Alternatives Report

Tree-Climbing Robot Group

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I. Working Criteria Overview

The problem statement put in place by the group was to minimize the injury and fatality rate of loggers across the world due to inclement weather, structurally unsound tress, and bulky equipment to trim the trees. The success of the project is based on how well the group can construct a robot that can climb a 13-inch diameter tree, which is to be simulated by a telephone pole. Additionally, the robot needs to be able to avoid branches, which are to be simulated by dowels attached to the telephone pole. Due to constraints on the project, working criteria were assembled to give the group a direction when researching solutions to this problem. These criteria include vertical speed, capability to carry extra weight, reversibility, maneuverability, simplicity, and capacity to vary the diameter the robot needs to climb. The importance of each working criteria is shown in Figure 1.

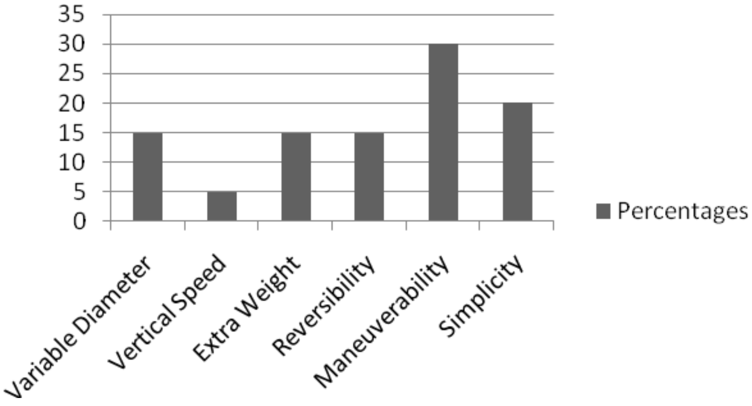

Figure 1: Group rankings of the working criteria

The above criteria pertain mainly to the locomotion of the robot. One choice implemented a design already proven in the field. This concept involves two sets of clamps on the north and south ends of the robot. The bottom clamp would remain attached to the tree while the northern clamp would detach and extend upward. The northern clamp would then grip the tree, and in a similar fashion, the robot would pull up the southern end, and repeat this process in between branches, proceeding up the tree in a caterpillar-like motion. The second concept came through a brainstorming session. It involves one clamp that would remain attached to the tree at all times. This clamp would then be embedded with multi-directional wheels of some sort, and the rotation of the wheels would propel the robot up the tree. Also, the wheels would have to be able to maneuver around branches.

II. Locomotion

The next step called for a decision amongst the group regarding the style of robot which would be most feasible to solve the problem at hand. On an individual basis, so as to eliminate biases toward certain robots styles, the group met and ranked each robot in the previous working criteria on a scale of 1-10. Then, a simple addition of each ranking multiplied by the weighted percentage was obtained. This design matrix is presented in Fig. 2.

	Variable Diameter (15%)	Vertical Speed (5%)	Extra Weight (15%)	Reversibility (15%)	Maneuverability (30%)	Simplicity (20%)	Totals
Caterpillar	7	3	6	8	7	5	640
Wheels	7	8	5	8	7	3	610

Figure 2: Design matrix of locomotion concepts

As demonstrated by the results of the test matrix, the caterpillar robot had a slight edge over the robot using wheels as its main form of locomotion.

A. Justification

The results for the variable diameter criteria were tied due to each style using a clamp as its method of clinging to the tree. The justification is that a clamp will most likely be controlled by a motor, which can then have a variable force applied depending on the diameter of the tree.

The motors, through coding and voltage monitoring, could clamp down to a specified pressure, which correlates with the overall weight of the robot. Finally, the clamping arm, due to budget and time restrictions, will have a curve that will conform to the cylindrical shape of trees. No robot will have an advantage over the other, and since simulation in this project is based solely on the 13 inch diameter, it will be simple and feasible to make solid arms that conform to the exact shape of the tree.

