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 remotely-operated tree-cutting robot. A snake inspired model was chosen since it has high mobility and required little interaction during set up. Research has shown the existence of other snake robots that can be used for inspiration, also demonstrating the feasibility of this project. The research includes other types of robots to be able to compare and examine them with the snake-like model. After deciding for the snake robot the team focused the development on a gripping mechanism, a driving mechanism, the environmental awareness and the power consumption of the robot. This report details the designing process for the manufacturing, reliability and costs of the snake 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. Design for Manufacturing

The first step is to assemble each module individually. There are 2 different types of modules, the clamping/body and motor module. In the current iteration, there are 5 clamping/body modules and 2 motor modules. They each mainly consist of a shaft, wheels and motors, if applicable. Once each module has been assembled, they need to be connected to one another using the eyebolts. After the modules have been fully connected, the electronics will be added and wired. The final step is to make sure all the components are fully functional.

The team expects the assembly to take around 12 hours to complete. The team believes that the assembly of the mechanical components will take 7 hours and the implementation of the electronics will take 5 hours. The majority of time for the mechanical components comes from laser cutting the body, for testing a wooden iteration. It is important to note that the electronics need special care when wiring and soldering to the boards.

The team simplified the overall design because of time and money constraints. However, it can be improved if the design had more components. For example, the clamping is generated by a single metal cable running through the entire snake. If each module had its own clamping motor, it would increase the efficiency and amount of clamping. Also, in the current iteration only two modules have wheels that being actuated, the rest are passive wheels. The motion and the helix generation would be improved if each module had actuated wheels.

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.

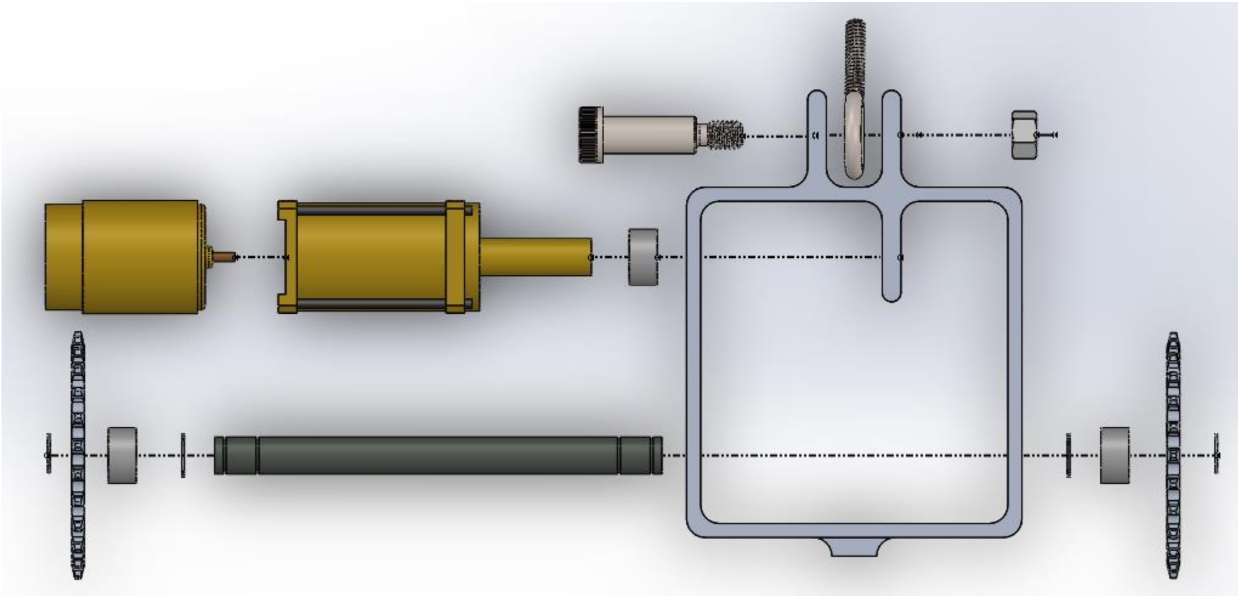

Figure 1. Exploded Clamping Module.

