Design and Construction of a Tree Climbing and Trimming Robot

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1. Introduction

This paper presents a senior design project completed by three multidisciplinary students enrolled in an Engineering Technology program at an ABET-ETAC–accredited four-year institution. The goal of the project was to design and construct a robotic system capable of climbing trees and trimming branches at height. Current tree-trimming practices are largely manual and require extensive safety measures, including harnesses, ropes, belaying lines, and other protective equipment. Despite these precautions, the task remains highly hazardous, as equipment failure or operator error can result in significant falls that may cause severe injuries or fatalities. The proposed robotic solution seeks to mitigate these risks while also offering a faster and more cost-effective alternative to the large, specialized machinery currently used in industry. In addition to addressing an important industrial safety challenge, this project serves as a comprehensive educational experience that emphasizes applied design, prototyping, and system integration within an Engineering Technology curriculum.

The current robot design is inspired by insect locomotion, particularly caterpillar movement. It is intended to use hydraulic mechanisms to extend and contract the main body and pneumatic actuators to clamp the robot's legs securely around the tree. The system is designed for remote operation, allowing the user to control the robot safely from the ground. A key design challenge is achieving an optimal balance between weight and durability: the robot must be lightweight enough to climb a variety of trees, yet robust enough to withstand impacts from branches or potential falls resulting from slippage or loss of grip. Overall, the design objectives are to enable safe and reliable tree climbing, reduce costs relative to existing large-scale equipment, and provide a user-friendly system that requires minimal operator training. From an educational perspective, the project integrates mechanical design, pneumatic systems, electrical controls, and embedded programming, providing students with hands-on experience that aligns with ABET-ETAC student learning outcomes and industry-relevant engineering technology practices.

2. Problem Definition and Objectives

Trees are an important part of urban life in that they provide many ecological and life-sustaining benefits, yet they still have massive risks associated with them; falling branches, rotten wood, and extreme weather with lightning strikes can cause many issues . For homeowners, landscapers, and arborists, maintaining trees is a necessity to reduce health or property-damaging hazards. One such process, however, involves the hands-on removal of branches from the ground or, worse, scaling the tree with climbing equipment, posing life-threatening dangers. Our goal is to remove this risk and create a remote-controlled solution to keep the maintenance at a safe distance. Chainsaw-related accidents during the removal of tree branches and limbs have long posed a serious safety risk for individuals involved in outdoor, tree-related work. One of the primary objectives of this project is to eliminate the need for humans to operate in such hazardous conditions. This goal is expected to be achieved through the design and development of a robotic system capable of climbing small trees and removing dangerous limbs. From an engineering technology perspective, the problem is addressed through practical design constraints related to safety, manufacturability, cost, and system integration.

This proposed project will employ a series of pneumatic circuits to actuate pistons that enable controlled climbing and positioning along the tree. In addition, the robot will be equipped with a three-axis robotic arm designed to precisely position an integrated, compact chainsaw for tree limb removal. By automating these tasks, the system aims to significantly reduce the likelihood of injury associated with manual tree trimming. The system is intended to operate on small- to medium-diameter trees commonly encountered in residential and light commercial environments, reflecting realistic use cases and design constraints appropriate for a senior design project.

The overall objectives of the project are as follows:

1. Design and implement the necessary pneumatic and electrical control circuits that provide reliable gripping, extension, and retraction during vertical climbing operations.
2. Design and fabricate the robot body, ensuring compatibility with the dimensions and functional requirements of the pneumatic components while maintaining structural integrity and minimizing overall system weight.
3. Design and construct a functional robotic arm meeting the operational goals of the system by enabling controlled three-axis positioning of the cutting tool.
4. Ensure the robot can be operated remotely from a safe distance, thereby eliminating direct human exposure to potential hazards and reinforcing the primary safety-driven motivation of the project.

