Update Report

Team 10

Development of a Tree Climbing Snake Robot

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ABSTRACT

The removal of trees is a hazardous task for those involved. Human interaction can be reduced by using a remotely-operated tree-cutting robot. Due to time constraints, this project will focus solely on the climbing aspect, leaving the cutting and removal of trees a future project for another senior design team. To climb trees a snake inspired model was chosen, since it has high mobility and required little interaction when setting up. Research has shown the existence of other snake robots as well as climbing robots that can be used for inspiration, demonstrating the feasibility of this project. A three degree of freedom, modular design was developed by the team. This was done to decouple the main aspects of climbing helically, which are: clamping, helix generation and driving. The prototype is undergoing testing and refinement. Early testing showed promise, with the wooden prototype holding 11lbs of distributed weight with 18lbs of force being used to tension the cable mechanism. The team expects the helical generation and motorized driving tests to be successful.

1. Problem Statement

When trees become unstable, they pose a great threat to their surroundings. If these trees are not removed, they can cause significant damage. Removal of trees should be done by professionals. Chopping down trees requires specialized skills, precision and a good understanding of safety measures. However even with professional training, tree removing is still considered a hazardous occupation. The main reason being that, when 'topping' a tree, the workers need to climb to the top of the tree to chop it into smaller small segments as they climb down. There are on average 200 [1] tree-related fatal injuries every year in the United States. The Senior Design Team would like to minimize this number by substituting the climbing workers with a robotic snake.

2. Project Definition

2.1 Need Statement

The original scope was to create a robotic snake that will climb a tree in a helical manner and cut it down via the method of 'topping.' However, due to time constraints and limited resources the scope was altered to focus on the climbing aspect of the robot. The revised scope is to create a robotic snake that will climb a branchless tree, in a helical manner, carrying a payload for future iterations. The reason for the tree being branchless is because branch avoidance is not part of the focus for this year's project. The payload will represent the cutting mechanism that will be implemented in the future. Even with a revised scope, the goal statement remained the same.

2.2 Goal Statement

The goal is to build a remotely operated snake-like-robot that will safely climb trees.

2.3 Objectives

The team has created some objectives with the new scope in mind. The robotic snake must be able to ascend and descend a tree while satisfying the following:

- Tree must have a diameter of at least 10 inches
- Climb in a helical manner
- Ascend with a speed of at least 1 foot per minute (60ft per hour)
- Hold a payload of at least 10 pounds
- Have a camera attached to provide feedback

These are the objectives that the team believes they can accomplish by the end of the semester. Originally the team stated that the payload would be 20lb. Since it is a concentrated payload, the team believes that 10lb is achievable. If the team has enough time, they would like to increase the payload to 20lb. Team 10 hopes to achieve this stretch goal by implementing a deployable stability arm. The arm would act as a kickstand to be dug into the tree, hence providing more support.

3. Testing

There are many tests that need to be performed to gauge the design's success. The tests will assess each individual component's reliability. The finalized test will consist of all the components working together to have the robot remotely climb the tree with a 10lb payload.

The first test that needs to be performed is to test the strength and reliability of the clamping mechanism. For this test it was calculated that a minimum of 9 modules were necessary to wrap around a 10in diameter tree. This was based on the constraint that the total length of the snake must be at least 1.5 times the circumference. This test needs to be performed with a wooden prototype or the final aluminum design. The prototype will be useful for this test as it is testing how much force is necessary to keep the robot clamped to the tree while applying a distributed load and an isolated load. Originally this test was performed with a cardboard prototype but, because of the softness of the material, it was unable to withstand the tension from the cable-mechanism without ripping. This test needs to be performed on a smooth surface, such as a cardboard cylinder – which has a low coefficient of friction – and once more on a tree's surface –

which contains a higher coefficient of friction. The main reason for choosing to test on both surfaces is because if it works on the smooth surface then it should work on the rough surface much more reliably. For this test there are no motors implanted, instead the cable is tensioned by hand to test the amount of clamping the modules can handle with an increasing payload and clamping force. It is also pre-tensioned with a spring to show that it can hold on the tree without anyone handling the prototype. Early testing showed promise, with the wooden prototype holding 11lbs of concentrated weight with 18lbs of force being used to tension the wire mechanism.