The vertical speed had the lowest percentage of importance in the group, and was sought as a luxury goal. Although speed might be crucial in future development, the project at this point in time is solely to provoke interest in the concept of a robotic logger. As long as the robot makes the climb up the tree, it is deemed successful. The caterpillar robot has a lot of dead time in between actions, which is detrimental to its vertical climbing speed. Similarly, the caterpillar robot separates its vertical and horizontal climbing motions, adding even more time. The robot that incorporates wheels would most likely have multi-directional wheels, and could possibly traverse both horizontal and vertical motions as well. Lastly, the wheels provide a constant vertical motion, which gives the wheel robot a significant edge over the caterpillar robot.

The capacity to carry extra weight promotes future expansion of components on the robot, such as the capability to yield a saw to prune branches in tandem with climbing up the tree. Although the weight isn’t the most heavily weighted, the group feels that it is an important criterion. Once again, since both robots use clamps, they should be equally capable of bearing the load of batteries, components, and future add-ons. The slight edge was given to the caterpillar robot because one of the clamps would always be in stable contact with the tree. In addition, extra weight on the minimal surface area from the wheels could cause pressure and friction problems later in design. The lessened surface area on the wheel propelled robot should lead to more expensive motors since motor pricing is a function of power output, which detriments the limited budget for the completion of the project.

Reversibility is useful for the project, and there would be no point in the robot if the logger, or supervisor of the robot, had to climb the tree to release the robot. This could be dangerous, would defeat the goal of the project. This category has a moderate weight for the project, and both robots seemed likely to successfully implement a reverse climb. Members suggested the idea of mapping the route of the robot, so it will be able to descend by memory.

Also, both robots, if the right motors were chosen, should be able to operate every moving part in reverse. The results for this category were tied, and other working criteria were needed to make a final determination of design.

Maneuverability was given the highest ranking by the group. In order to get to the top of a tree, the robot will need to navigate around branches with as much ease as possible. Even if the robot had the capacity to sever unwanted limbs on the tree, it would still need to maneuver above each branch before cutting it. Trouble would most likely ensue if the robot were to cut a branch while sitting below it, and this would lead to collateral damage. In this category, both robots fared well, and were given complimentary scores. It turns out that, in theory, both robots should be able to traverse around branches with ease. The rotational components on either design should allow the robot to position itself properly in order to climb, hence the moderately high ranking of each.

Lastly, the group assigned rankings in the simplicity category. Constraints limit the complexity of the robot as a whole, so in turn; the group assigned the second highest ranking to simplicity. In order to complete the robot on time and within budget, the robot should be as simple as possible and not incorporate exceedingly intricate moving parts. Although both projects are complex in design, the group felt that the wheel robot would be the most difficult to construct. The caterpillar robot should provide difficulties as well, but it seems more feasible for the given working conditions. The low scores indicate the ambitiousness of both designs, but the group realizes the challenges and trials ahead in part ordering and construction.

B. Locomotion Decision

Finally, the group decided to go with the caterpillar robot due to its slight edge over the wheeled robot. It was felt that this project was a little more manageable, yet complex enough to stimulate the minds of the growing engineers in the group. The caterpillar robot combines intricate structure with feasible goals, which lead to this decision. The group will expand knowledge on topics such as hydraulics, linear actuators, motors, and structural design while learning to manage an ambitious project with deadlines.

III. Subsystems Design

The next options discussed lie in the subsystems of the robot. The subsystems that aid the caterpillar robot in its climb to the top of the tree include clamping, extension, rotation, and detection. All of these systems, with the exception of the extension system, could be implemented on either robot, and were therefore considered as subsystems of the robots. They do not affect the locomotion of the robot, which was the preliminary decision of the group, but provide equally important qualities that will affect the overall success of the robot.

A. Clamping Systems

As far as clamping systems go, numerous options exist. This decision should be based on ability to conform to the tree and surface area in contact with the tree, as well as on simplicity.

i. Pneumatic Clamps

If the robot were to be made into a pneumatic robot that carried a tank of compressed air to provide the force to operate all the machinery, a clamp that inflated could possibly be implemented. The clamp acts similarly to a bike tire inner tube, but for this project, the inflatable ring need not encompass the full 360°. For a clarification, refer to Fig. 3.