3. Literature Review

One widely used method for the manual ascent of trees involves throwing a safety line over selected branches to support the climber during ascent and operation [1]. A similar approach can be adopted in robotic systems by feeding a hydraulic line or integrated safety rope up the tree to alleviate mechanical stress acting on the robot during climbing. These auxiliary support lines may also be coupled with a motorized winch mechanism to hasten vertical ascent, thereby improving the climbing efficiency and reducing wear and fatigue on the robot's primary structural and locomotion components [1-2]. Robotic climbing systems can be categorized according to their adhesion mechanisms, which are generally classified as either active or passive. Active adhesion systems require an external power source to generate attachment forces, while passive systems rely on mechanical interaction with the climbing surface [1-3]. One adhesion approach of particular interest is the use of pneumatic or hydraulic systems to generate pressure through devices such as suction cups [2-5]. Suction-based adhesion offers a notable advantage over magnetic techniques in that it can be applied to a wider range of surface materials. However, its effectiveness is limited by surface uniformity, as adequate sealing is required to maintain the pressure differential necessary for adhesion [3–5]. Because tree bark surfaces are irregular and non-uniform, suction-based adhesion was considered less reliable for the proposed application, motivating the selection of mechanical gripping mechanisms combined with pneumatic actuation in this project.

Additional climbing strategies, interestingly, draw inspiration from biological systems [2]. Some designs employ claw-based gripping mechanisms, while others utilize adhesion techniques modeled after the microstructures found on gecko feet models [1-2]. Another notable bio-inspired approach is the use of *microspines*, which mimic the gripping behavior of spider legs and other arachnid appendages [6]. Microspine-type climbing mechanisms allow individual limbs to interlock with surface irregularities, distributing mechanical loads across multiple contact points. This load distribution is sufficiently effective to enable some robots to climb even inverted or overhanging surfaces [6]. Figure 1 shows one microspine gripper called LEMUR IIB Robot during an inverted free-climbing experiment on vesicular basalt rock developed by Parnes et al. [6]. Although microspine systems offer strong adhesion performance, their mechanical complexity and fabrication requirements were determined to be beyond the scope of a two-semester undergraduate engineering technology capstone project.

Trees contribute a significant part of urban life in that they provide several life-sustaining benefits, yet they still have massive risks associated with them; falling branches, rotten wood, and extreme weather can cause many issues [7]. Trees require constant pruning and care to minimize this risk, and this comes at the expense of safety for an arborist. Many arborists use ropes to ascend [1], [7], [8], and these can present a massive risk if the rope is frayed or hit while the arborist is using power tools. These risks can be mitigated with extreme caution, experience, and training [7], but they will still be present regardless due to the non-uniform nature of trees [7]. Taking all these factors into account, a group of researchers developed a climbing robot named Treebot [9]. Treebot utilizes a unique setup to extend and retract the body of the robot [9]. The ability to stick to the tree comes from a pair of "Omni-directional Tree Grippers," which are a set of curved rods that can grip the tree [9]. It also uses a piston and springs to push the grippers on the tree, and the springs retract the grippers when the piston recedes. The main component of Treebot is a "Continuum Manipulator", which gives Treebot its maneuverability and the ability to climb the tree as shown in Figure 2 [9]. The Treebot design provided key inspiration for the proposed robot's inchworm-style climbing motion; however, the present project emphasizes a simplified mechanical architecture and readily available components to better align with engineering technology educational objectives and cost constraints.

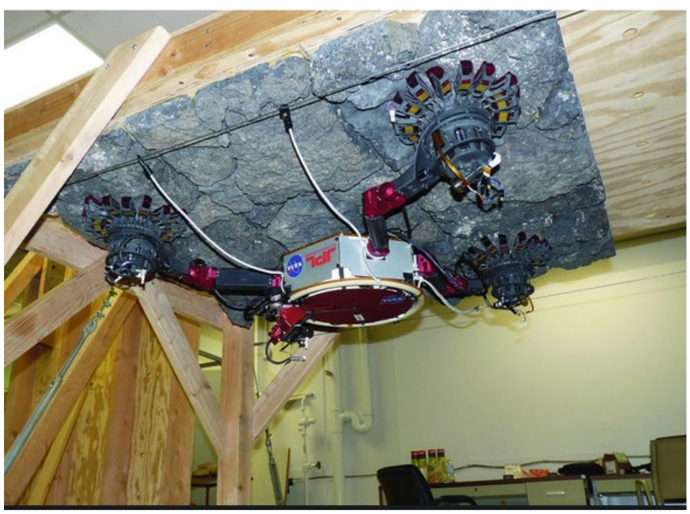


Figure 1. The LEMUR IIB robot with microspine grippers during an inverted free-climbing experiment on vesicular basalt rock [6].