After the clamping is tested and relationships are made and compared with analytical results, the helix generation needs to be tested. This test uses the same number of modules as the clamping test and is also actuated by hand, instead of a motor. The first step is to apply tension to the cable controlling the helix and see that it is successful on a rigid body – such as wood, rather than a compliant material such as cardboard which was previously tested. Once proven successful, it needs to be tested at different pitch angles with a constant weight applied to the head of the robot. This will provide information on how much tensile force is needed to lift and hold a weight against gravity. These results will be compared to the theoretical calculations. This test also shows the max angle the weight can be held at before it slips (the no-slip condition), which will be important for speed of the climbing action. This test also needs to be tested on a smooth and rough surface as did the clamping test. The last step is to test the snake robot when it is clamped around a structure using a pretension spring to hold it in place. With this, it will be demonstrated how the two cables interact and if each can be activated individually or if the two motions need to happen simultaneously.

The next test can be performed parallel to the clamping and helix testing. It will consist of prepping the wheel motion with the use of motors where a test apparatus is to be made consisting of one motor, a wheel, a microcontroller, a motor driver, and a breadboard. This test needs to be done since no one in the team is familiar with implementation of electronics. One of the electronics aspect of this project are the wheels for the robot need to be able to rotate clockwise and counter clockwise since it can climb up and down the tree. Another is that the motor for the clamping and helix should be able to turn both directions – to tighten and loosen – as well as be able to hold its position. For the clamping and helix generation a stepper motor will be used because of it high torque properties and a DC motor will be used for the wheels because of their high angular velocity.

The goal of this test is to be able to actuate the motors properly, both stepper and DC. The motor does not need to be the one being used for the robot, instead this is just to get familiar with coding the microcontroller for each type of motor. It is also to learn how to control the motion and activation of the motor with 2 switches. One will control direction of rotation while the other controls the state of the motor – on or off. After this is achieved, a wireless connection can replace the switches to allow for remote controllability.

Once the wheels are successfully actuated, the next few tests can be performed. The simplified test will be for the wheel motion on the ground. This test needs only a couple modules. It is to observe the ability of the wheels moving and hauling a train of modules behind it. If successful, the next step will be placing the robot on the tree and clamping it using a spring. Clamping the robot with the spring allows the forces to be contained within the system, rather than having a person providing the force and having to walk with the robot, eliminating sources of error. Once the robot is clamped, the wheels will be tested for the ability to pull and move itself on a cylindrical surface. Just as the other few tests this one should be performed on a smooth and rough surface for completeness. Weights will be added to the body to test the rotational ability of the wheels as the load being pulled increases. The final test can be performed after all the prior test are performed.

4. Progress Made

Team 10 spent most of their time prototyping and testing in the fall semester. Figure 1 shows the “funky” prototype that the team built. The purpose of this prototype was to obtain a general idea of the motions of a robotic snake. The prototype had alternating joints between each module. One joint allowed the robot to bend up and down, while the other joint allowed the robot to bend left and right. Thus giving the robot 2 degrees of freedom (DOF). The team figured out that the triangular cut out of the modules limited the range of motion between the modules.

Figure 1. "Funky" prototype.

The team then created their first prototype using square cut outs for the modules, to improve the flexibility between each module. A strap ran through the inside of the prototype and was used to generate the clamping force. Below, Figure 2 shows an image of the first prototype successfully clamping on the tree. Although the wheels are not attached in the image, one can see the modules in contact with the tree are not perpendicular. The wheels must be perpendicular to the tree in order to maximize the clamping ability of the robot. Therefore the team decided to add a third DOF, which would allow the modules to twist. This modification can be seen on the second prototype in Figure 3.

Figure 2. First working prototype.

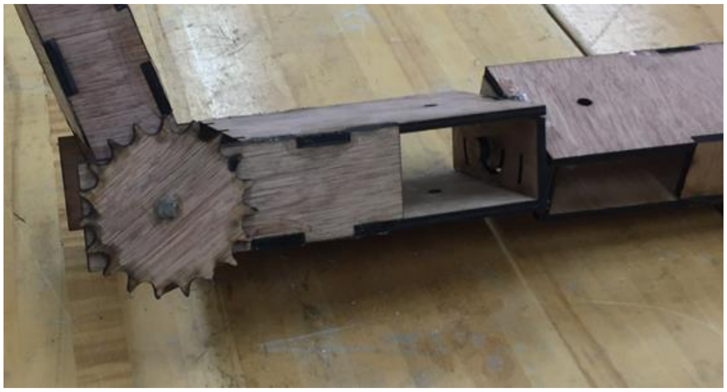


Figure 3. Second working prototype. It now includes a third DOF for rotation between modules.

After testing the second prototype, the team noticed that the modules were too long. A third prototype was created with all three DOFs combined at the joints, in the hopes of solving this problem. Figure 4 shows the third prototype successfully curling up, improving the robot's ability to wrap around the tree. After showcasing this prototype to the sponsor, some slight modifications were made to establish the final design for the body of the robot. Figure 5 shows a wooden model of the robot successfully clamping on the tree.