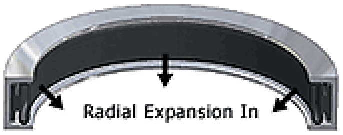

Figure 3: Pneuma-Seal Inflatable Ring Clamp

[http://www.pneuma-seal.com/typical_configurations/index.htm]

Advantages of this system include strong clamping power and solid fitting to most contours. Plus, the inflatable clamp would provide a large contact area and high coefficient of friction. The drawbacks of this system include unnecessary weight due to the air tank it needs to carry and difficulty in implementing a system of wheels and/or treads to rotate the robot. Also, the circular structure of the robot will stay in close proximity to the tree at all times, and might prohibit vertical climb of the robot due to collisions with surroundings. Due to the aforementioned, the pneumatic clamps do not seem feasible for the scope of this project.

ii. Linear Actuators

Another idea for clamping came from linear actuators. Linear actuators exist in both a hydraulic version and a purely DC linear actuator, but hydraulic actuators were ruled out on basis of carrying an extra air tank. The arms of the clamp could be machined to the robot and fixed at a certain point, while the actuator was attached behind the clamps. To grip the tree, the actuator would extend and cause the clamp to compress on the tree. For clarification, refer to Fig. 4.

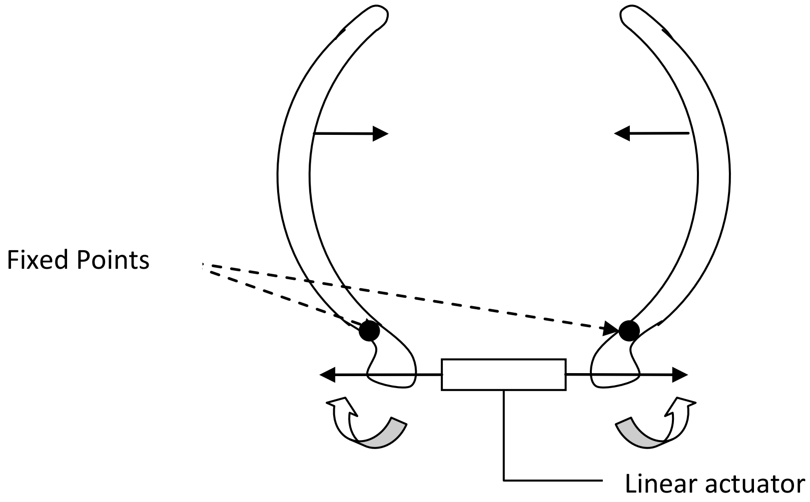

Figure 4: Linear Actuator Concept

The arms will respond to the moment provided by the actuator by clamping inward toward the tree. The actuator should be powerful enough to bear the weight of the robot, and this could lead to feasible calculations of pin distance that will yield the necessary moment to hold the robot onto the tree.   Also, due to the DC actuators being electrically controlled, the programming for clamping and releasing would be simple and effective.   Lastly, if the pin distance is relatively small, the robot could draw back its arms a greater distance, which would allow for easy traversing of branches as the robot's upper section moved above the branch to clamp on.

Another idea proposed by the group was skeleton constructed of a light, rigid metal. The metal would form the shape of the tree, but not lay on top of the tree, and there would be a gap given to allow branches to pass through as the robot moves above the branches. Two linear actuators would be mounted on this frame, and they would be pointed toward the gap. A band of some sort would be wrapped around the tree and connected to the linear actuators. To clamp onto the tree, the linear actuators would extend, allowing the band to conform to the tree. See Fig. 5 for a depiction of this concept.

