Design Document

Team 10

Development of a Helical Path 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 snake-like remotely-operated tree-cutting robot. For this year's project, the team focused on the climbing aspect. This operations manual provides the user with a complete guide to the project; defining each component, assembly as well as instructions for operating and maintaining the robot.

1. Introduction

Fallen trees cause over $1,000,000,000 worth of damage every year. To prevent damage from trees, professionals are hired to remove them before the trees fall on property. But even with all their technical skill and equipment, there are still over 200 tree related deaths yearly. There is a need for the removal of trees, and it is not safe to do so. The aim of this project is to build a robot that will be remotely controlled that would aid in the safe removal of trees. A snake-like robot that climbs in a helical manner was chosen by the sponsor and verified to be a valid solution by the team. However, removal of trees is a complex process as it requires the climbing of the tree first. Due to time constraints, this is the sole focus of the team. A payload will represent a cutting arm, which would be replaced in future iterations. Thus the goal for this project becomes:

"To build a remotely operated snake-like robot that will safely climb trees in a helical path, carrying a payload for future iterations."

2. Functional Analysis

Due to the complexity of the project, the team separated the functionality into sub-systems of motions. To simplify the analysis, the forces were broken down as a combination of 2D problems that, when put together, they add up to complex 3D motion. The two main aspects that were deemed necessary to create the desired helical motion were a clamping (Figure 1), which would keep the snake robot bound to the tree's surface, and a differential (Figure 2), which forces a helix by pivoting about an instant center.

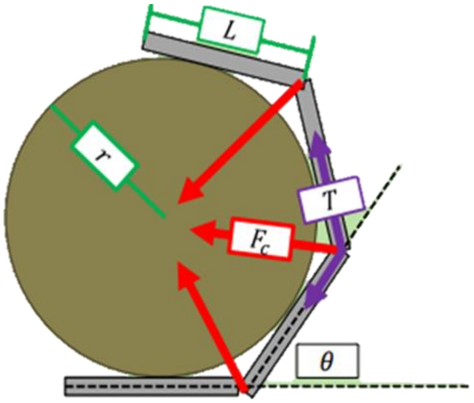

Figure 1. Clamping Analysis.

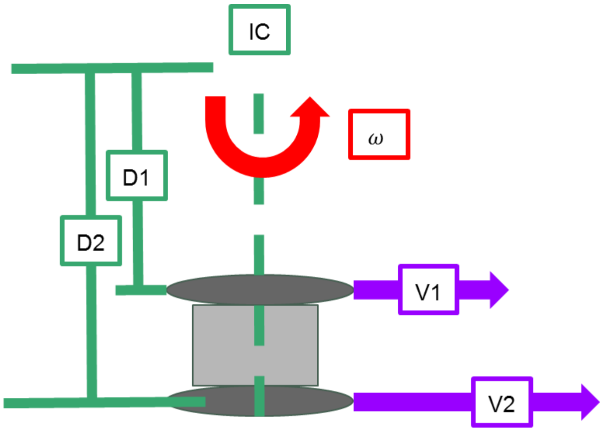

Figure 2. Differential / Helix Analysis.

The clamping works via a tensioned cable, which shortens in length and curls the snake into a circular shape. Once this circular shape is acquired, it can be molded into a helix by adding an additional force. Originally, the team had planned to use another cable, tensioned in a perpendicular direction to that of the clamping. However, it was unfeasible as too many issues arose with that design. As a workaround, the team looked into a differential, which operates by having two wheels rotate at different velocities, causing the object to rotate. This rotating motion showed promise in early testing and the team decided to carry onwards with it. As a benefit, this differential can be equalized to operate as a forward driving motion once in a helical configuration.

3. Project Specification

3.1 Motors

The selected motors were purchased from BaneBots. Due to the torque requirements for motion, the same motor was used with two different gearboxes. The motor chosen was the RS550-12V and the two gearboxes were the from the P60 series for RS500 motors, with a 326:1 and a 672:1 gear ratio. The resulting specifications can be seen in Table 1.

Table 1. Motor Specifications.

Element	No-load Speed (rpm)	Stall Torque (lb-ft)	Weight (lbs)
Motor (output shaft)	19,300	0.36	0.48
+Gearbox (326:1)	59.2	117.4	1.2
+Gearbox (672:1)	28.7	242.1	1.2

Table 2 has a list of specifications needed to make sure the different components are compatible, as well as making sure nothing exceeds the specified power limits.

