linemen safe from compromised power poles. To do this a device will be designed to automate parts of the inspection process and to generate an accurate analysis of the safety of the poles by working alongside the linemen. The goals of the pole inspections are to detect rot and determine the integrity of the wood. To best aid the linemen in the inspection the device will have a means to interface with them, by sending the information to a screen to convey important information such as its determination of the stability and if it would be safe to attempt to climb the pole.

Market

The primary market would involve our sponsor, Florida Power and Light. This will also include other utility and energy companies who have to inspect the integrity of power poles and perform routine maintenance. The secondary market would be directed towards telecommunication companies such as Comcast and construction companies that would also need to perform routine inspections and maintenance on wooden poles.

Assumptions

To focus on scope development, T505 generated assumptions that will guide our project. We assume that the operator will have prior training completed before inspecting and working on poles. It is assumed that the line worker will be present while operating the device. The device will be used under normal working conditions. Normal being defined as safe conditions a crew would operate under, no inclement weather. It is assumed that the poles are wood and have a circular cross-section with a set range of diameters within 17.5 inches to 6.7 inches. The device will operate strictly above ground. The pole is assumed to be straight and flush surface.

Stakeholders

The stakeholders involved in the overall project range from individual professors/administrators to larger-scale Universities and companies. The main stakeholder in this project has been determined to be Florida Power and Light as the project directly benefits their company moving forward in the future. That said, the linemen working for Florida Power and Light will also be stakeholders as they will be in charge of operating the device. More stakeholders include the project sponsors Genese Augustin and Troy Lewis, who represent Florida Power and Light. In addition to Florida Power and Light, the FAMU-FSU College of Engineering is also a stakeholder in the project, since the joint University will be funding the project. Dean Gibson and Dr. Hellstrom are also stakeholders as the two head administrators for the FAMU-FSU College of Engineering. Dr. McConomy and Dr. Clark as class professor and project advisor respectively will serve as the main project guides for structure and aid throughout the design and production stages. Lastly, the repair personnel would also be deemed stakeholders as they will be performing maintenance on the device.

2.2 Results

Prototype Iterations

Throughout the spring semester, team 505 developed 3 additional variants of our prototype from the fall semester. Our most recent prototype (prototype 6) was able to climb without any additional support. Each prototype helped to identify issues with our system including: the ability to adapt to variable pole diameters, pinching, motor power, traction and tension. Throughout our prototype iterations we were able to solve the issues discovered.

Our final prototype was able to ascend and descend a pole with no external support and had the capability to support a load of 20 pounds. The final prototype included all the mechanical engineering components and was able to successfully climb the pole while being controlled by an IR sensor and remote.

Frame Design

Our final frame design was composed of two triangles created from 6061 aluminum, supported by four rectangular tubes made from 6061 aluminum as well. The triangular frames were machined by the water jet system in the machine shop. The frame was machined to have holes for the tensioning strap so it could be neatly incorporated. The frame was 18 inches tall and only weighed eight pounds. The frame also consisted of a mounting plate made out of sheet metal, bolted to the back of the climber. This mounting plate allowed for the mounting of the electrical components in a neat and organized manner.

Drivetrain

The robot drivetrain consists of serval parts that interact with each other to create movement that allow smooth traversing of the wooden utility pole. The selected motor for the drivetrain is a Pololu 24V DC motor with a gear ratio of 150:1. This motor also includes an encoder that is essential for determining the height of the robot on the pole with some additional mathematical calculations. This motor was selected because of the large gear ratio that creates sufficient torque which is critical for providing the movement necessary for the robot to climb up the pole. The next component in the drivetrain is a ridged linear coupler. The coupler is used to connect the output 6mm motor shaft to an 8mm Al6061 shaft to allow for smooth rotation. The Al6061 shaft is ran through skateboard bearings which are mounted in 3D printed bearing blocks to the frame. The Al6061 shaft is connected to an hourglass wheel with setscrews. The hourglass wheel contains 1/4-inch track spikes that are imbedded for the most possible traction to the wooden utility pole. The hourglass wheel design was chosen because of the large surface area that results in greater contact compared with a conventional wheel.

Variable Wheel

In order to compensate for changing diameter of the pole, a specialized passive wheel mount was designed in CAD and 3D printed out to satisfy needs. The design takes the advantages of the hourglass wheel design and couples it with a longer shaft that allows it to translate across the shaft and simultaneously rotate about the shaft.

Tensioning

The most important aspect of the robotic design is tensioning. The tension for the robot is created by using a ratchet strap and a bungee cord. The ratchet strap was selected to provide tension for the top stage of the robot, where the driver wheel is located. The ratchet strap is situated in a weave wrap layout that is run through ratchet strap rings to obtain the maximum tension possible and harness the driver wheel to the pole while simultaneously supporting the robot's weight.

The bungee strap is situated on the bottom stage of the robot in a perimeter wrap. The bungee cord was selected for the bottom stage to pull in the robot's arms. Since all the tension is primarily focused on top stage that is supporting the entire robot, the bungee cord has a more basic function which is to supply sufficient tension to pull the bottom components together snug on the pole for stability purposes.

Sensory Space

The robot is designed to carry a payload that contains all the components necessary to power and control the robot, along with supporting the essential sensory technology needed to detect defects. A flat sheet of metal was chosen to be mounted on the backside of the robot on the driven side. The sheet metal was selected strictly for easy mounting and accessibility. The components will be attached to the sheet metal in various ways depending on their sensitivity. All electrical components will be placed on the plate including a ground penetrating radar (GPR) that will be carefully mounted in the sensory space section on the backplate.

2.3 Discussion

The robotic pole inspection collar was able to climb and descend a pole sample with a fully assembled frame and mounted components. The inspection collar had the controller and battery mounted when performing the final climbing test, but the GPR technology was not fully assembled and mountable at the time. The time to mount the robot on the pole and have it traverse the pole sample was also conducted. Overall, the inspection collar took 60 seconds to mount and approximately 13 seconds to climb and descend the pole sample.

In the end, the final robotic pole inspection collar was fully functional with components that allowed the robot to traverse the pole sample, but it was missing the sensory technology that would scan for rot. The electrical engineering team suffered from multiple late part deliveries which hindered the assembly of the sensor array. The unassembled GPR components were placed on the back of the payload plate to verify that all components would fit. Based on preliminary weight test using a scale, team 505 is confident that all components can be mounted adequately, and that the inspection collar can withstand the additional weight of the sensor array as it weighs less than five pounds.

2.4 Conclusions

The Robotic Pole Inspection Collar is a device that has the potential to replace the OSHA hammer test. The final product was a result from several early issues discovered from rapid prototyping that were solved across multiple iterations of the robotic design. The final design demonstrates the robot's ability to scale utility poles, while providing space for sensor technology that is implemented to determine pole health.

The robot has the capability to safely traverse a utility pole prior to a lineman climbing it. Since the sensory technology is more objective than the current hammer test, it makes it a viable testing standard and could be implemented as the new standard for pole integrity testing. Team 505 firmly believes that this technology can greatly aid lineman and create a safer environment for them to work in.

2.5 Future Work

For the robot to be fully functional as initially intended, there would need to be several additional features implemented, and testing would need to be carried out on a regulated utility pole. The next steps that would need to be satisfied would be to finish the assembly and calibration of the GPR. Since the GPR is employing a machine learning feature, it would need to be tested on hundreds of pole samples, both healthy and non-healthy to be fully calibrated and accurate.

It has been proven that the current robotic design can successfully climb a pole with a 9-inch diameter. Furthermore, more tests will need to be conducted on larger pole samples to fulfill the project scope requirements of a varying pole diameter from a class I pole to a class IV pole.

A Bluetooth module that is compatible with the current robot's controller will need to be research and selected. The Bluetooth module will be attached to the robot's controller and paired to the Blynk application. The application will be used on a Bluetooth enabled device for the interface and will receive and send important commands to the robot while climbing, such as move to a certain location on the pole and relay critical information that involves the utility pole's structural integrity.

After all these requirements from the project scope are completed, final testing and optimization for the robot can begin. This would involve numerous tests on regulation utility poles that would accompany training for the lineman who will be operating the robot.

References

Ahmadabadi, M. N., Moradi, H., Sadeghi, A., Madani, A., & Farahnak, M. (2010, October). The evolution of UT pole climbing robots. In *2010 1st International Conference on Applied Robotics for the Power Industry* (pp. 1-6). IEEE.

Appendix

Appendix A: Code of Conduct

Mission Statement

Team 505 is creating the next wave of robotic innovation to scale the poles of the future. We are committed to professionalism in the workspace, integrity, respect, and quality. Team 505 defines professionalism as taking responsibility for actions and owning up to mistakes. We show up to the occasion dressed professionally and ethically find a solution to the problem. Honesty and strong moral principles define our dedication to integrity. We respect each other and every other person we interact with regardless of gender, sex, disability, religion, or opinion. Our team is committed to excellence and ensuring the utmost quality of our deliverables.