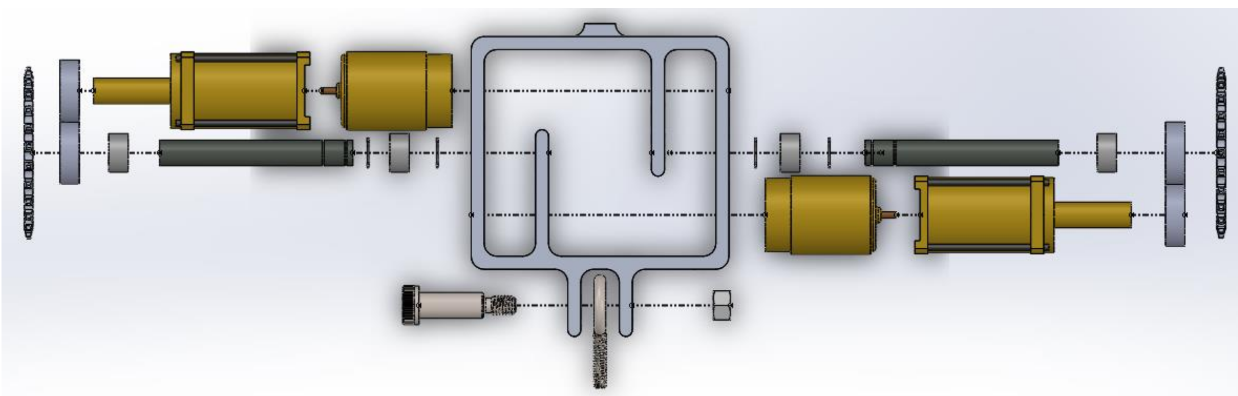

Figure 2. Exploded Motor Module.

Both, Figure 1 and Figure 2, show an exploded view of each module. 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.

3. Design for Reliability

The team's design is not meant to be fragile. Careful consideration was made when choosing components and their interaction with other parts of the design. To better understand how the components behave, a Failure Mode Effects Analysis (FMEA) was developed. Table 1 explains in detail what aspects of the design were scrutinized, while Table 2 inspects each component under these parameters.

It was found that some critical components, such as the motor and the electric boards are the most hazardous during failure. This means that additional measures must be taken to ensure that they will not break during operation. Other components such as the wireless communication are also critical, but the prevention method is simply replacing it with a better option, something that the team's time and budget won't allow.

Table 1. FMEA Ratings and Explanation

Functional Parameter	**Failure Mode**	**Impact on Overall Product**	**Cause**	**Method of Detection**	**Likelihood of Occurrence**
Rating / Description	How the component fails	1- Minimal Impact, product can still work for short periods of time 3- Moderate. Damage to product is inevitable. Some damage to environment may be present. 5- Catastrophic. Product fails entirely and lives are at stake.	What causes the component failure (i.e. Overloading, Fatigue, etc.)	1- Easy to detect before /during operation 3- Detection is difficult, but achievable through specialized equipment 5- Impossible to detect before/ during operation	1- Unlikely 3- Very likely 5- Almost guaranteed

Table 2. FMEA for Snake Robot.

Functional Parameter	**Failure Mode**	**Impact on Overall Product**	**Cause**	**Method of Detection**	**Likelihood of Occurrence**
Wheels	Wheel deforms or teeth become dull	2. Snake becomes stranded / mobility severely reduced	Wear, fatigue, concentrated stress	2. Inspecting component pre-operation	1. Stress concentration should not reach the point to where this occurs
Wheel Axle	Wheel axle bends or breaks	2. Snake becomes stranded / mobility severely reduced	Wear, fatigue, concentrated stress	2. Inspecting component pre-operation	1. Stress concentration should not reach the point to where this occurs
C-Clips	C-clips bend or break	3. Wheel / axle are free to slide, causing wheel / axle failure	Wear, fatigue, concentrated stress	2. Inspecting component pre-operation	1. Stress concentration should not reach the point to where this occurs
Motor (clamping and driving)	Motor overheats or a gear set breaks	4. Motor catches on fire. 2. Motor stops working	Damaged wire, extended runtime, power spike	5. Impossible to detect until it occurs	2. Careful management of power is necessary, fail-safes can be employed to prevent
Clamping Wire	Clamping wire snaps	3. Robot becomes loose and falls	Wear, fatigue, concentrated stress	2. Inspecting and testing component pre-operation	2. Stress concentration should not reach the point to where this occurs
Main Body	Material deforms or breaks	2-4. Failure to other systems (clamping, wheel axle, etc.)	Wear, fatigue, concentrated stress	2. Inspecting component pre-operation	1. Stress concentration should not reach the point to where this occurs
Wireless Communication	Damage on transceiver / interference	3. Snake is unable to be operated 2. Camera stops broadcasting video	Water damage, short circuit, environmental noise	2. Visual indicator for current functionality (LED)	3. Interference is likely to occur with the branches as robot climbs trees
Power Supply	Battery overheats, runs out of power, leaks	4. Snake robot ignites 2. Snake robot shuts down	Damaged wire, extended runtime, water damage	5. Impossible to detect until it occurs	3. Careful management of power is necessary. Fail-safes can be employed to prevent
Camera	Camera breaks / stops broadcasting video	2. Operator loses visibility	Damaged wire, water damage	2. Visual indicator for current functionality (LED)	2. Careful operation of robot should prevent direct damage to camera
Micro-controller / Motor Driver	Component breaks or catches on fire	3. Snake robot's motors are inoperable.	Current spike, water damage	5. Impossible to detect until it occurs.	2. Careful management of power is necessary. Fail-safes can be employed to prevent