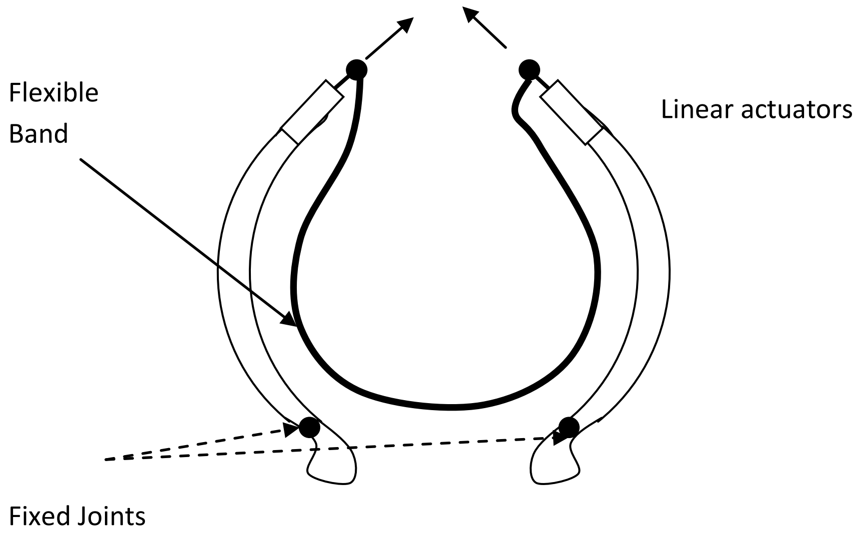

Figure 5: Alternative Band Concept

This idea seems feasible, but not practical. Pros include the large contact area with the tree trunk and the variable band. Changing the band would allow the group to get the optimal coefficient of friction to carry the robot to the top. However, the rigid frame would restrict vertical motion past branches, because unlike the previous option, the arms will not bend back enough to compensate for foliage around the robot.

iii. Final Decision

Overall, the most effective solution to clamping systems lies in an electronic actuator. This surpasses all hydraulic and pneumatic concepts due to the fact that it can be controlled via an onboard computer system and some coding. Also, the force can be varied depending on how snug the clamp needs to fit on the tree. As mentioned before, the pushing force of the linear actuator will need to be calculated, but this should be a simple mechanical calculation.

B. Extension Systems

The goal of this particular module is to allow the distance between the two sections of the body to be changed with a relatively high precision. It would also be beneficial to have a form of feedback to evaluate how much extension has taken place and how far the robot has traveled, while stressing the need for simplicity.

i. Gears

The first method that came to mind was a system of gears to allow the two body sections to expand. These gears would be driven by a standard controllable rotational motor. While the creation of a gear train would give a mechanical advantage, only single and double gear scenarios are shown because these represent the two possible directions of the resulting force. The first design utilizing a single gear, as seen in Fig. 6, would create a force in both directions.

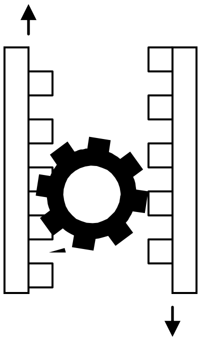

Figure 6: Single Gear

Unfortunately, this bi-directional generated force would cause an asymmetric force distribution between the two body sections, resulting in an unnecessary moment within each body section. This type of design is also not particularly stable and would require the gear and motor to always be suspended halfway between the two sections on a back brace or track.

The reversal of this solitary gear system would actually be a much better approach. If the tracks shown in the diagram were part of a motorized belt and the gear was free-spinning and attached to the one of the body sections, the extension would be more uniform and remove the moment as well. For example, if the lower section had a track the height of the robot with a rotary motor powered belt inscribing the track, the upper section with gear in the track would be forced upward when the top was not clamped. Once the top was clamped, the same motion would raise the lower section. The greatest problem with this design is that it is fairly complex and would require considerable construction time to build.

The two gear design, as illustrated in Fig. 7, corrects some of the faults of the single gear design and presents the best gear scenario.

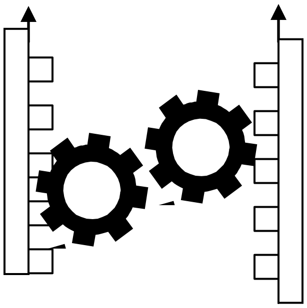

Figure 7: Double Gears

The directions of the forces generated would go in the same direction eliminating the moment caused by asymmetry. It is also more stable because the gear system would be mounted on one of the body sections and either run on a track or cause a track to run removing the need for a suspended motor. Before more research was conducted, this was the design of choice.