Table 2. Electronics Specifications.

Component	**Teensy**	**Wixel**	**Motor Driver**	**5V step-down voltage regulator**	**12V step-down voltage regulator**	**Camera**	**Monitor**	**Transmitter**
Current draw (mA)	60.2	30	17A continuous	600	2.2A	150	250	200
V in (V)	3.6-6.0	2.7-6.5	6.5-30	7-42	13.5-36	12	12	12
Voltage signal (V)	0-3.3, 5v tolerant	0-3.3	1.8,3.3,5v compatible	N/A	N/A	N/A	N/A	N/A
Max output current pin (mA)	10	4	N/A	600	2.2A	N/A	N/A	N/A

3.2 Teensy &Wixel

The Teensy is a microcontroller that sends a Pulse Width Modulation (PWM), which directs signals to the motor drivers to run the motors at specific speeds. The Teensy has multiple digital output pins, which allow each motor driver to be connected to a separate pin to be commanded individually. The Teensy can only handle outputting a max current of 10mA from each pin. By having a separate pin connected to each element on the motor driver, the Teensy is protected from burning out. The Teensy is directly connected to a Wixel to receive serial information that determines the action that the robot should be performing. The Wixel pair is crucial to wireless communication with the Teensy. Two Wixel boards communicate wirelessly with each other, over radio signals. This data is then sent to the Teensy through the serial port, which is then translated into a PWM.

3.3 Motor Driver

The motor driver that was chosen was the Pololu G2 High-Power Motor Driver 18v17. It is a high power, high current motor driver. It can handle a max current of 30A and a continuous current of 17A without a heat sink. The operating current that is intended for our motors is a max of 11A, therefore these motor drivers are more than capable of handling the current. They are very compact, 1.3x0.8 inches, which is needed for the limited space available in the body module.

3.4 Voltage Regulators

Voltage regulators control the input voltage to a value specified by the type of regulator. For the robot, 2 different regulators are needed: a 5V step-down regulator and 12V step-down regulator. The 5V regulator limits the voltage for the Teensy and Wixel. Anything higher than 6.0V could cause permanent damage by shorting out the boards. The 12V step-down regulator is to adjust the power to both, the camera and monitor system, for the same reason. The output current of each regulator is important as well since both the Teensy and Wixel will be powered from the same regulator. The combined consumed current must not exceed the output current of the regulator to prevent damage to the component. In both applications, neither setup exceeds the output current of the regulator.

3.5 Camera system

The camera system sends real-time video wirelessly to the monitor using a transmitter. This gives the user feedback, allowing them to see where the robot is going, while making the control of the snake easier. The camera system is a simple plug-and-play device, meaning set-up is minimal. The set-up should include mounting the camera to the front of the snake and connecting the batteries and transmitter to it. On the receiving side, the user will have a monitor connected to the corresponding receiver and another battery powering the system.

4. Assembly

A full assembly of the robotic snake can be seen on Figure 3. This figure depicts the team's robot assembled with a pattern of clamping and motor modules. The clamping module (Figure 4) also doubles as a body module, when the motor is removed from the assembly. The motor module (Figure 5) is located right after the clamping module to provide extra traction for the wheels.