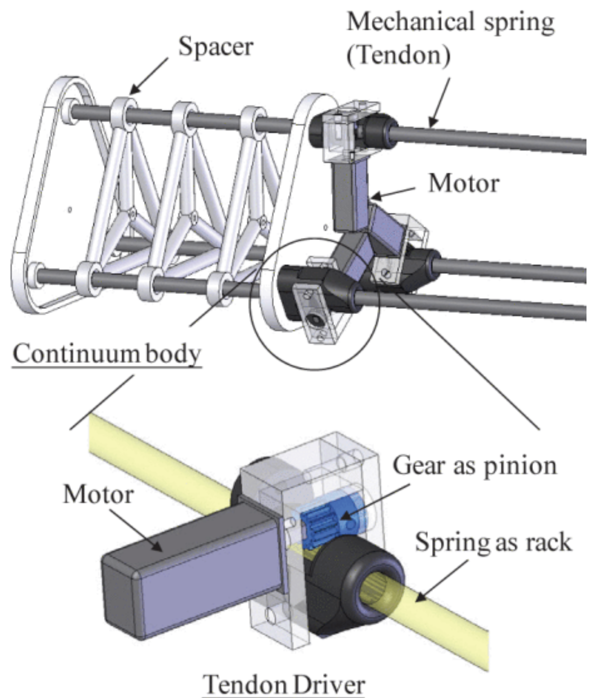


Figure 2. Design of a continuum manipulator [9].

4. Engineering Approach

Figure 3 shows the overall block diagram of the Robot and how each module will communicate and interact with the others. Our main idea is to design and build an inchworm-like robot with a mechanical arm at the top that has a commercially available low-powered chainsaw attached. The tree-climbing and trimming robot (TCTR) is designed to use several series of pneumatic circuits shown in Figure 4 to pinch onto the body of the tree. As it climbs, the pneumatic linear actuator operated leges moves alternatively to ascend the tree much like an inchworm. At the desired location, the robot will then be able to use a remote-controlled saw to remove branches. This sequential actuation strategy was selected to simplify control logic while maintaining stable contact with the tree throughout the climbing process.

The main method of motion is for the robot to grab the tree with the bottom legs, then extend the core. With the core fully extended, the top legs will clamp the tree. After this, the bottom legs will detach, and the core will move up by retracting the linear actuator, and this process will repeat as needed. This approach ensures that at least one set of gripping legs remains engaged at all times, reducing the risk of slippage and improving overall climbing stability.

For the design of the Robotic arm, we are looking at ones currently employed in the manufacturing industries, but instead of a claw or welder, we are replacing it with a commercially available chainsaw. This design allows us to have a near three-hundred-and-sixty-degree motion along all three axes. It also has the benefit of giving extra reach to the Robot to avoid the limbs falling right on top of it. Our initial design was based on using a hydraulic circuit instead of a pneumatic one, but we decided to switch based on the cost of the hydraulic components. The hydraulic pistons were anywhere from double to triple the price of pneumatics for the same increase in pressure. Considering that the pressure needed to remain to the tree would not need to be that much, we decided to switch to pneumatics. This decision reflects an engineering technology–focused trade-off analysis emphasizing cost efficiency, component availability, and ease of integration over maximum force capability.

This proposed method utilizes our knowledge of circuitry and electrical engineering, along with the ability to create a working remote control that can properly integrate with the machine. It also needs knowledge of pneumatic systems to create the necessary pressures and movement required to make the robot function as desired. It finally needs to work with design tools to get all these parts to mesh and make sure that they all fit properly and have the full range of motion desired. Collectively, this systems-level approach reinforces key engineering technology competencies, including multidisciplinary integration, hands-on prototyping, and practical problem solving under realistic design constraints.