4. Design for Economics

4.1 Cost of Design

The total resulting cost of the project was $3,750. The budget allocation of the project may be seen in Figure 3. The cost was mostly due to machining cost and electronics. Therefore, it is important to analyze these aspects of the project when attempting to reduce cost.

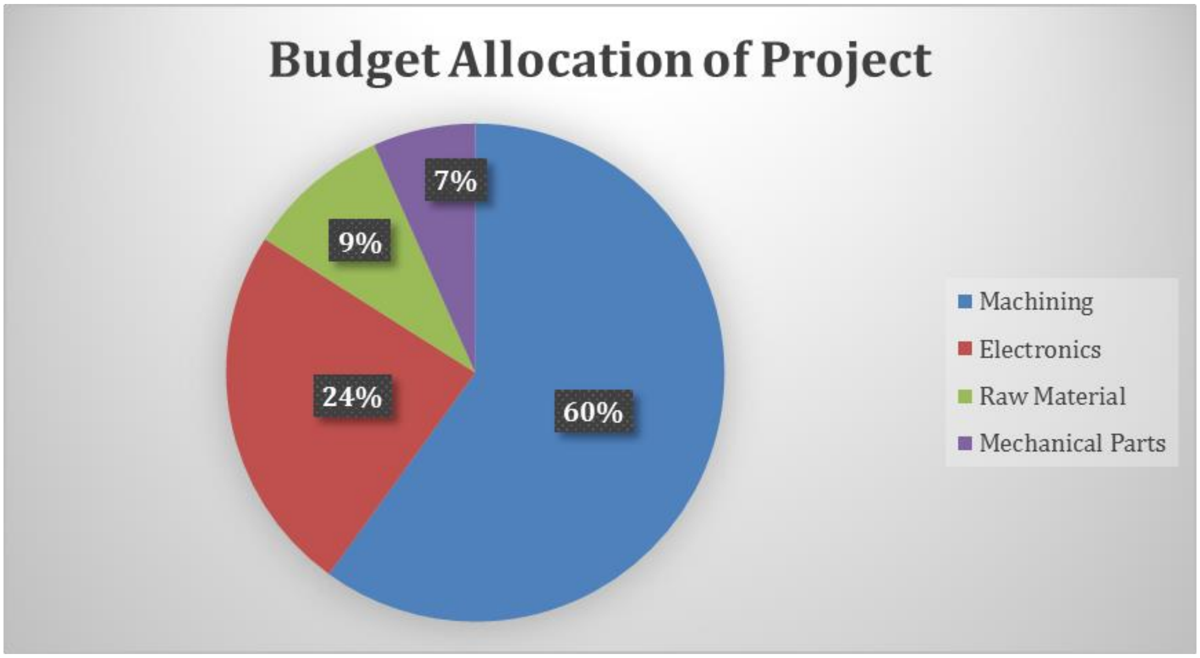

Figure 3. Budget Allocation of the Project.

Machining cost is by far the largest contributor to expenses. The main factors associated with increased cost in machining are the time it takes to cut and the desired time it takes to return. The time it takes to cut may be further broken down into complexity and size of the part. Table 3 shows the quote generated from velocity works where the machining was outsourced.