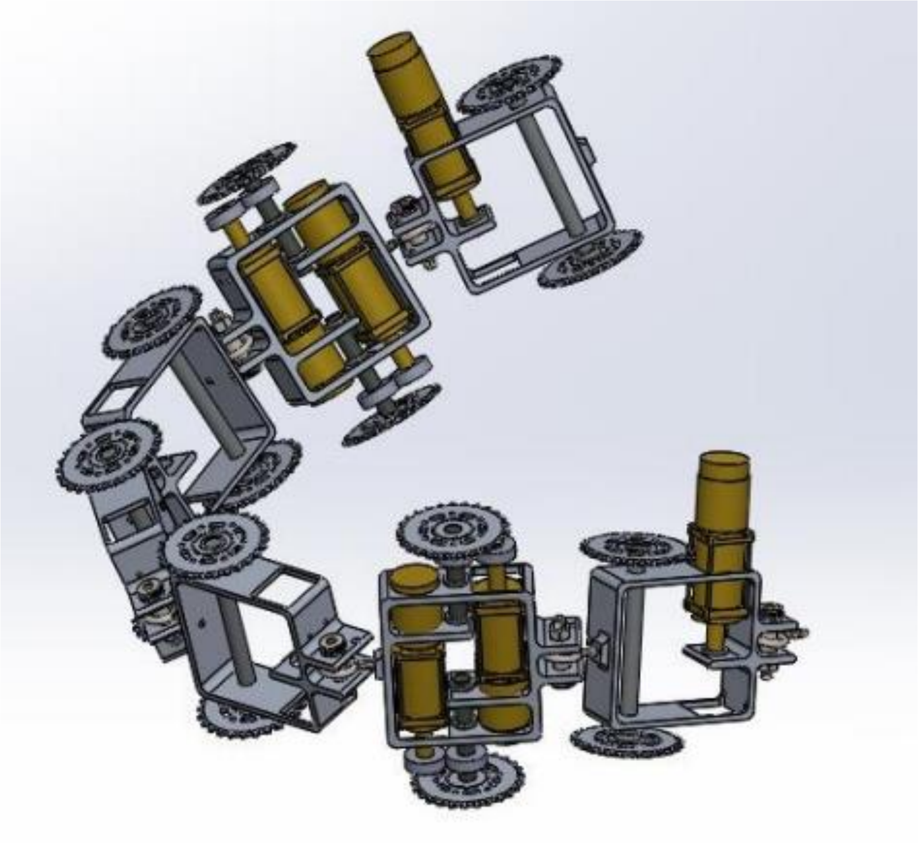

Figure 3. Robotic Snake Full Assembly.

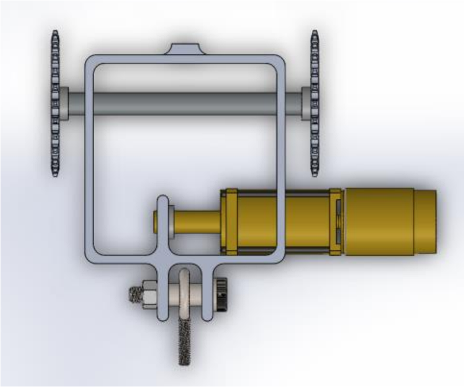

Figure 4. Clamping Module Assembly.

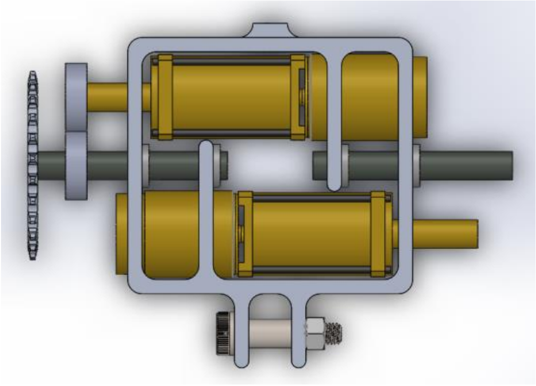

Figure 5. Motor Module Assembly.

To assemble the body module, a bushing will be press fit into the inner wall to provide the clamping motor with extra support. A bushing is also press fit onto the wheel allowing them to rotate freely on the shaft, which is press fit across the module. Since the wheels are free spinning, they are restricted from sliding by the c-clips. The motor is held in place by M3 screws, and the eye hook is detained by the shoulder bolt and nut. The body module is identical, except for the bushing in the wall, and the motor.

To assemble the motor module, bushings are press fit into each wall to provide a smooth surface for the shaft to rotate on. These shafts have a gear and the wheel press fit onto them, and are prevented from sliding by c-clips close to the inner walls. The gearbox shafts also have a gear press fit onto them, which will rotate the gear on the shaft. They are held in place by M3 screws. Again, the eye hook is placed between the ‘bunny ears’ with a shoulder bolt and a nut.

The finalized design for testing will consist of an arrangement of seven modules in the following order:

$$CLAMPING - MOTOR - BODY - BODY* - BODY - MOTOR - CLAMPING$$

Where the motor module provides the driving, the clamping motor helps the robot stay on the tree and the body module is passive. The middle body module will have to be machined to allow placement of electronic components by removing the inner wall. It is important for the design that the motor module have two or more modules around it so that traction is maximized when driving the wheels.