Team Roles

- Angelo Mainolfi - Project Engineer
    - Managing project deadlines and progress
    - Assisting team members
    - Validating and creating presentations and reports
    - Contacting sponsor
    - Submitting assignments
- Carey Tarkinson - Mechatronics/Programming Engineer
    - Developing code for the robot’s operation
    - Designing an interface between the electrical and physical systems of the robot
- John Flournoy - Design/Material Engineer

  - Validating and researching designs and materials
  - Keeps in direct contact with the project manager
  - Responsible for material section and designing parts to fill needs.
- Mathew Crespo - Mechanical Systems Engineer
  - Designs, fabricates, and constructs mechanical systems used in robotic pole inspection collar design
  - Maintain constant contact and communication with members of the team

Other duties-

Other duties will be presented to the team and will be assigned weekly to keep the project moving forward. All assignments will be conducted fairly in a meeting.

Communication Standards

Basecamp and GroupMe will serve as the official messaging source for setting up meeting dates and addressing pertinent information. Regularly scheduled meetings will take place via Zoom on Mondays 5:30PM-6:30PM as well as immediately after the end of the Senior Design class (Tue/Thu) unless otherwise noted.

Email will be used as a secondary form of communication for non-time-sensitive matters or for the transfer of info such as transferring of files. Google Docs and One Drive will serve as the main source used for the sharing of file information throughout the group. Members must check Basecamp as well as their school email regularly to stay updated with important information and updates from the group. Responses to messages must be prompt, allowing the members 24 hours to generate an acknowledgment response to the original message.

**Every team member is okay with providing a progress report and is open to communications with Project Engineer. Every expectation and change should be communicated and understood by everyone.

Dress Code

I. Standard Meetings: Casual

II. Official Meetings: Business Casual

    A. Official Meetings: Meetings with Sponsors/Professionals

III. Presentations: Formal

Attendance Policy

I. Max Number Absences Allowed: 3 Per Semester

    A. Absence: Agreeing to Meeting but Backing Out with Notice

        1. Notice: 24-Hour Minimum/Emergency (With Approval by Group)

II. Any Failures to Meet without Notice will be Discussed in a Special Meeting (Point Deduction from Peer Review) (Mandatory Full Attendance) and external help will be contacted if deemed necessary.

III. Late Policy: Joining 15 minutes late without Late Notice will result in a penalty of 0.5 Absence Tally.

A. Late Notice: Within 3hrs or as deemed appropriate by Team.

Team Dynamics

Team 505 will work together and communicate as a functional team to complete our objective. All team members should be transparent with the rest of the team and will be held accountable if they are absent or miss an event. Team members are encouraged to communicate any concerns they have about the project at any time. Everyone has a voice in every aspect of the project and is encouraged to make contributions without fear of criticism from the rest of the team. If anyone finds a task too difficult, then they should immediately bring it up to the team to be assessed and promptly addressed. If anyone feels belittled or treated unfairly, a meeting should preside, and all concerns shall be discussed and fixed. Team members' attitudes should be fair and impartial. All team members are expected to complete their fair amount of work. Any changes to the project should be communicated during team meetings, and subsequently, a vote will be cast to determine the preferred outcome that will benefit the team in the most positive way.

Standard Meeting Days

Monday: 2PM - 3:15PM

Tuesday: After SD-9:30PM (Latest)

Thursday: After SD-9:30PM (Latest)

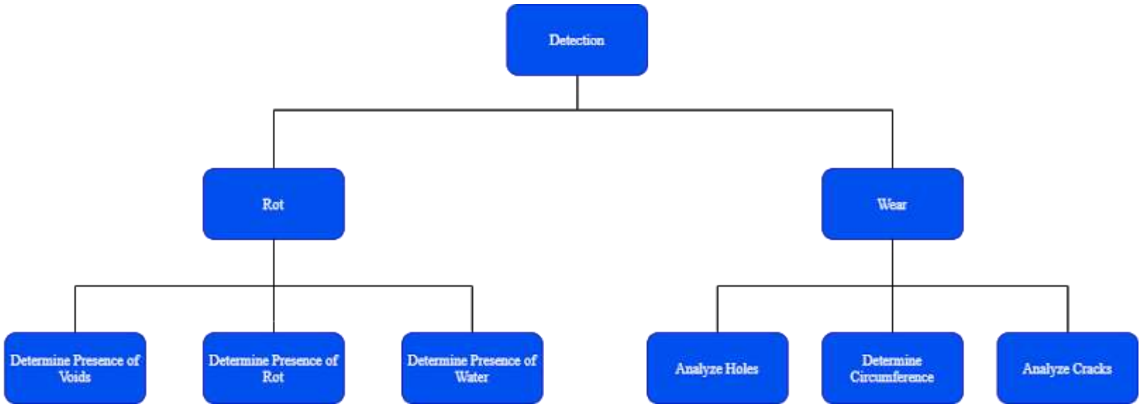
Statement of Understanding

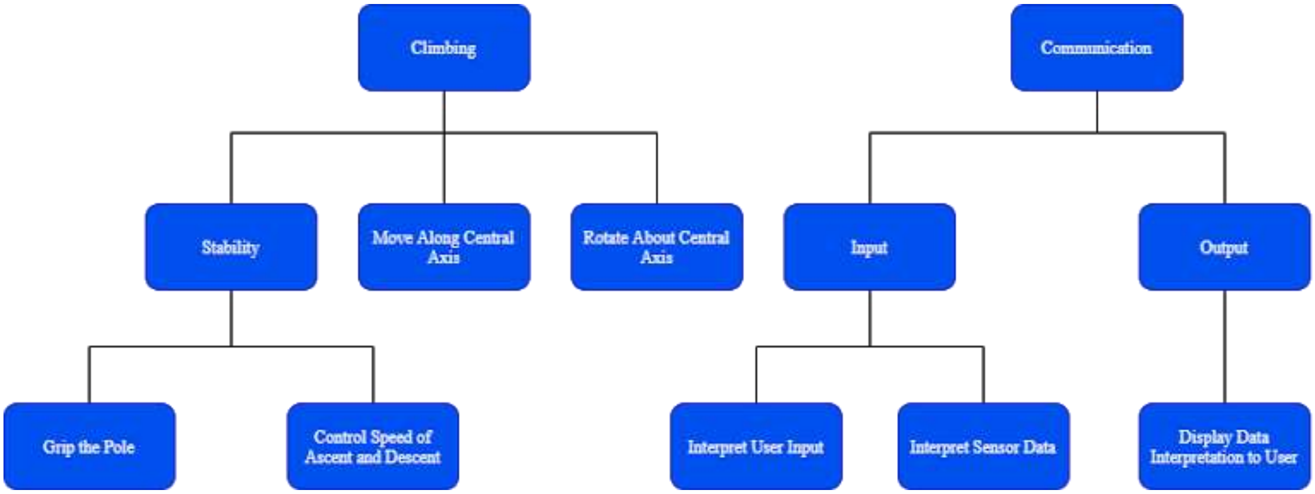
All team members have read the statements above and accept the responsibility of being a team player and completing their work as assigned.

Sign and print below

Angelo Mainolfi	Angelo Mainolfi
Carey Tarkinson	Carey Tarkinson
John Flournoy	John Flournoy
Mathew Crespo	Mathew Crespo

Appendix B: Functional Decomposition Charts





Appendix C: Target Catalog

Table 12 *Target Catalog*

Metric No	Needs	Metric	Units	Exact Value	Ideal Value
1	Traverse utility pole	Robots ability to climb up and down a wooden pole	Feet	15	35
2	Detect voids in wood	Test ability to detect the difference in wood density	Inches	8	16
3	Reasonable Weight	Robot total weight with full sensor array	Pounds	3510	<30
4*	Grip the Pole	A perfect cylinder cannot be assumed, so the robot must be tested on multiple varying-sized poles	Number of slips	2	0
5	Controlled wirelessly	Test robot remote control range from varying distances	Feet	50	50
6	Powered wirelessly	Actively display the battery life while the robot is powered on	Hours	1	1.5
7	Attachment	The robot should be attached within a certain amount of time	Minutes	5	4
8*	Interface	The speed at which the robot can process its data and send a report	Seconds	60	30
9*	Kill Switch	The User must be able to manually disable the robot in case of emergency	Speed of operation halt (seconds)	<5	<1
10*	Ascent/Descent Control	The robot speed will be constant and controlled	ft/minute	4	12
11*	Circumference Calculation	Needs to be able to identify circumference of pole	Error (inches)	1	0.2

12*	Complete Operation Time	The robot needs to complete the task in a timely manner	Time to Complete (minutes)	15	10

Appendix D: Operations Manual

Project Overview

The robotic pole inspection collar was developed to keep linemen safe when working on wooden utility poles. Florida Power and Light's linemen currently use a hammer to test these utility poles, just by judging the sound of the rebound. Since the degree of hearing and other senses varies from person to person, and are subjective, this makes the hammer test inaccurate and a safety concern. The motivation of this project came from a safety incident where a lineman was injured after a utility pole broke while the linemen was climbing it.