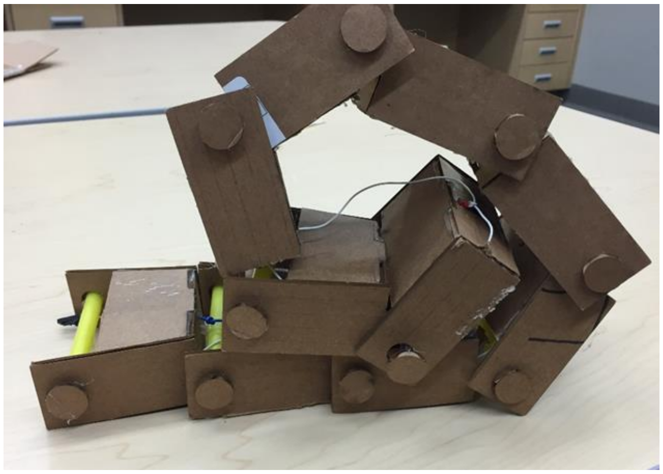


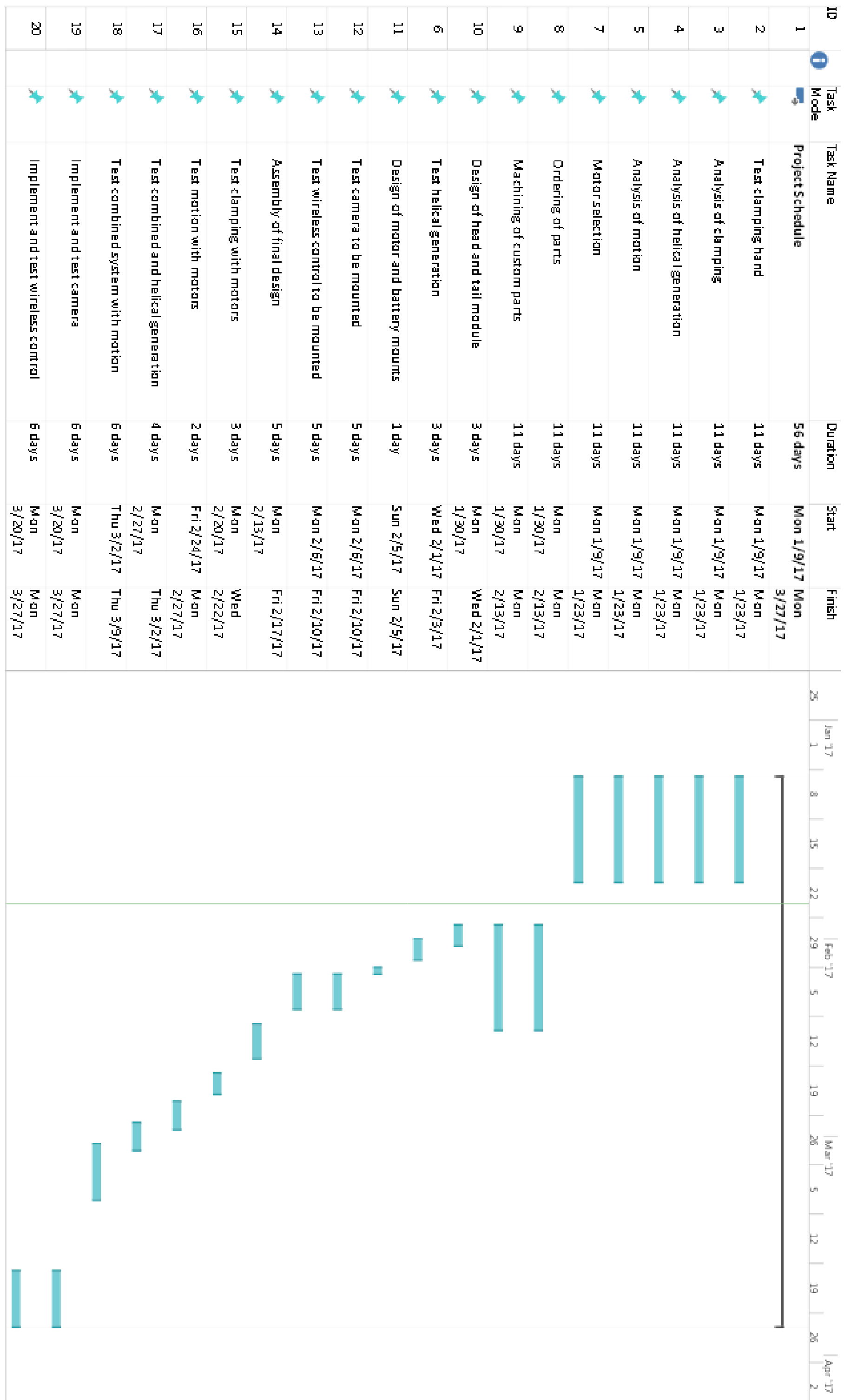
Figure 4. Third prototype. No robust testing was done as it was mostly made for showcasing.