5. Operation Instructions

The snake is operated using a controller made of 6 buttons attached to a Wixel board. A Wixel is a wireless communication hub that make the snake operable using a wireless controller. The signals are sent via radio to a corresponding Wixel located on the robot. The on-board (on the robot) Wixel is directly attached to the microcontroller using a physical wire linked to a serial port. The off-board (off the robot) Wixel is able to send 6 commands to the on-board Wixel using the 6 buttons that are attached. The organization of the button placement can be seen in Figure 6. The forward button moves the all the wheels at the same rate in the clockwise direction. The backwards button moves all the wheels at the same rate in the counter-clockwise direction. The left button rotates the wheels on the right side of the robot faster (causing the snake to turn left) and the right button moves the wheels on the left side faster (causing the snake to turn right). Not pressing a button will cause the snake to stop and hold its place. The other two buttons control the clamping and unclamping. The A button clamps the robot while the B button unclamps the robot.

5.1 Button Functionality

Upon startup the default command for the robot is Pause, meaning it does not move; it holds its position. When the forward button is pressed the robot will slowly accelerate to top speed and hold that speed. When the button is released the robot will begin to decelerate to a stop. The backwards button operates the robot in the same fashion but in the reverse direction. The left and right veering can only be operated after the direction of the snake is set by the forward/backward button. The left turn will increase the robot pitch angle on the tree and the right turn will decrease the pitch angle. The clamping and unclamping buttons work in a similar way, although the speed for clamping and unclamping is much slower than the wheel speed and do not need to go through an acceleration process. Sufficient time should be given between commands to let the motors come to a complete stop before changing directions. Sudden change in directions could cause current spikes which will damage the motor controllers.

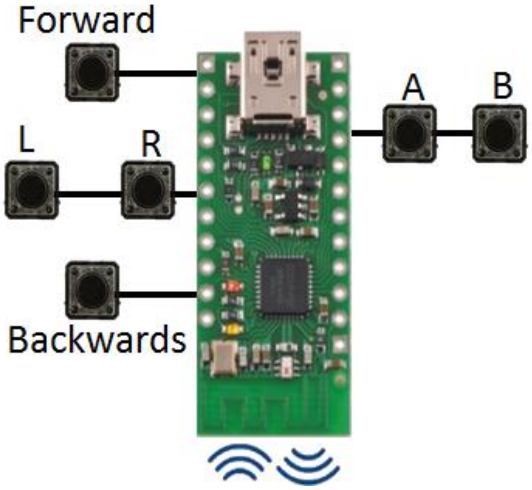

Figure 6. Wixel Button Schematic.

6. Troubleshooting

One of the biggest potential problems is for the snake robot to get stuck on the tree. Several factors can cause this problem to occur. Such as the batteries running out of power, motor failures or communication errors. These issues can all be prevented by ensuring all the components are fully functional before operating the robot. If the robot does get stuck on the tree, the user will need to manually unclamp it. Another potential issue is if the robot begins to slip down the tree. In order to prevent this, the user must ensure that the robot has sufficient clamping force before attempting to drive the robot.

7. Regular Maintenance

After every climb with the snake robot, the user must check the battery levels. In the current iteration, it is recommended that the user replaces the battery after every use to maximize climbing time. The batteries are rechargeable, therefore the user simply needs to replace the low battery with one that is fully charged. The user should also check the robot to make sure none of the components have been damaged. If a component is severely damaged, it should be replaced before attempting to use the robot again. After several uses, the aluminum spiked wheels will become dull and need to be replaced to maximize the efficiency of climbing.

8. Spare Parts / Inventory Requirements

The tree climbing snake robot contains both electrical and mechanical parts that all work in unison to complete helical climbing up a tree. It is therefore important to understand and have spare parts to ensure that the robot may be used effectively after multiple uses. The spare parts that should be kept at a short distance during operation may be seen below. The inventory may be found in the appendix.

1. Batteries
2. Eye-hooks
3. Wheels
4. E-Clips
5. Shafts

9. Conclusion

The design of a snake robot is complex. The team simplified the kinematic model to analyze and obtain estimates for the force requirements for motion. Using this, the team selected motors and designed around them. Motor and other electrical components were specified and assembled in the prototype. Operating instructions are defined so that the user is aware of the different functionalities of the design. The team hopes that this design is iterated and perfected upon, to the point where the robot can be rented out for a reasonable price to civilians hoping to remove trees in a safe manner.