The robotic pole inspection collar is designed to climb utility poles and scan the interior of the pole in search of voids that would make the pole unsafe for climbing. To do this, a ground penetrating radar (GPR) was selected and tailored to the utility pole's geometry. The GPR checks for discontinuities by scanning the wooden structure in search for anomalies in the dielectric constant that vary within the wooden pole. After the scanning is finished, the readings are interfaced to the linemen via their cell phones using a Blynk application. The robot is calibrated to climb poles of diameter between 9 inches to 13 inches, and to a height of 15 feet from the base. The ground penetrating radar can scan up to depths of 15 inches. This mechanism is designed to prevent a subsequent injury from occurring by offering an objective means to determine pole integrity.

Component/Module Description

The pole climbing robot is constructed of serval important modules that are combined to create a robot that can climb a utility pole safety, while also being able to transport a payload that determines the pole’s structural integrity.

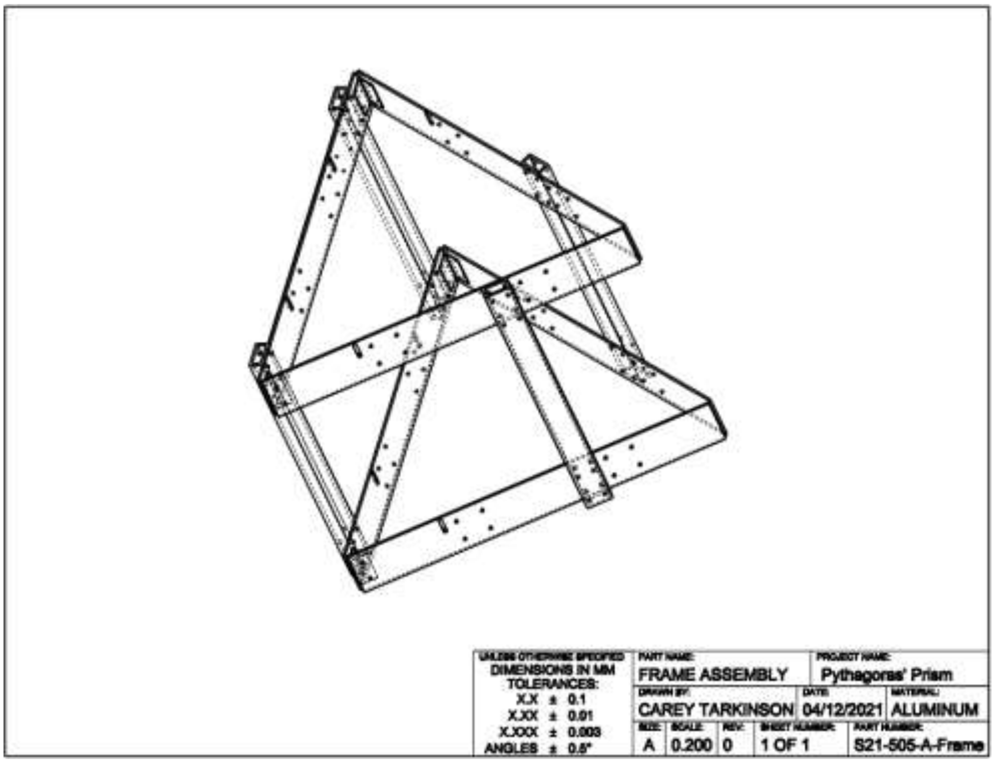


Figure 4 Drawing of assembly of the robotic frame.

The robot frame consists of 6 multipurpose 6061 rectangular aluminum bars that are 21 inches long, 3 inches wide, and with a $\frac{1}{8}$ inch thickness. Two sets of three of the bars are combined using hinges to produce two identical triangles. The two triangles form a prism and are connected by 4, 18-inch-long rectangular multipurpose aluminum 6061 tubes that are 1.5 inches by 0.75 inches with a .14inch wall thickness. The tubes are bolted to the triangles to ensure a strong connection between the top and bottom of the robot. The top triangle slots for mounting a ratchet strap to provide the required tension. Additionally, a piece of sheet metal is affixed to the back of the robot for mounting the ground-penetrating radar components and other electronics.

The tensioning module consists of two parts, a 1-inch-wide ratchet strap for generating high amounts of tension on the top triangle and a bungee cord to hold the bottom triangle around the pole.

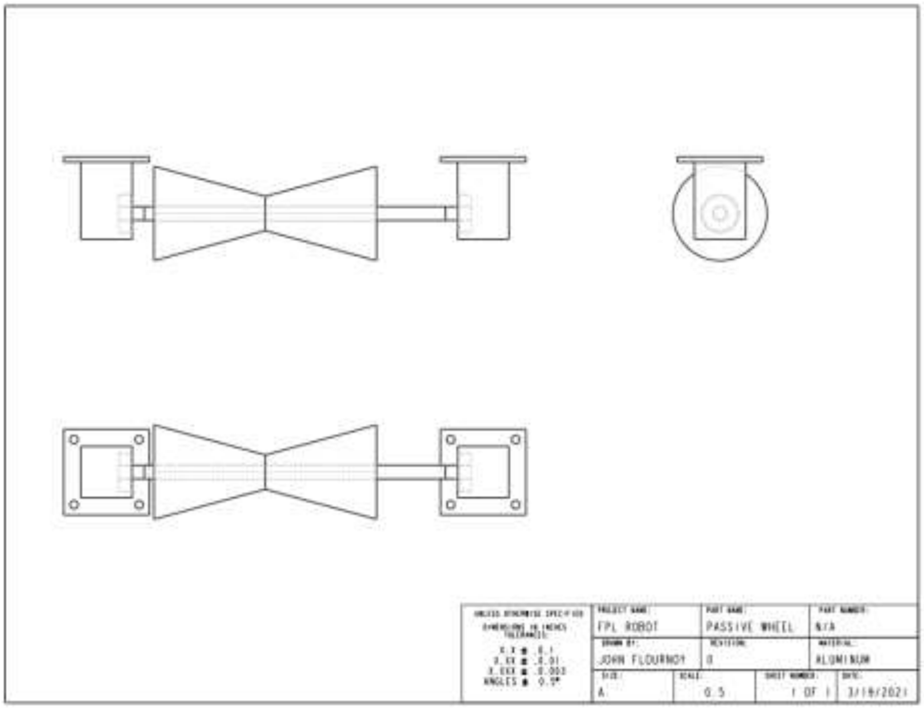
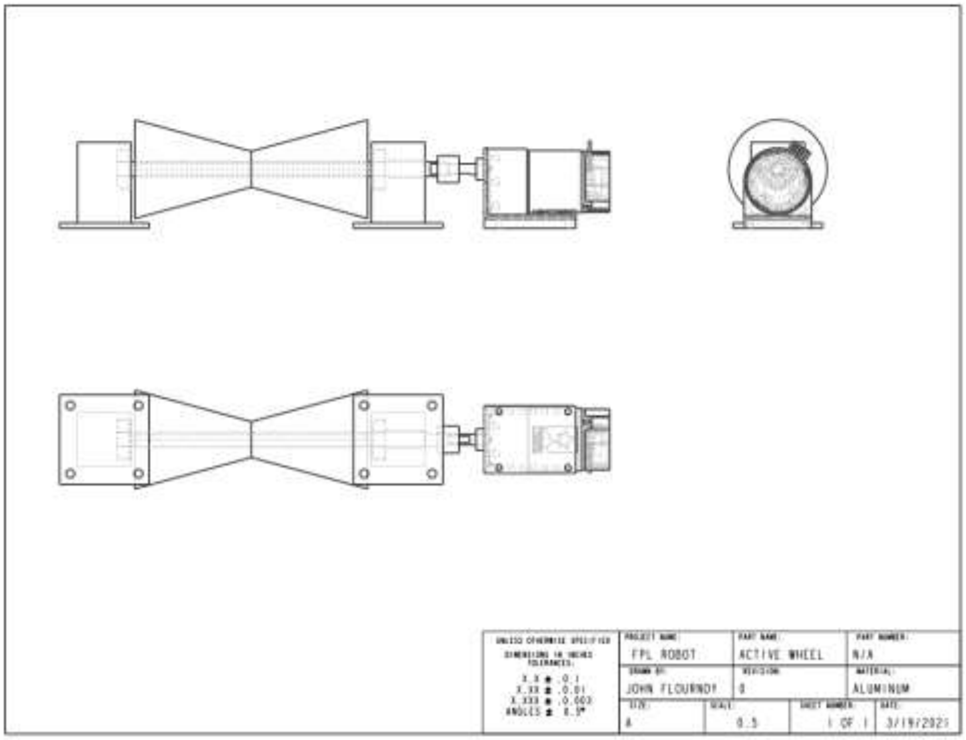


Figure 5 Drawing of assembly of the passive wheel.