Ultimately while these types of systems could accomplish the desired module's goals, the system would be relatively unstable and require extreme care in construction to ensure no slipping occured between the gears and tracks. Although the motors would be fairly easy to control and rotations could be counted to measure distance of travel, this type of idea would require considerably more hours in the shop than some of the other alternatives. It would be wasteful to spend so much time and effort when the entire module can essentially be bought in one piece as later discussed. Additionally, each of these designs would give the robot a constant height by requiring a track, which would severely limit the robot's overall mobility. If the robot is put into a scenario where it needs to only partially expand, the track would prevent it from rotating past branches either below or above the frame.

ii. Scissor Lift

Utilizing any of the above gear scenarios, a scissor lift could be fashioned. As shown in Fig. 8, when a horizontal force is applied at the bottom of the lift, the entire assembly will tighten causing the length to extend.

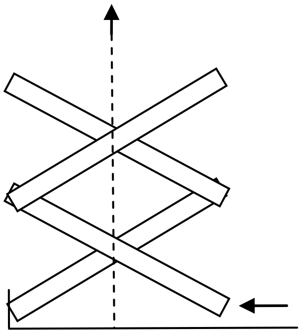

Figure 8: Scissor Lift

A rotary motor with a gear assembly could be utilized to create this horizontal force. This would eliminate the instability of the gear based modules, but actually generate even more. A scissor lift's structural integrity is based on the width of the bars, and in this situation the entire system would require too much space to be functional. As the system is expanded, the footprint becomes smaller and smaller, causing it to lose stability. This type of design would also require the corners of the lift to be able to slide along a horizontal track, which would only complicate matters and construction.

Essentially this type of design would require extensive construction time to create all of the moving parts, and would not ensure that much stability. If the design was even slightly misaligned, the lift could rise at an angle and add an incredibly more complex problem to climbing a tree. This type of module would also be fairly bulky and weigh more than the other options. The one great advantage of the scissor lift over the gears is the ability to have a variable height, but this can also be accomplished in other scenarios.

iii. Linear Actuators

Before delving into the design of the modules, the idea of using pneumatics or hydraulics was tossed around and researched. A system like these would generate the type of force locomotion we had originally pictured. The fallback of these types of designs is that they would require a supply sub-system to run that would need to be entirely leak proof, which would cause considerable construction time as well as be quite bulky. In the case of hydraulics, it would require the electronics to be fairly close to an amount of water causing any failure to be catastrophic. Additionally, both of these types of power would also be expensive to implement.

After discovering the existence of electric linear actuators on the other hand, the original concept of extension is feasible without the negatives of a bulky supply system. As can be seen in Fig. 9, when a voltage is applied to the motor of a linear actuator, the arm extends out of the case causing a direct extensional force.

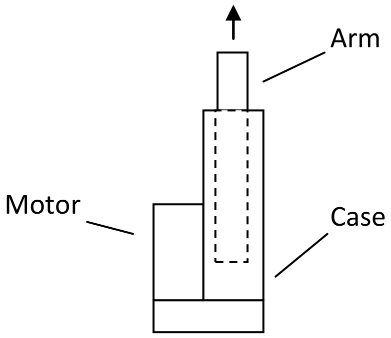

Figure. 9: Linear Actuator

One of the benefits of this type of extension is that it is double acting and either pushes or pulls based on the polarity of the voltage applied creating a simple on/off reversible system. They can also be purchased with feedback for precise movement, which would be necessary on the robot. The right combination of force, stroke length, and speed can essentially be picked and ordered from numerous companies. After deciding on a stroke length, either force or speed is chosen based on the applications requirements while the other sacrificed since they are inversely related. This variety of possibilities ensures that exactly the right part can be order without having to spend additional funds for more power or speed than is necessary to accomplish the job.

The fallback of the gear designs rested in the requirement of a cumbersome track for the gears to run on. The actuator design's greatest superiority lies in its ability to create a variable height robot, while still providing stability. Since the upper section would be attached directly to the end of the arm of the actuator which telescopes out from the case, the overall height will vary based on the extension length. This will allow the robot to maneuver around considerably more branch scenarios.