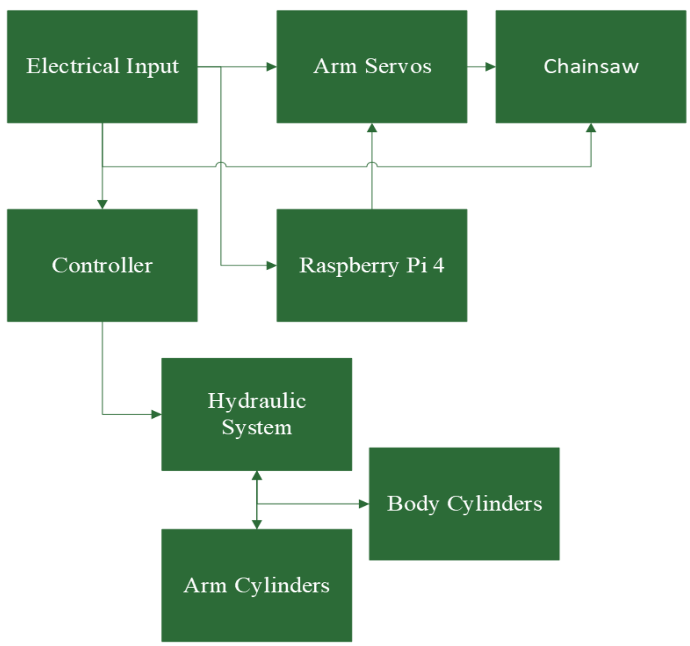
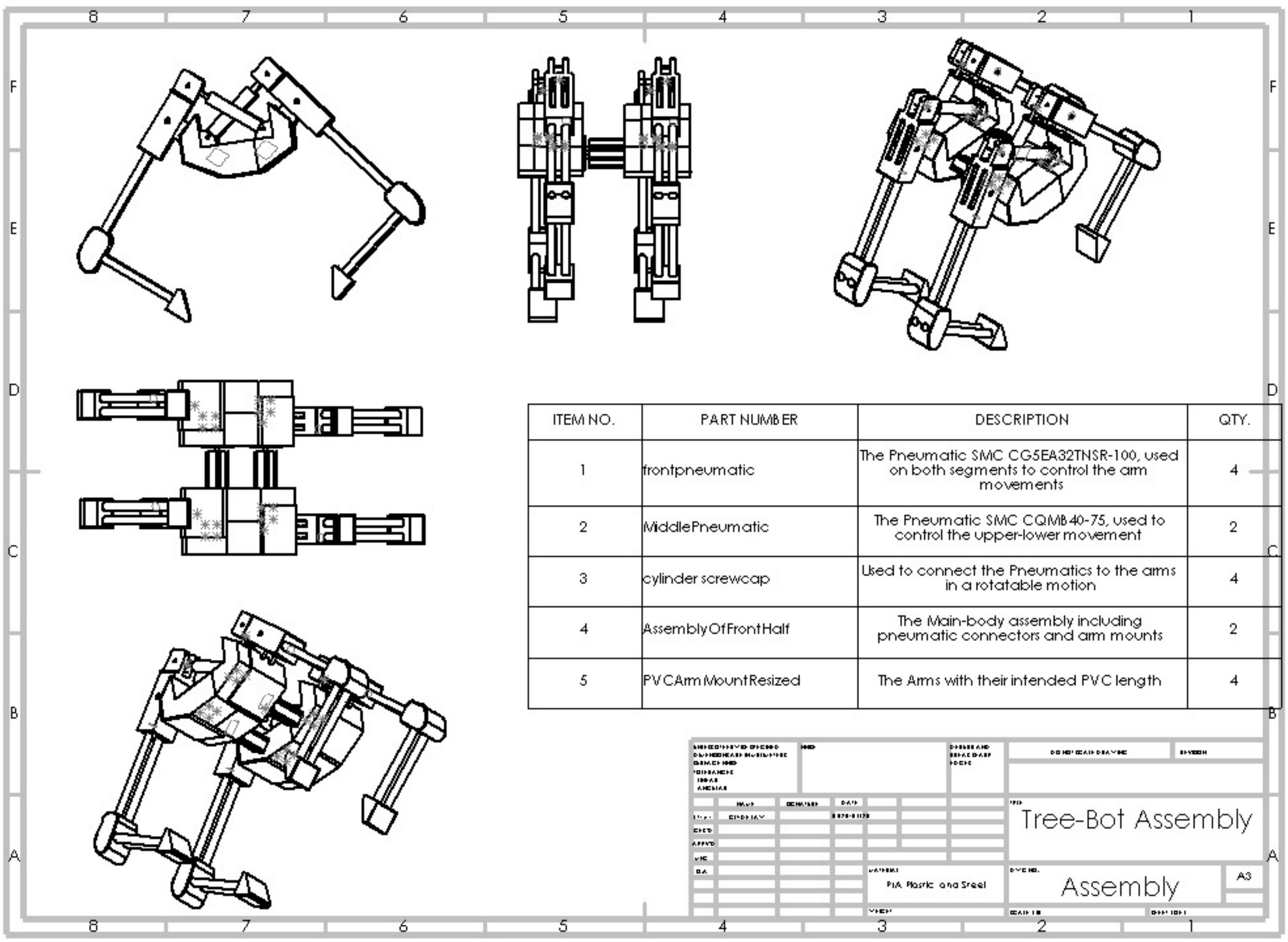