Figure 5. Final design. No major modifications are foreseen as testing goes on.

5. Challenges / Constraints

There are and will be many challenges as progress is made. A few of the challenges that have been encountered already is the limited literature to use as reference. Currently in research there are only a few groups that build and analyze snake like robots. Many of these robots do not climb trees and the few that do climb by rolling their linkages up the tree or pole. This is less like snake like climbing and more like vertically rolling up the tree. The other setback when it comes to analyzing and picking apart these papers for useful information is the actuators that are used for the modules. Most of the links have motors that rotate the module in the necessary 3 degrees of freedom. These research projects are not limited by their budget, as significantly as a senior design project, and the robots tend to be very expensive as a result. The solution to the budget limit for this project was to use a single actuator to clamp the robot instead of multiple motors at each module. The idea to use a cable-mechanism, to clamp the body, is a unique and innovative idea that hasn't yet been attempted. There has been one paper found on helical climbing [2] but the information is still very limited and much of the work still needs to be developed. As progress continues many unforeseen issues will arise. This is being compensated for by allowing some cushion time in the schedule. This is done by being flexible and decoupling as many of the problems as possible, so that components can be worked on in parallel. Lastly it will be time consuming to learn and put together the electrical components as no one in the team specializes in electronics. But these issues will be solved as they arise through perseverance and team work.

6. Deliverables and Schedule



ID	Task Name	Duration	Start	Finish
1	Project Schedule	56 days	Mon 1/9/17	Mon 3/27/17
2	Test clamping hand	11 days	Mon 1/9/17	Mon 1/23/17
3	Analysis of clamping	11 days	Mon 1/9/17	Mon 1/23/17
4	Analysis of helical generation	11 days	Mon 1/9/17	Mon 1/23/17
5	Analysis of motion	11 days	Mon 1/9/17	Mon 1/23/17
7	Motor selection	11 days	Mon 1/9/17	Mon 1/23/17
8	Ordering of parts	11 days	Mon 1/30/17	Mon 2/13/17
9	Machining of custom parts	11 days	Mon 1/30/17	Mon 2/13/17
10	Design of head and tail module	3 days	Mon 1/30/17	Wed 2/1/17
6	Test helical generation	3 days	Wed 2/1/17	Fri 2/3/17
11	Design of motor and battery mounts	1 day	Sun 2/5/17	Sun 2/5/17
12	Test camera to be mounted	5 days	Mon 2/6/17	Fri 2/10/17
13	Test wireless control to be mounted	5 days	Mon 2/6/17	Fri 2/10/17
14	Assembly of final design	5 days	Mon 2/13/17	Fri 2/17/17
15	Test clamping with motors	3 days	Mon 2/20/17	Wed 2/22/17
16	Test motion with motors	2 days	Fri 2/24/17	Mon 2/27/17
17	Test combined and helical generation	4 days	Mon 2/27/17	Thu 3/2/17
18	Test combined system with motion	6 days	Thu 3/2/17	Thu 3/9/17
19	Implement and test camera	6 days	Mon 3/20/17	Mon 3/27/17
20	Implement and test wireless control	6 days	Mon 3/20/17	Mon 3/27/17

Figure 6. Gantt chart.

The Gantt chart above shows the work needed to be done in order to accomplish the task of developing a tree climbing snake robot. In order to understand the plan to be executed it is important to know the objectives of the project. The tree climbing snake robot being developed must be able to ascend and descend a 10 in. tree while doing the following: climb in a helical path, travel at a speed of 1ft/min, hold a concentrated load of at least 10 lb., and attach a camera to provide feedback to the operator.

In order to ascend and descend a tree of 10 in diameter at a climbing speed of 1ft/min while maintaining a helical path, one must consider the necessary clamping force, helical generation forces, and forces to produce motion. This task will be broken down into two main components: analysis and testing. Analysis will be done to relate the motor requirement to the clamping force, helical force requirement, and speed requirements. Analysis will first be done by decoupling each of the individual tasks: clamping, helical generation, and motion.