The other designs also would have required extensive construction time to create the necessary track and ensure that the gears were in precise location to prevent slipping. These would also necessitate a large amount of moving parts and complexity, which would leave greater room for mistakes. A linear actuator system, on the other hand, can basically be designed by purchasing the entire module in one guaranteed package.

iv. Final Extension Design

As discussed, the use of electric linear actuators for the basis of the extension system is the best alternative to accomplish the module's goals. Actuators are easy to use and can be customized to the exact needs of the project. They also provide feedback to provide precision movement as well as calculations to measure the distance of travel. The final design centers on a linear actuator perpendicular between the two body sections as shown in Fig. 10.

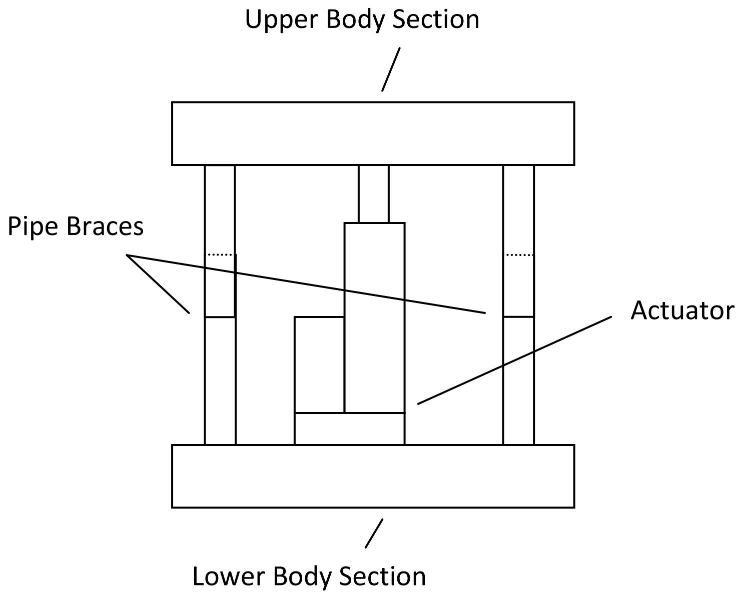

Figure 10: Final Extension Design

Additional support is provided by a pipe brace on either side of the actuator comprised of a larger diameter pipe with a slightly smaller diameter pipe inside to create a sliding action.

C. Rotation Systems

One requirement of the design is that the robot be able to avoid obstacles in its path of motion. In order to meet this requirement, the body of the robot must be able to rotate around the tree, while maintaining its grip on the tree trunk. Two different types of rotational subsystems, wheels and treads, were considered to execute this motion.

i. Wheeled Rotation

The first rotation system considered would consist of wheels spaced about the body of each clamp, as shown in Fig. 11.