The wheels are hourglass-shaped and mounted to each internal face of the two triangles using two ABS bearing mounts, metal bearings, and aluminum 6061 shafts of $\frac{5}{16}$ inch diameter. The bearing mounts house the bearings with a force fit while providing support to the aluminum shafts and the wheels for better contact to the pole. The two base wheel modules are unique in that the top has an extended shaft through one of the mounts and is coupled to a motor and a spiked wheel, while the bottom has the same mount-to-mount distance without the additional motor modifications. The four remaining wheel modules on the arms are all passive, featuring extra-long shafts along which the wheels can freely slide and rotate for better compliance to the varying diameter of the utility pole.


UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
TOLERANCES:
X.X ± .0.1
X.XX ± .0.01
X.XXX ± .0.003
ANGLES ± 0.5°

PROJECT NAME: FPL ROBOT
PART NAME: ACTIVE WHEEL
PART NUMBER: N/A
DRAWN BY: JOHN FLOURNOY
REVISION: 0
MATERIAL: ALUMINUM
SIZE: A
SCALE: 0.5
SHEET NUMBER: 1 OF 1
DATE: 3/19/2021

Figure 6 Drawing of assembly of the motorized base wheel mount.

Figure 7 Assembly of battery system.

The battery system is designed to provide sufficient power to the microcontroller, GPR, and the motor that will be driving the robot. For convenience, a rechargeable 21.6 V 5.2 Ah battery was selected to be interchangeable with the linemen's drill power supply. Since the devices will need power are incompatible with the same finite voltage, both buck and boost converters are used to control the necessary input voltage for these separate devices. The battery system is powered on and off with a rocker toggle switch on the outside of the cargo box. The power supply will also feature a kill switch in case of emergency.

Integration

The frame module is machined to have mounting holes for the mounting of the wheel modules, various sensors, and other electronic components. For added durability, the wheel module will be affixed to the frame using nuts, bolts, and epoxy adhesive to prevent decoupling. The rachet of the ratchet strap is mounted to the bracket on the top of the frame and the strap is fed through the tensioning loops during operation. The bungee cord is wrapped around and attached to the frame by their hooks fitting on the lowest point of the support tubes between the triangles. The backplate is meant to provide ample space for mounting all the electrical components for the robot. The electrical components are secured to the backplate by various methods, depending on the sensitivity of the electrical component.

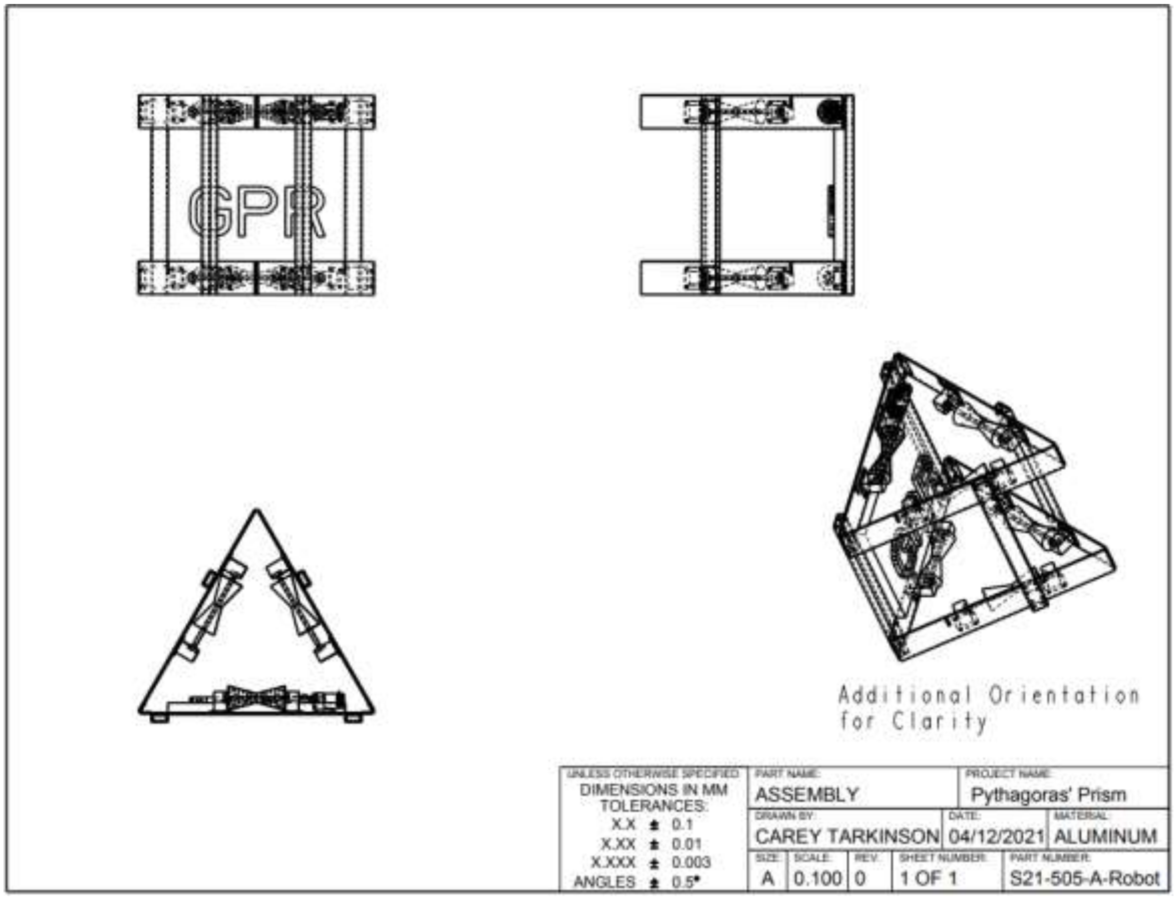


Figure 8 Drawing of full robot assembly.

Operation

To use the robotic inspection collar:

- Charge the removable drill batteries to give the machine power.
- Once charged, mount the battery on the battery slider on the interior of the robot.
- Open the two arms and wrap the robot around the base of the wooden utility pole.
- Feed the ratchet strap through the tensioning loops.
- Start tightening the straps until taught.
- Wrap the bungee cord around the lowest point of the support tubes and connect the hooks to each other.
- Turn on the master power switch with the red cap.
- Connect the Blynk application to the Bluetooth receiver on the robot.
- Select a distance for the robot to travel.
- Select either ascend or descend to move the robot.
    - The robot will scan automatically after stopping motion.
- Press the submit readings button and look at the terminal on the Blynk application for safety rating.

To remove the robot inspection collar:

- Turn off the master power switch with the red cap.
- Carefully remove the bungee cord from the frame.
- Disengage the rachet strap and remove it from the loops.
- Open the arms and remove the robot from the pole.

Troubleshooting

If the robot does not move

1. Check to see if the battery is charged.
2. Check if Blynk app is connected.
3. Check to see if there are any loose connections.
4. Make sure the robot is not attached too tightly or loosely.
5. Reset microcontrollers.

If the robot does not scan

1. Check for loose connection to sensors.
2. Reset microcontrollers.

Emergency Procedures

In case of emergency, immediately power off the device using the kill switch. If possible, after being powered off, remove the battery. Report situation to supervisor.