Figure 3. Functional block diagram of the proposed TCTR project.

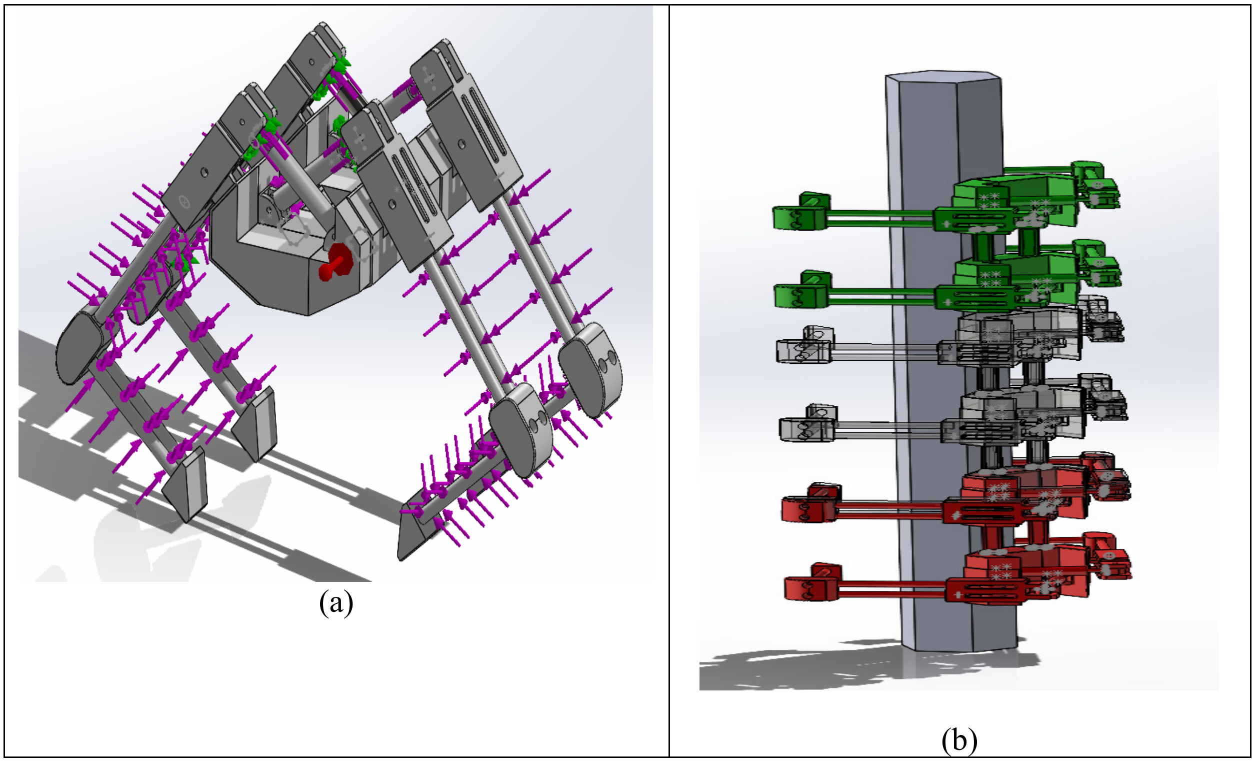
Other designs we considered take inspiration from coconut harvesting robots in use today. It is a small body with wheels that wrap around the tree. If it runs into an obstacle along the path it can rotate around it. Or it can have wheels attached to limbs that can be moved out of the way, allowing space to be made. While wheel-based systems offer simplicity and continuous motion, their effectiveness is limited on irregular tree surfaces and in the presence of branches, which can reduce traction and stability. We can also change the center section of the robot to mirror similar to the *Treebot* [9] mentioned above. By having motors along rails in the center, it will get rid of the need for hydraulic cables or pneumatic tubes to supply the air. This will also allow it to have the flexibility to avoid branches or obstacles along its path. However, this approach introduces additional mechanical complexity and increases fabrication and control requirements, making it less suitable for an undergraduate engineering technology capstone project.