Clamping force analysis will be done to find the relationship between the motor and the normal force keeping the robotic snake adhered to the tree. Taken into consideration will be the helical pitch and orientation of each module of the snake as this will change the direction of the force being applied by each module and thus where the resultant force is located. The net effect will be to produce a moment about the world x-axis and y-axis (along the tree's circumference). Depending on the location of the center of mass this will cause the robotic snake to rotate toward (providing stability) or away from the tree (decreasing stability).

The helical generation will consider the kinematic analysis necessary to provide a climbing speed of 1ft/min. The pitch angle will cause a variation in required tangential speed (along the circumference of the tree) that will affect motor selection as well as the clamping force required. Also, one must consider the required force to generate a helix while overcoming the resistive forces of anisotropic friction along the tree. The motion analysis will consider the forces required to achieve the speed found from analysis of the helical generation. This will be used to compute the motor required to achieve the desired task.

Analysis will be used to compute motor selection as well as design the head and tail modules that will act as the driving modules. Once these components are specified and ordered, there will be a span of two weeks in which testing may continue. Testing will consist of helical generation in order to verify the analysis done as well as to determine the optimal pitch for stability. Motion testing will be done to determine the optimal pitch to obtain the required speed of 1ft/min.

During this two week span the wireless communication and camera will also be tested in order to prepare for when the final design is fully assembled. This will facilitate their implementation into the final product.

Once all the parts are available assembly of the final design will begin. This will require numerous man hours, however it is essential to complete the task in a timely fashion. In order to accomplish this feat, the team must develop a plan for assembly prior to the parts arrival. After the final design is fully assembled testing will commence in a decoupled fashion. The clamping will first be tested with motors followed by the helical generation with clamping, and finally the combined system will be tested and optimized. Results from analysis will be verified and altered if need be at this point. The final step will be to implement the wireless controller as well as the camera. If time permits an additional optimization phase will commence with the remaining time.

While above specifies the plan to accomplish these goals it does not directly state its connection to the Gantt chart nor the major milestones. The Gantt chart will be used as a tool to measure the efficiency of the group in accomplishing tasks. Included in the Gantt chart is a two-week margin of error that will allow for some possible unforeseen challenges. With that being said, it is imperative to accomplish each task described above in a timely fashion. By doing so, the task of developing a tree climbing snake robot should be possible.

The major milestones will be assembly of the final design as well as testing the final design with the constraints listed above as measurements of success. The milestones are therefore ordering of parts, motor selection, testing of wireless communication and camera, implementation of motors in clamping, helical generation, and motion. While these are major milestones, given the constraint of a shorter semester each of the tasks will be treated as a milestone (to the team). This is due to the fact that not achieving the tasks in the time set by the Gantt chart will significantly increase the chance of the team not fulfilling the goal statement.

7. Conclusion

A tree cutting robot is to be designed with the goal of improving the safety associated with removing trees. The team has developed several prototypes and began testing on the components that will be implemented on the project. Early design showed promise with regard to helical generation, clamping ability and motion of the wheels. These, however, have not been tested all together on a heavier prototype. Motor selection and attachment is an important step that can set back the project and possibly lead to failure, so special attention is given to this process.

The team is confident in the current design and will continue forward with testing until proof of concept – the achievement of the goal statement – is obtained. Currently, a wooden prototype is undergoing testing and refinement. This is done before the assembly and assessment of the finalized aluminum prototype. The team is pressured by time, but believes that within the scope of three months, that a finalized product can be achieved. Since the early clamping tests showed promise, the team expects the helical generation and motorized driving tests to be successful as well.

References

[1] US Bureau of Labor Statistics.

[2] Pongsakorn Polchankajorn, Thavida Maneewarn,, 2011, “Development of a Helical Climbing Modular Snake Robot”, IEEE Transactions on Robotics and Automation 11: 790-801.

Team 10 - Biography

The group leader of this project is Jorge Campa. He is pursuing a career in robotics and control systems. In his time at Florida State University he has been a teaching assistant in Dynamic Systems I and II. He has also served as an undergraduate research assistant at the High Performance Materials Institute.

Justin Morales is currently finishing his Bachelor’s degree in mechanical engineering and plans on pursing his Master’s after he graduates. He is the WebWizard for his team and is responsible for design and updating the senior design website.

Michelle Maggiore is serving as the lead Mechanical Engineer. She is interested in pursuing the field of robotics and is currently working at Florida State University’s STRIDE lab.

Esteban Szalay is a Senior Mechanical Engineer student at Florida State University. By having an interest in teaching and robotics, he aids with the calculations for the design, as well as serving as a source of information whenever possible.