Appendix E: Engineering Drawings

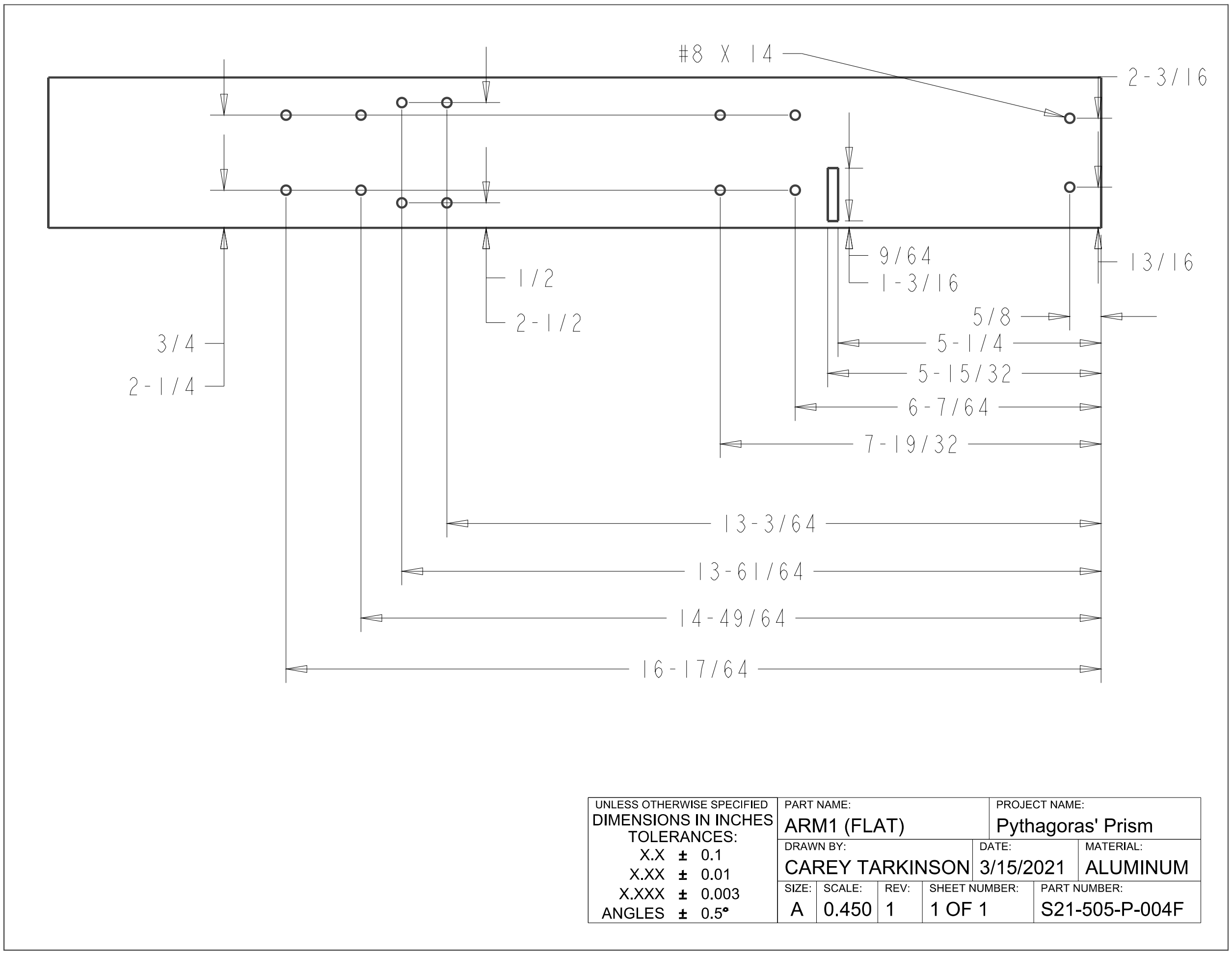


Figure 9 Engineering drawing of passive arm with dimensions for machining.

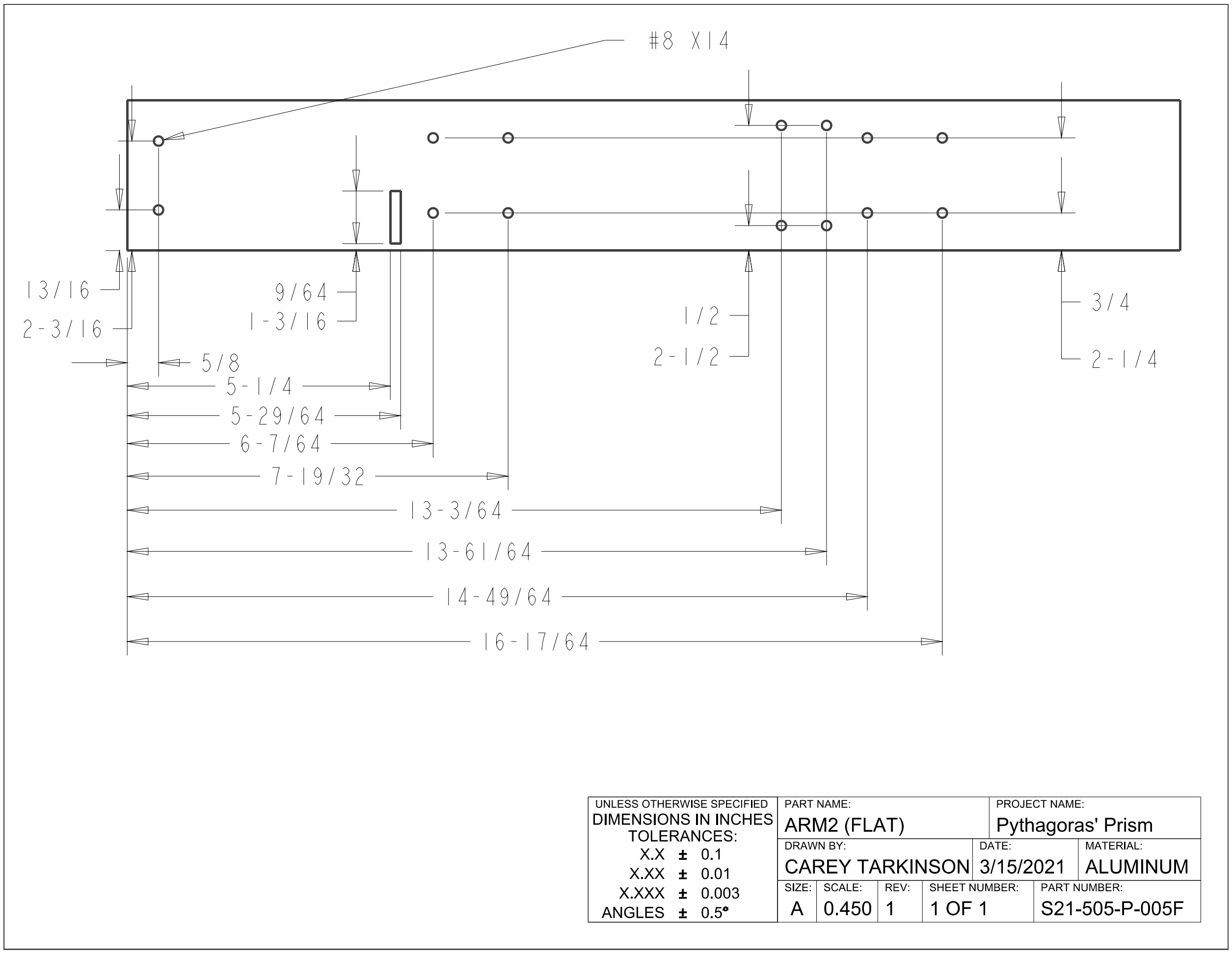
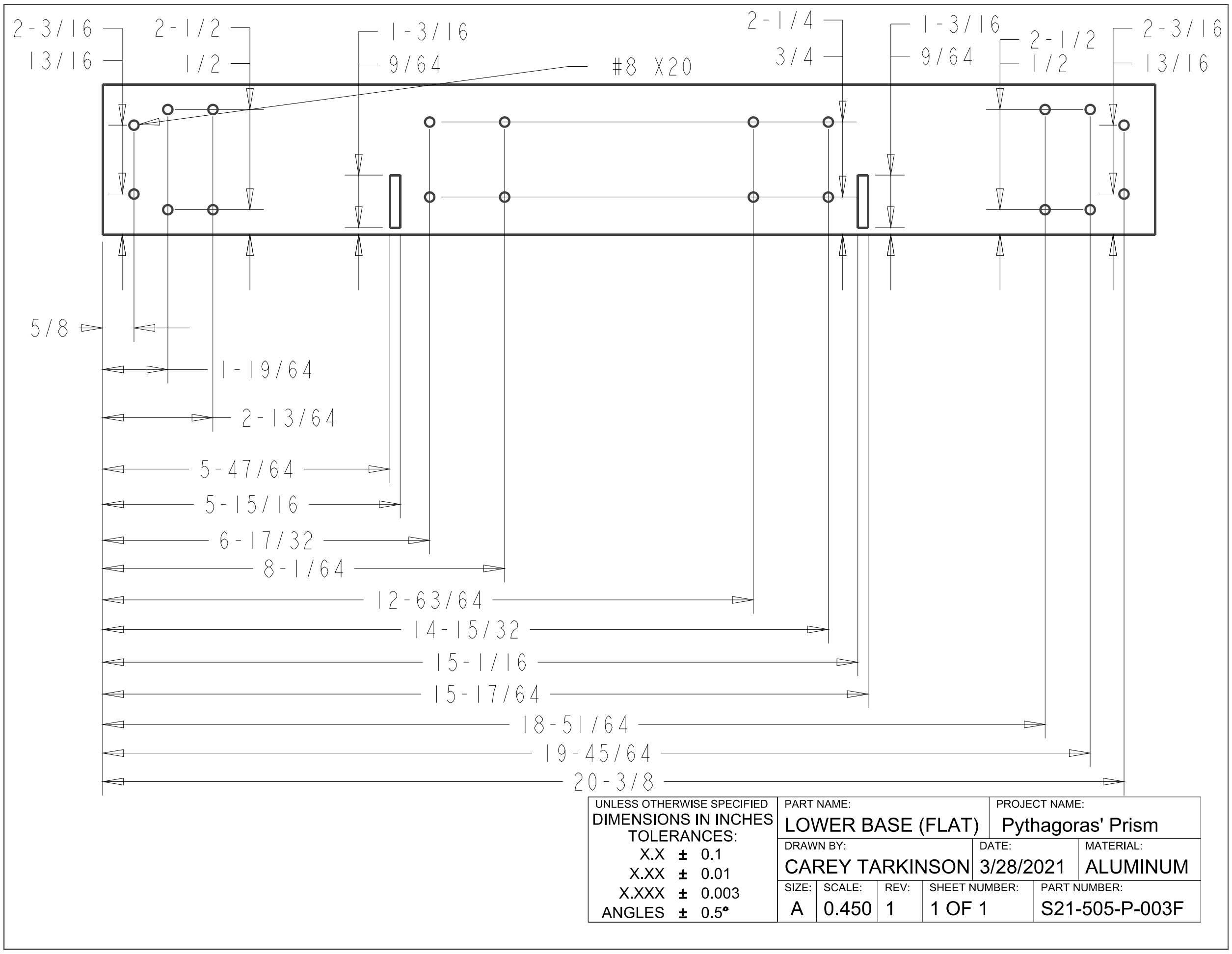