For the main body we have settled on a manual pneumatic circuit. This is a cheaper option in the end as the electric versions of parts can get vastly more expensive than the manual counterparts. This does bring up the problem of properly triggering it but if we keep the manual components down by the operator, it should allow for easy control. This configuration supports a cost-effective, robust, and educationally appropriate solution by allowing students to focus on fundamental pneumatic principles, system integration, and operator safety. Figure 4 illustrates the assembly drawing model of the proposed TCTR.



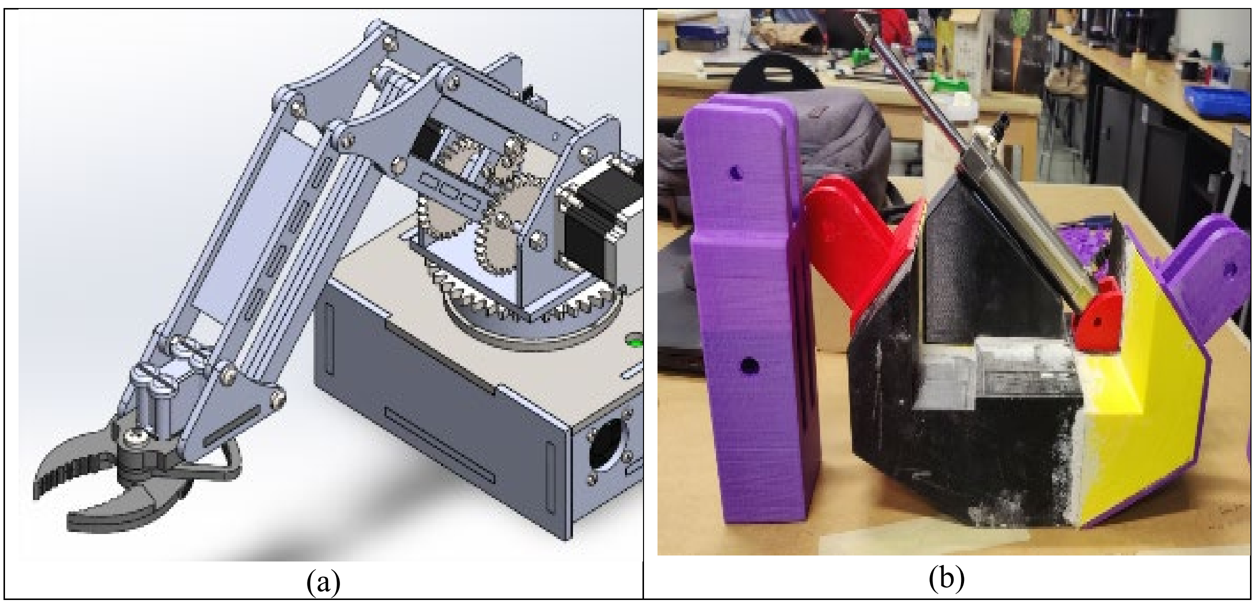
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	frontpneumatic	The Pneumatic SMC CG5EA32TNSR-100, used on both segments to control the arm movements	4
2	MiddlePneumatic	The Pneumatic SMC CQMB40-75, used to control the upper-lower movement	2
3	cylinder screwcap	Used to connect the Pneumatics to the arms in a rotatable motion	4
4	AssemblyOfFrontHalf	The Main-body assembly including pneumatic connectors and arm mounts	2
5	PVCArmMountResized	The Arms with their intended PVC length	4