Table 3. Quote from Velocity Works Machine Shop.

Description	**Price/Unit (dollars/unit)**	**Number of Units**	**Extension (dollars)**
Motor Modules	363	2	726
Clamping Modules	238.35	5	1191.75
Total	-	7	1917.75

As seen in the table above, a total of 7 modules were produced, resulting in a cost of $1917.75. The table also shows that the motor modules cost more per unit to machine. This was due to the difference in complexity of the cuts for the parts. However, this is necessary as each module serves a specific function. Another distinction between the clamping and motor modules is the amount of material in each part. The clamping and motor modules correspond to a volume of 6.5 in^3 and 7.8 in^3, respectively. This also contributes to longer time for machining, increasing the cost associated with it.

What is not shown in the table are two important factors when minimizing cost. First, the time asked to have the parts ready was expedited to two weeks. This, based on discussion with Velocity Machine Works, was by far the largest contributor to cost. It is therefore highly recommended for future engineers working on this project to obtain a quote for a standard return rate for the parts to be machined, which will undoubtedly lower machining cost. Secondly, the senior design team attempted to reduce cost by simplifying the models to be machined. This attempt took a week of reworking the CAD models. This reduced cost by nearly $250. This contributed to a reduction in cost of 13%, which shows that complexity is not nearly as large a factor as the time desired to have the parts returned by. Based on the approach taken by the senior design team to mitigate cost, the best approach would be to allow for standard machining time. It would also be recommended to obtain quotes from various machine shops in order to find the minimum price for machining in the case for standard machining time.

The second largest contributor to the overall budget was found to be electronics. An allocation of the cost due to electronics may be seen in Figure 4.

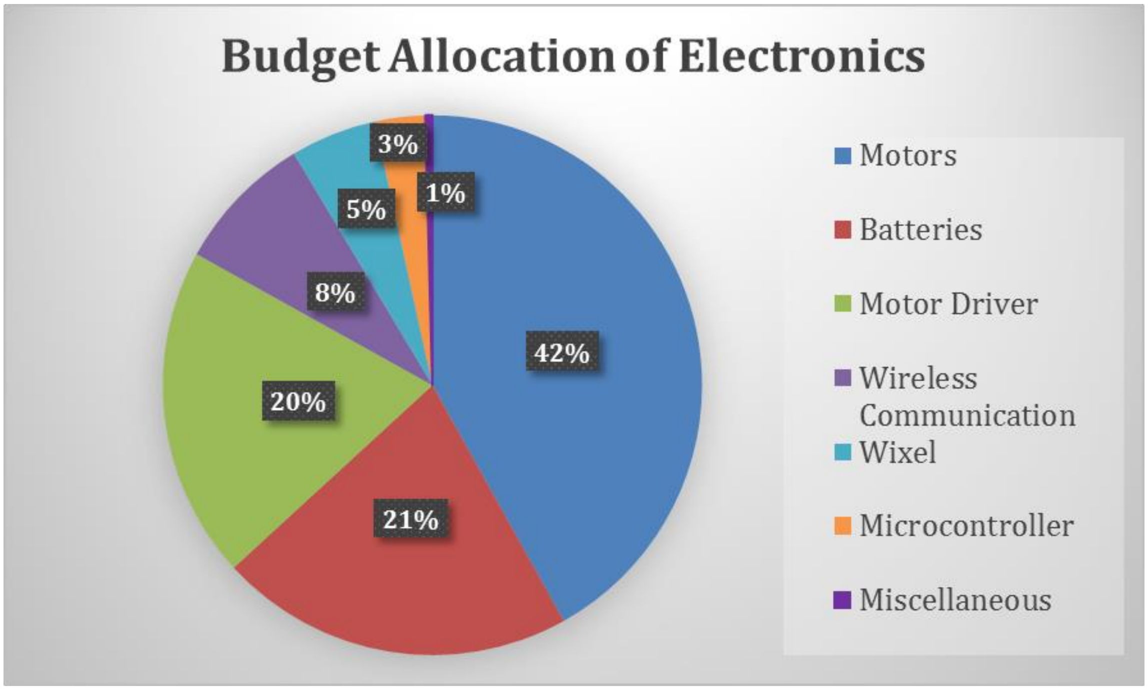

Figure 4. Budget Allocation of Electronics.