Figure 10 Engineering drawing of other passive arm with dimensions for machining.



UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES TOLERANCES: X.X ± 0.1 X.XX ± 0.01 X.XXX ± 0.003 ANGLES ± 0.5°	PART NAME: LOWER BASE (FLAT)		PROJECT NAME: Pythagoras' Prism	
	DRAWN BY: CAREY TARKINSON		DATE: 3/28/2021	MATERIAL: ALUMINUM
	SIZE: A	SCALE: 0.450	REV: 1	SHEET NUMBER: 1 OF 1	PART NUMBER: S21-505-P-003F

Figure 11 Engineering drawing of passive base with dimensions for machining.

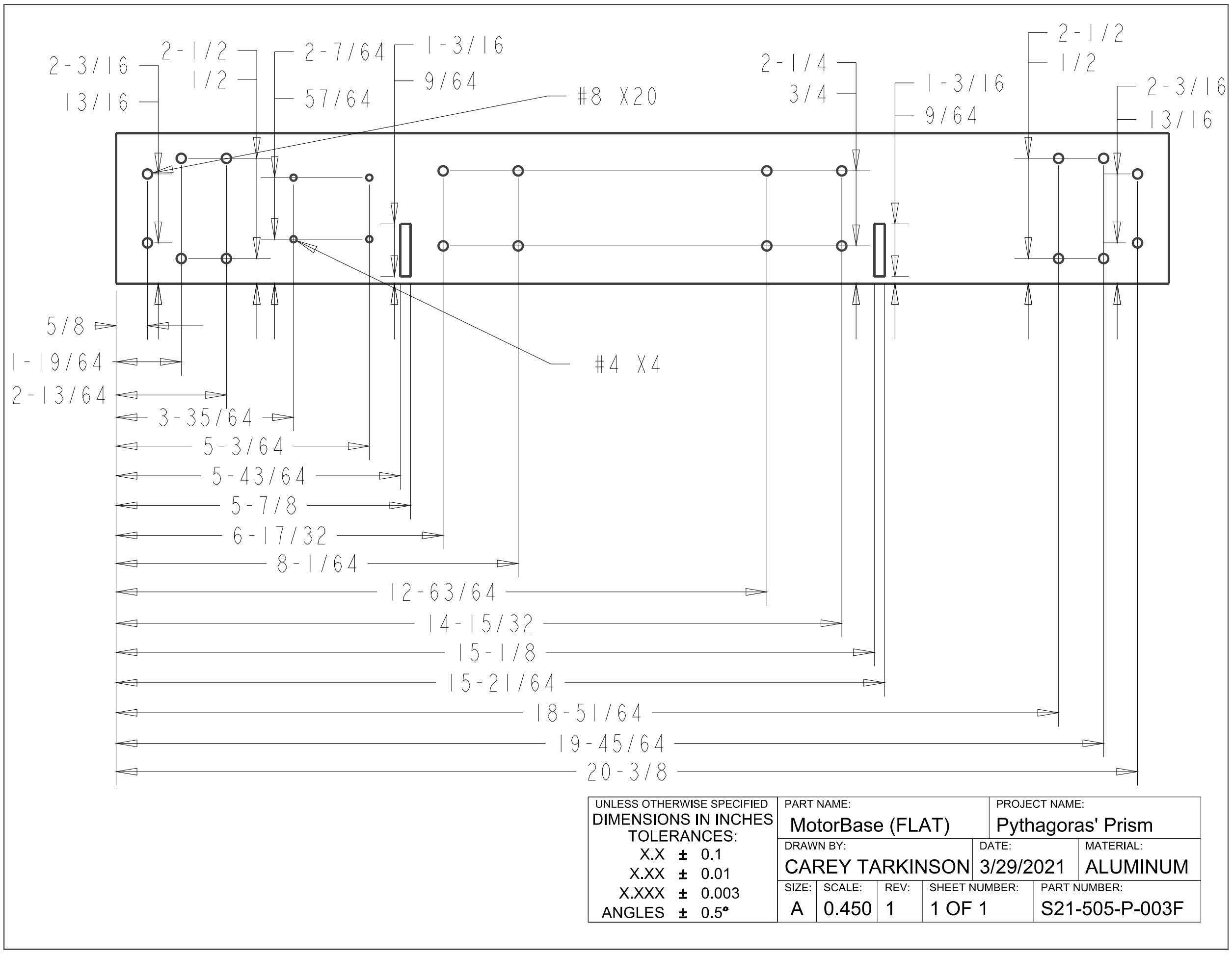


Figure 12 Engineering drawing of motorized base with dimensions for machining.

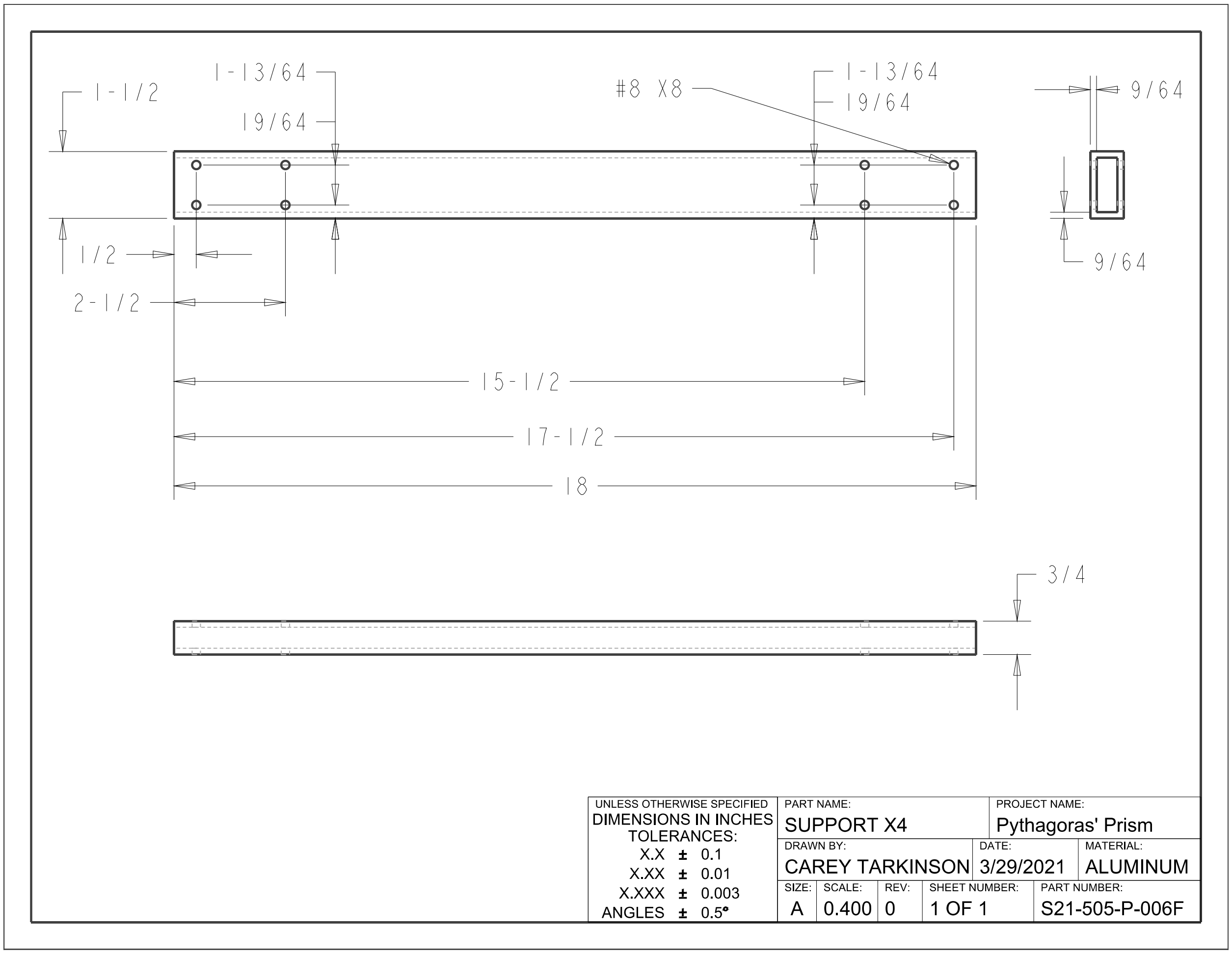


Figure 13 Engineering drawing of support tubes with dimensions for machining.