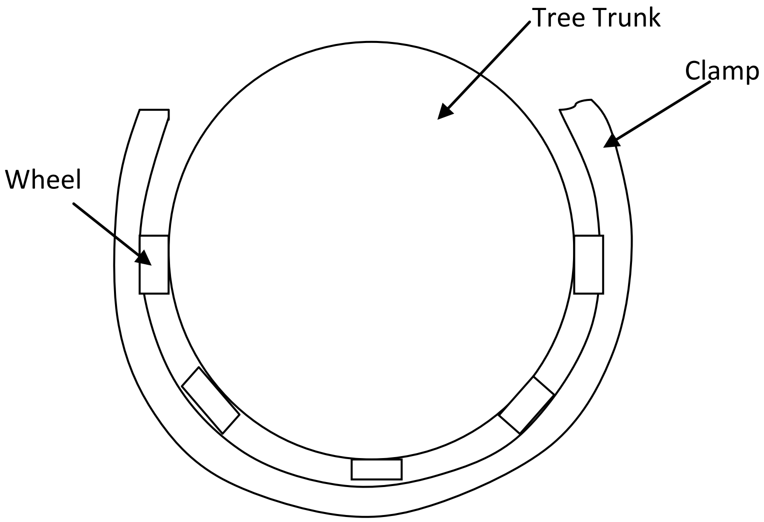

Figure 11: Wheeled Rotation System

These wheels, driven by motors, would move the robot around the tree trunk. The biggest appeal of this system is that it is fairly simple conceptually. However, it also has several drawbacks. The main concern with this design is that robot would be in contact with the tree only at the points of contact of the wheels. This is an issue because each clamp needs to be able to support the full weight of the entire robot while the other clamp is being extended up or down the tree, and such a small area of contact with the tree would increase the likelihood of the robot losing its grip and sliding or falling down the tree. Also, in order for this system to work, there should be an equal amount of force exerted on the tree by each wheel to ensure that no slipping occurs, and that the motion around the tree is uniform and smooth. This even force distribution could be quite difficult and time consuming to achieve.

ii. Tread Rotation

The other rotation system considered would utilize a tread stretched around rollers on each clamp, as shown in Fig. 12.

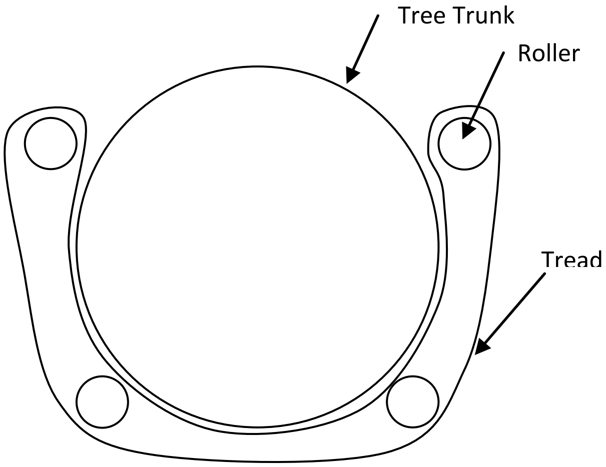

Figure 12: Tread Rotation System

Motors would be used to power one roller on each clamp, which would in turn cause the band to move the body of the clamp around the tree trunk. This system would provide a maximum area of contact with the tree, which would help to ensure that the robot maintains traction. Only two drive motors would be required for this system, one for each clamp, so the cost of the system would be minimized. Another benefit of this system is that it would make the robot more adaptable to a range of tree diameters. As in the wheeled rotation system, the force exerted by the tread on the tree must be evenly distributed for the system to work. However, the design of this system makes it easier to distribute force evenly, as long as the tread remains in tension. The drawback of this system is that its construction is very labor intensive, since it is a more complicated system and the components must be placed very precisely. This system could also be designed to accommodate a larger range of diameters than would be possible with the wheeled rotation system.

iii. Final Decision

After weighing the options for the rotational subsystem, the group decided to implement the tread system. Both systems would be difficult and time consuming to perfect, so the group decided to go with the option that will provide the most stable design and the least room for failure.

D. Detection Systems

Without external inputs, the ability of the robot to 'see' potential collisions and impacts is simply nonexistent. To achieve an optimal solution to the design problem, some type of sensors must be implemented, giving the robot electronic inputs that allow it to predict and avoid impact with branches on the tree. The sensor systems considered were bumper collision, infrared, and sonar detection.

i. Bumper Collision Detection

A bumper proximity detection system is by far the simplest form of collision detection. It allows for a cheap solution, as it would need to be constructed of economical push button switches, but would unfortunately be very time consuming. The concept was considered as a way of one-dimensional detection, as the input from a bumper system would be a series of ones and zeros ('one' being branch detected, 'zero' being no branch detected). This would require either a parallel based port, or an external converter to utilize either: I2C, USB, or serial. These more common inputs (USB, I2C, serial) would be far easier to use in programming, but come with the overhead cost of the converter.