The largest contributor to the cost of electronics were the motors, while the second and third largest contributor were batteries and motor drivers. These were so large because the batteries and motor driver's specifications are a dependent of the motors selected. This was due to the large stall current, 80 A, of the motors selected for the project. This lead to the necessity of motor drivers that could handle larger amounts of current. This is in order to protect the micro controller and prevent hazards such as overheating electrical components. The batteries were also a function of the motors, and this was also due to current draw. This may be seen in Equation 1 below.

$$t_{run} = \frac{Q}{i} \tag{1}$$

Where t_{run} is the run time, Q is the capacity of the battery, and i is the current being drawn from the battery to supply the electronic components. Since the motor draws a large amount of current, a large capacity battery was needed to have a long enough run time for the snake robot. Furthermore, the size of the modules had to be redefined with motor size. As a result, the price of machining increased. It is therefore recommended that future engineers optimize the torque requirements. This will lead to less cost in the following: motors, batteries, motor controllers, and machining. Since each of these contribute to a large majority of the budget, it may be declared that in order to reduce cost, one must change the motors of the system.

It is worth mentioning that the initial budget was of $2,000 and the total cost was of $3,750. If machine costs were excluded (using the engineering school's machine shop), the total cost would drop to approximately 1,800$, which is still within budget. The team's sponsor was well aware of the increase in cost due to machining and was willing to support the team's expenses.

4.2 Comparison to Competition

To put into perspective how expensive the team's design is, a comparison to other products in the market can be made. It's important to note that this topic is mostly research based, so very little was found on the cost of production for snake like robots in general. To show a rough comparison of the cost of our design to another helically climbing snake-like robot, a few key components were totaled and compared. The components that were chosen were based on what was able to be found from the paper "Development of a Helical Climbing Modular Snake Robot". The components mentioned in the paper included motors for the joints and wheels, the microcontroller and the material used to make the body. The total cost of these components for them was approximately $1,900 while the same components for our design totaled to about $700. This is a significant $1,200 reduction from the competitor design, which equates to about a 60% difference of cost.

Figure 5 shows a bar graph comparing the cost of some of the components used in the "Development of the Helical Climbing Snake Robot" paper and the same components that were used for the team's design.

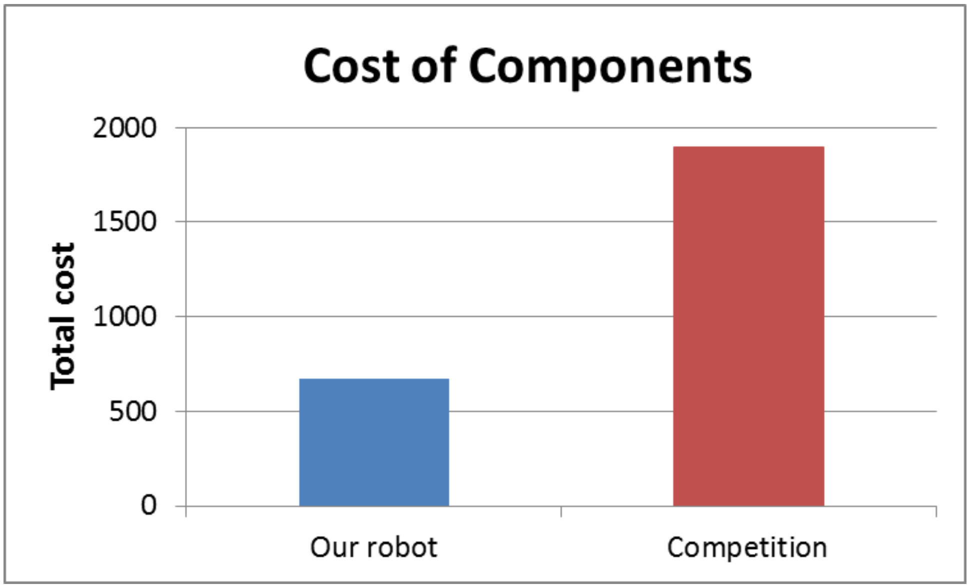

Figure 5. Bar Graph for Cost of Certain Components.

5. 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. Through careful consideration of components and their interactions, a prototype was designed, which would cost approximately $3,800. Though over the original budget, the team was successful in making a cheap, but effective alternative to what is currently available. 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.