Appendix F: Calculations

$$\tau = \mathrm{F} \times r$$

$F = 18.14369kg$

$r = 25mm$

$\tau = 453.9225\ kg * mm$

For our robot we utilized the torque equation to determine which motor to purchase

Appendix G: Risk Assessment

FAMU-FSU College of Engineering
Project Hazard Assessment Policy and Procedures

INTRODUCTION

University laboratories are not without safety hazards. Those circumstances or conditions that might go wrong must be predicted and reasonable control methods must be determined to prevent incident and injury. The FAMU-FSU College of Engineering is committed to achieving and maintaining safety in all levels of work activities.

PROJECT HAZARD ASSESSMENT POLICY

Principal investigator (PI)/instructor are responsible and accountable for safety in the research and teaching laboratory. Prior to starting an experiment, laboratory workers must conduct a project hazard assessment (PHA) to identify health, environmental and property hazards and the proper control methods to eliminate, reduce or control those hazards. PI/instructor must review, approve, and sign the written PHA and provide the identified hazard control measures. PI/instructor continually monitor projects to ensure proper controls and safety measures are available, implemented, and followed. PI/instructor are required to reevaluate a project anytime there is a change in scope or scale of a project and at least annually after the initial review.

PROJECT HAZARD ASSESSMENT PROCEDURES

It is FAMU-FSU College of Engineering policy to implement followings:

1. Laboratory workers (i.e., graduate students, undergraduate students, postdoctoral, volunteers, etc.) performing a research in FAMU-FSU College of Engineering are required to conduct PHA prior to commencement of an experiment or any project change in order to identify existing or potential hazards and to determine proper measures to control those hazards.
2. PI/instructor must review, approve and sign the written PHA.
3. PI/instructor must ensure all the control methods identified in PHA are available and implemented in the laboratory.
4. In the event laboratory personnel are not following the safety precautions, PI/instructor must take firm actions (e.g., stop the work, set a meeting to discuss potential hazards and consequences, ask personnel to review the safety rules, etc.) to clarify the safety expectations.

5. PI/instructor must document all the incidents/accidents happened in the laboratory along with the PHA document to ensure that PHA is reviewed/modified to prevent reoccurrence. In the event of PHA modification a revision number should be given to the PHA, so project members know the latest PHA revision they should follow.
6. PI/instructor must ensure that those findings in PHA are communicated with other students working in the same laboratory (affected users).
7. PI/instructor must ensure that approved methods and precautions are being followed by:
    a. Performing periodic laboratory visits to prevent the development of unsafe practice.
    b. Quick reviewing of the safety rules and precautions in the laboratory members meetings.
    c. Assigning a safety representative to assist in implementing the expectations.
    d. Etc.
8. A copy of this PHA must be kept in a binder inside the laboratory or PI/instructor's office (if experiment steps are confidential).

Table 13 *Hazard Assessment Contact Info*

Project Hazard Assessment Worksheet				
PI/instructor: Dr. McConomy	Phone #: 850-410-6624	Dept.: Mechanical Engineering	Start Date: 12/01/2020	Revision number: 1
Project: Robotic Pole Inspection Collar			Location(s): Tallahassee, FL	
Team member(s): Angelo Mainolfi			Phone #: (954) 288-6076	Email: adm16j@my.fsu.edu

John Flournoy Carey Tarkinson Mathew Crespo	(850) 464-1283 (561) 268-6666 (786) 909-1059	Jwf16@my.fsu.edu cet17@my.fsu.edu mc16av@my.fsu.edu

Table 14 *Hazard Assessment Steps*

Experiment Steps	**Location**	**Person assigned**	**Identify hazards or potential failure points**	**Control method**	**PPE**	**List proper method of hazardous waste disposal, if any.**	**Residual Risk**	**Specific rules based on the residual risk**
Prototyping	-EE/ME lab	John Flournoy	-Electrocution from wiring -3D printer thermal runaway	-Avoid working with live wires	Non-conductive gloves	N/A	HAZARD: High CONSEQ: High Residual: Low/Med	-Always use non-conductive gloves when working with high voltage.

	-Advanced Mechatronics Lab -FSU Innovation Hub			-Supervise print and check for thermal runaway settings	-Fire Extinguisher			- Use caution when handling a 3D printer
Assembly	-College of Engineering -Advanced Mechatronics Lab	Carey Tarkinson	-Potential Cuts or Bruising -Solder Inhalation and burns	-Carefully lay out equipment -Use tools in designed manner	-Safety Goggles -Gloves -Air Filtration Systems	-Soldering iron will be cleaned after use -Wait until Cooled to dispose of	HAZARD: Medium CONSEQ: Medium Residual: Low	-Treat wounds promptly and sanitarily

			-Electrical Shock			components		
Testing	-ME Senior Design Lab	Angelo Mainolfi	-Physical strain from lifting pole specimen - Splinter from wood	-Have multiple team members assist the erecting of pole specimen	-Closed toed shoes -Gloves	N/A	HAZARD: High CONSEQ: Medium Residual: Medium	-Proper lifting posture will be used -Sanding sharp wood edges
Operation	-College of Engineering	Mathew Crespo	-Robot falling from pole -Wire short circuiting and	-Maintain proper distancing	-Closed toed shoes -Gloves -Helmet	N/A	HAZARD: High CONSEQ: Medium	-Obtain proper training before usage

	-Utility poles in use by FPL		shocking linemen -Battery malfunction and explosion	while in use -Maintain supervision			Residual: Low	-Always abide by safety standards and regulations
Transportation	-College of Engineering -Florida Power and light offices	John Flournoy	-Weight of robot can cause injury if not carried properly	-Proper carried training	-Moving dolly or cart	N/A	HAZARD: Med CONSEQ: Med	-Only transport once proper training is completed
							Residual: Low Med	

Principal investigator(s)/ instructor PHA: I have reviewed and approved the PHA worksheet.

Name	**Signature**	**Date**	**Name**	**Signature**	**Date**

Team members: I certify that I have reviewed the PHA worksheet, am aware of the hazards, and will ensure the control measures are followed.

Name	Signature	Date	Name	Signature	Date
Angelo Mainolfi	Angelo Mainolfi	12/04/2020	Carey Tarkinson	Carey Tarkinson	12/04/2020
John Flournoy	John Flournoy	12/04/2020	Mathew Crespo	Mathew Crespo	12/04/2020

DEFINITIONS:

Hazard: Any situation, object, or behavior that exists, or that can potentially cause ill health, injury, loss or property damage e.g., electricity, chemicals, biohazard materials, sharp objects, noise, wet floor, etc. OSHA defines hazards as “*any source of potential damage, harm or adverse health effects on something or someone".* A list of hazard types and examples are provided in appendix A.

Hazard control: Hazard control refers to workplace measures to eliminate/minimize adverse health effects, injury, loss, and property damage. Hazard control practices are often categorized into following three groups (priority as listed):

1. **Engineering control:** physical modifications to a process, equipment, or installation of a barrier into a system to minimize worker exposure to a hazard. Examples are ventilation (fume hood, biological safety cabinet), containment (glove box, sealed containers, barriers), substitution/elimination

(consider less hazardous alternative materials), process controls (safety valves, gauges, temperature sensor, regulators, alarms, monitors, electrical grounding and bonding), etc.

2. **Administrative control:** changes in work procedures to reduce exposure and mitigate hazards. Examples are reducing scale of process (micro-scale experiments), reducing time of personal exposure to process, providing training on proper techniques, writing safety policies, supervision, requesting experts to perform the task, etc.
3. **Personal protective equipment (PPE):** equipment worn to minimize exposure to hazards. Examples are gloves, safety glasses, goggles, steel toe shoes, earplugs or muffs, hard hats, respirators, vests, full body suits, laboratory coats, etc.