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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.

Appendix I – Exploded Views

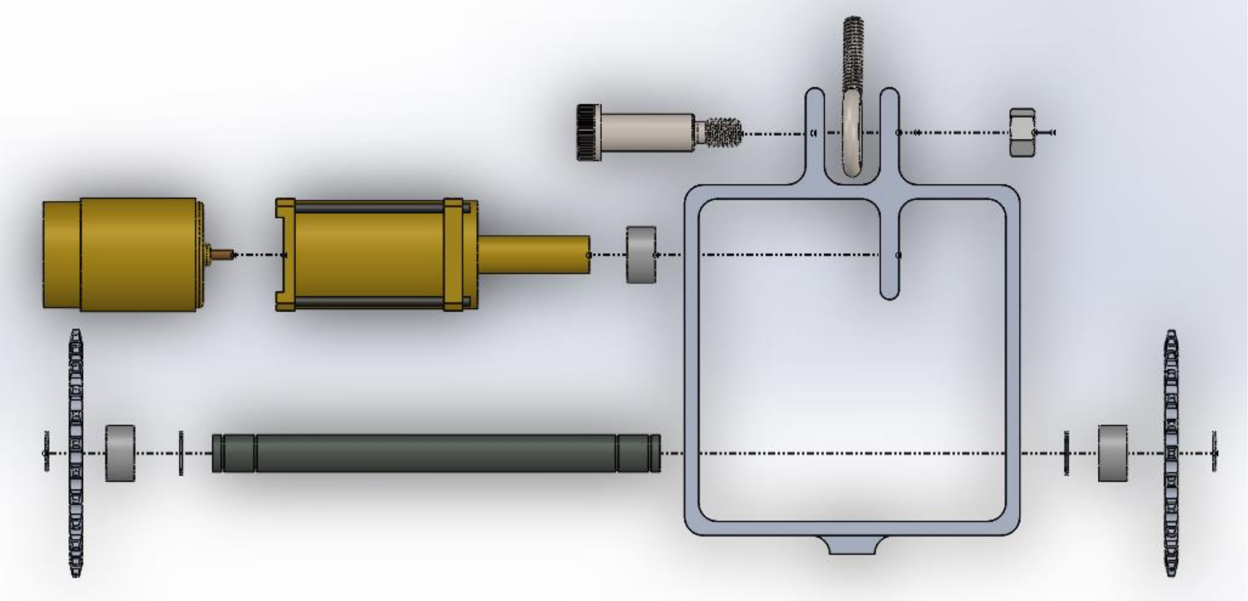

Figure 7. Exploded Clamping Module.

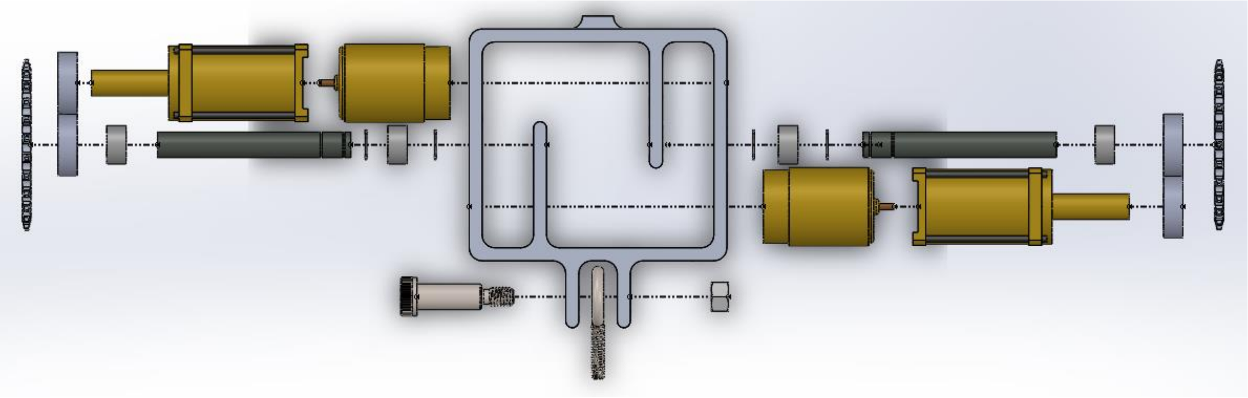

Figure 8. Exploded Motor Module.