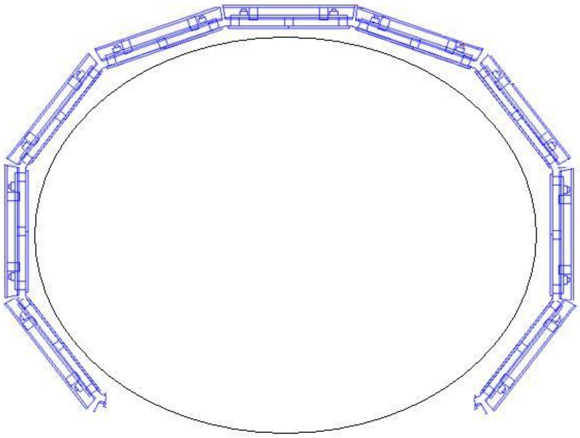

Figure 13. Bumper Based Proximity Detection Apparatus

The bumper itself could be constructed as a series of aligned plates, the plates being attached to evenly spaced switches over the entire surface length of front of the robot as seen in Fig. 13. The downside of this would be excessive wear to switches, and failures would be inevitable and undetectable. Other supportive ideas included using a styrofoam or similar compressive material to eliminate unnecessary torques on the switches by cutting out holes for the switches and placing them around the switches beneath the plates.

Negative arguments were that the suggested addition of compressive supporting material and plates would add enormous amounts of construction time to the sensory network. Also, there are issues with what to do with the interfaces between the plates, as any space gives the opportunity for failure and possible injury to the robot. The primary operating system of the computer in place is Debian Etch, which is a non-real-time system. Using a real-time system, this method could be pulled off without a hitch, but there is no way to predict the exact timing with which the robot will react without it, as individual thread control is not possible. This is evidence that the bumper system could wear the system prematurely, that is, cause the system to move slower than possible because of system lag time in collision response.

ii. Infrared Detection

The first form of two-dimensional collision detection considered was infrared based sensory. The prospect of collision detection with two dimensions allows for not only a signal of ‘branch or no branch’, but also ‘if branch, how far away’. This is profound when it comes to utilizing a non-real-time system, as it allows the operator to predict the collision with the branch, and input a stopping before a collision. A bumper system, on the other hand, would hit the branch, pull back, and then plan how to get around the branch. A two dimensional system can know when to stop and how to maneuver before it gets to the branch. A drawback of an infrared system is that ambient light causes large amounts of interference and noise, and there is no amount of threshold adjustment that could be done to correct this. Since the amount of ambient light changes greatly from nearly direct sunlight to foliage shadow, distinguishing a branch from a shadow would be extremely difficult. With this in mind, achieving coverage of the entire front surface of the robot also presents problems, as this would require an extremely large amount of sensors, which would then have to be coordinated and inputted into the system, creating IO problems. The advantages of an infrared system are that it is both economical and has an appropriate useful range of operation (up to ~18 inches).

iii. Sonar Detection

Sonar detection is the other two-dimensional form of collision detection and the method with which the robot will detect branches. Sonar is extremely popular in both amateur and professional robots, and is therefore readily available with a wealth of information and moderate cost. It has an affective detection distance from a few centimeters to several meters (6m to 8m max range in most cases). This system is significantly more expensive per sensor than a bumper or infrared system ($20 to $30 each versus $1 to $5), but it allows for a single sensor to manage a significantly larger portion of the tree. This reduces the overall resolution, but allows for manageable sensor inputs. For instance, if a sonar with a fifty-five degree signal spread is used on a thirteen inch diameter tree, only eight sonars are required to see 180°, versus twenty to thirty bumper switches or around thirty infrared sensors. This means that a sonar system is actually price competitive, as well as available in common input protocols for computers (USB, I2C, serial, etc.). Since a significantly smaller number of sensors are needed, not only is the coordination of signals simpler, but the construction time required for the sensor system is also significantly less. From a construction stand point, a mounting bracket is needed to attach the sonar at the proper angle such that the beam (which comes out in a cone shape) will not hit the tree before the desired maximum distance. For this project, a long detection distance is not necessary, as the robot will move slowly. This is convenient since as the cone is angled further away from the tree, false identification from nearby trees' branches becomes more likely. With a reduced minimal distance, there is a significantly smaller chance to get false readings.