Team member(s): Everyone who works on the project (i.e., grads, undergrads, postdocs, etc.). The primary contact must be listed first and provide phone number and email for contact.

Safety representative: Each laboratory is encouraged to have a safety representative, preferably a graduate student, in order to facilitate the implementation of the safety expectations in the laboratory. Duties include (but are not limited to):

- Act as a point of contact between the laboratory members and the college safety committee members.
- Ensure laboratory members are following the safety rules.
- Conduct periodic safety inspection of the laboratory.
- Schedule laboratory clean up dates with the laboratory members.
- Request for hazardous waste pick up.

Residual risk: Residual Risk Assessment Matrix are used to determine project's risk level. The hazard assessment matrix (table 1) and the residual risk assessment matrix (table2) are used to identify the residual risk category.

The instructions to use hazard assessment matrix (table 1) are listed below:

1. Define the workers familiarity level to perform the task and the complexity of the task.
2. Find the value associated with familiarity/complexity (1 – 5) and enter value next to: HAZARD on the PHA worksheet.

Table 15 *Hazard Assessment Matrix*

		Complexity		
		Simple	Moderate	Difficult
	Very Familiar	1	2	3

Familiarity Level	Somewhat Familiar	2	3	4
	Unfamiliar	3	4	5

The instructions to use residual risk assessment matrix (table 2) are listed below:

1. Identify the row associated with the familiarity/complexity value (1 – 5).
2. Identify the consequences and enter value next to: CONSEQ on the PHA worksheet. Consequences are determined by defining what would happen in a worst-case scenario if controls fail.
    a. Negligible: minor injury resulting in basic first aid treatment that can be provided on site.
    b. Minor: minor injury resulting in advanced first aid treatment administered by a physician.
    c. Moderate: injuries that require treatment above first aid but do not require hospitalization.
    d. Significant: severe injuries requiring hospitalization.
    e. Severe: death or permanent disability.
3. Find the residual risk value associated with assessed hazard/consequences: Low –Low Med – Med– Med High – High.
4. Enter value next to: RESIDUAL on the PHA worksheet.

Table 16 *Residual Risk Assessment Matrix*

Assessed Hazard Level	**Consequences**				
	Negligible	Minor	Moderate	Significant	Severe
5	Low Med	Medium	Med High	High	High
4	Low	Low Med	Medium	Med High	High
3	Low	Low Med	Medium	Med High	Med High
2	Low	Low Med	Low Med	Medium	Medium
1	Low	Low	Low Med	Low Med	Medium

Specific rules for each category of the residual risk:

Low:

- Safety controls are planned by both the worker and supervisor.
- Proceed with supervisor authorization.

Low Med:

- Safety controls are planned by both the worker and supervisor.
- A second worker must be in place before work can proceed (buddy system).
- Proceed with supervisor authorization.

Med:

- After approval by the PI, a copy must be sent to the Safety Committee.
- A written Project Hazard Control is required and must be approved by the PI before proceeding. A copy must be sent to the Safety Committee.
- A second worker must be in place before work can proceed (buddy system).
- Limit the number of authorized workers in the hazard area.

Med High:

- After approval by the PI, the Safety Committee and/or EHS must review and approve the completed PHA.
- A written Project Hazard Control is required and must be approved by the PI and the Safety Committee before proceeding.
- Two qualified workers must be in place before work can proceed.
- Limit the number of authorized workers in the hazard area.

High:

- The activity will not be performed. The activity must be redesigned to fall in a lower hazard category.

Table 17 *Hazard Types and Examples*

Types of Hazard	**Example**
Physical hazards	Wet floors, loose electrical cables objects protruding in walkways or doorways
Ergonomic hazards	Lifting heavy objects Stretching the body Twisting the body

	Poor desk seating
Psychological hazards	Heights, loud sounds, tunnels, bright lights
Environmental hazards	Room temperature, ventilation contaminated air, photocopiers, some office plants acids
Hazardous substances	Alkalis solvents
Biological hazards	Hepatitis B, new strain influenza
Radiation hazards	Electric welding flashes Sunburn
Chemical hazards	Effects on central nervous system, lungs, digestive system, circulatory system, skin, reproductive system. Short term (acute) effects such as burns, rashes, irritation, feeling unwell, coma and death. Long term (chronic) effects such as mutagenic (affects cell structure), carcinogenic (cancer), teratogenic (reproductive effect), dermatitis of the skin, and occupational asthma and lung damage.
Noise	High levels of industrial noise will cause irritation in the short term, and industrial deafness in the long term.
Temperature	Personal comfort is best between temperatures of 16°C and 30°C, better between 21°C and 26°C. Working outside these temperature ranges: may lead to becoming chilled, even hypothermia (deep body cooling) in the colder temperatures, and may lead to dehydration, cramps, heat exhaustion, and hyperthermia (heat stroke) in the warmer temperatures.

Being struck by	This hazard could be a projectile, moving object or material. The health effect could be lacerations, bruising, breaks, eye injuries, and possibly death.
Crushed by	A typical example of this hazard is tractor rollover. Death is usually the result
Entangled by	Becoming entangled in machinery. Effects could be crushing, lacerations, bruising, breaks amputation and death.
High energy sources	Explosions, high pressure gases, liquids and dusts, fires, electricity and sources such as lasers can all have serious effects on the body, even death.
Vibration	Vibration can affect the human body in the hand arm with `white-finger' or Raynaud's Syndrome, and the whole body with motion sickness, giddiness, damage to bones and audits, blood pressure and nervous system problems.
Slips, trips and falls	A very common workplace hazard from tripping on floors, falling off structures or downstairs, and slipping on spills.
Radiation	Radiation can have serious health effects. Skin cancer, other cancers, sterility, birth deformities, blood changes, skin burns, and eye damage are examples.
Physical	Excessive effort, poor posture and repetition can all lead to muscular pain, tendon damage and deterioration to bones and related structures
Psychological	Stress, anxiety, tiredness, poor concentration, headaches, back pain and heart disease can be the health effects

Biological	More common in the health, food and agricultural industries. Effects such as infectious disease, rashes and allergic response.

Project Hazard Control- For Projects with Medium and Higher Risks

Table 18 *Hazard Control Summary*

Name of Project: FPL Robotic Pole Inspection Collar		**Date of submission: 12/4/2020**
Team member	**Phone number**	**E-Mail**
Angelo Mainolfi	**954-288-6076**	**Adm16j@my.fsu.edu**
Mathew Crespo	**786-909-1059**	**Mc16av@my.fsu.edu**
John Flournoy	**850-464-1283**	**Jwf16@my.fsu.edu**
Carey Tarkinson	**561-268-6666**	**Cet17@my.fsu.edu**
Faculty mentor	**Phone number**	**E-Mail**
Dr. Shayne McConomy	**(850) 410-6624**	**Smcconomy@eng.famu.fsu.edu**
Prototyping -Main Risks: Electrocution and thermal runaway -Precautions: Wear proper PPE and stay vigilant **Assembly** -Main Risks: Cuts, Bruising, Burns, Solder Inhalation, and Electrical Shock		

-Precautions: Use tools only in intended fashion, do not work with live wires, wear PPE, organize workspace to avoid mishaps, and dispose of waste properly.

Testing

-Main Risks: Physical Strain, Cuts and Splinters

-Precautions: Keep knees bent when lifting, cover hands when dealing with untreated wood

Operation

-Main Risks: Bruising, Brain Damage, Cuts, Electrical Shock, and Splinters

-Precautions: Wear proper protective equipment and follow all standards and regulations

Transportation

-Main Risks: Muscle Strain, Bruising, and Cuts

-Precautions: Carry robot weight properly at all times

Thinking about the accidents that have occurred or that you have identified as a risk, describe emergency response procedures to use.

Risk

- Physical strain – call lab manager and local physician if necessary
- Fire- Call fire department if fire is beyond control of a fire extinguisher
- Electrocution- Call 911 if dire

For other severe injuries 911 will be contacted.

List emergency response contact information:

- Call 911 for injuries, fires or other emergency situations
- Call your department representative to report a facility concern

Name	Phone number	Faculty or another COE emergency contact	Phone number
City of Tallahassee Emergency Services	**911**	**Dr. Shayne McConomy**	**(850) 410-6624**
		Dr. Johnathan Clark	**(850) 410-6608**
Safety review signatures			
Team member	Date	Faculty mentor	Date
Angelo Mainolfi	**12/1/2020**	**Dr. Johnathan Clark**	**12/1/2020**
John Flournoy	**12/1/2020**	**Dr. Shayne McConomy**	**12/1/2020**
Carey Tarkinson	**12/1/2020**		
Mathew Crespo	**12/1/2020**		

Report all accidents and near misses to the faculty mentor.