Figure 4. Assembly Model of the proposed TCTR



(a) (b)

Figure 5. (a) Stress test of the TCTR's legs as it climbs a tree, (b) Representation of a TCTR as it climbs a tree



(a) (b)

Figure 6. (a) TCTR design for a Robotic Arm, capable of moving in all 3 axes, (b) 3D-printed parts that have yet to be assembled

Figure 7 shows the electrical power and control circuit of the proposed TCTR project. Figure 8 shows how the pneumatics modules are assembled to work as expected.

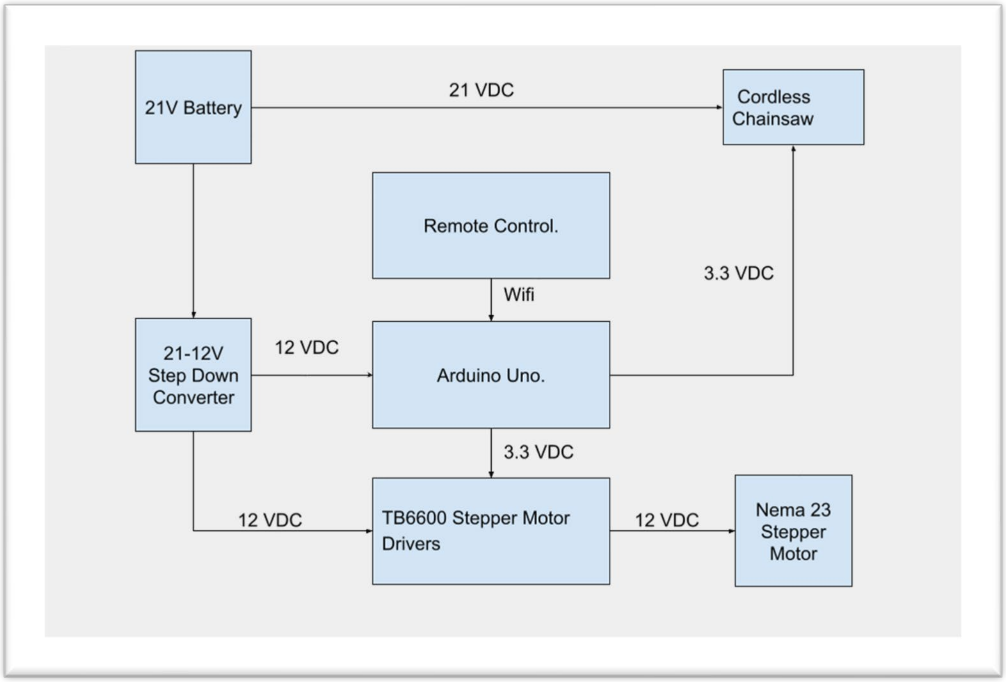


Figure 7. Functional block diagram for the robotic arm circuit

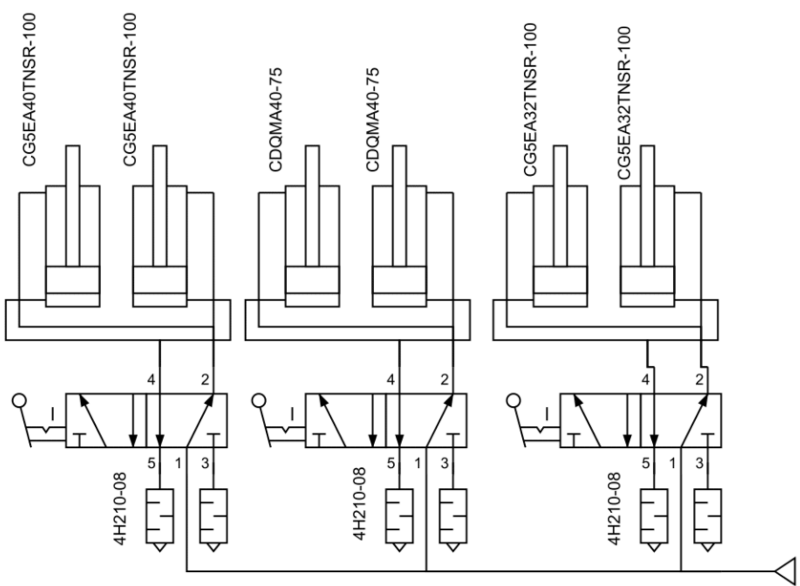
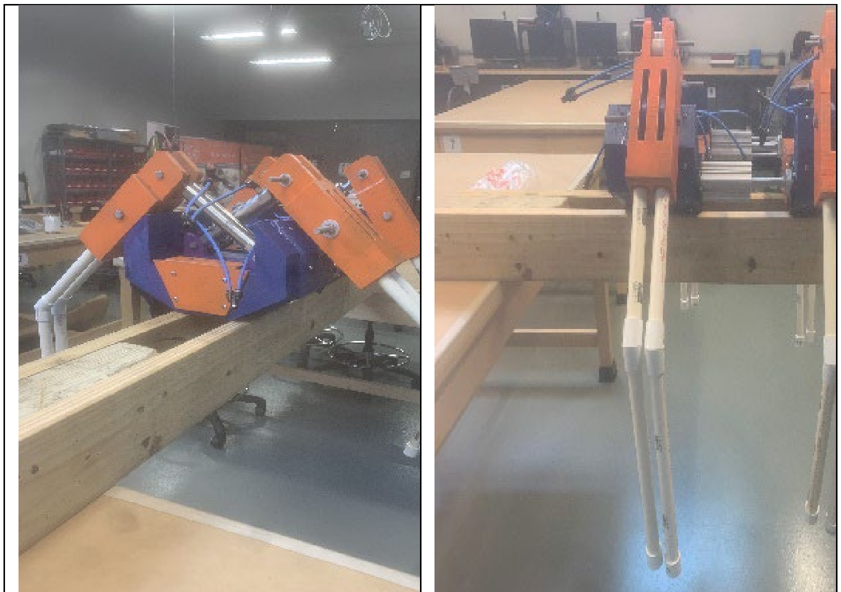


Figure 8. Pneumatics Circuit in the legs of the TCTR

For the arm’s circuits, it will use a standard 21V battery commonly used on modern power tools by companies such as DeWalt and Cobalt. This will allow it to give enough power to operate the chainsaw, and when combined with a step-down transformer, will provide sufficient power to the other components without passing the maximum safe voltage. Using a commercially available power-tool battery improves system reliability, reduces cost, and simplifies replacement and maintenance. The main control of the arm will come from the Arduino Uno board. This will provide a way of receiving the code and sending out the appropriate signals to the motor drivers or chainsaw. The Arduino Uno was selected due to its widespread use in engineering technology curricula, ease of programming, and compatibility with commonly available motor drivers. The motors are NEMA 23 Stepper CNC Motors, which can move precisely and with set speeds when controlled by their respective drivers. Stepper motors were chosen to provide accurate and repeatable positioning of the robotic arm without the need for complex feedback control. Figure 9 (a) shows the front view of the fully assembled TCTR, and Figure 9 (b) shows the side view of the TCTR



(a) (b)

Figure 9 (a) front view of the fully assembled TCTR, (b) side view of the fully assembled TCTR including the working pneumatics.

5. Tasks and Deliverables

For our project, the design process began with theorizing and conceptualizing what our project would do and how it would work. Our idea started with reducing the risk and amount of work in pruning and maintaining trees since it's an important process and any optimizations in the field would hopefully be widely applicable. We then began our research and analysis of the tree trimming process and challenges people face, where we collected information relating to products that fill a similar role and challenges, we expect to see in the design and application processes. This initial phase emphasized problem identification, benchmarking of existing solutions, and feasibility analysis—key components of the engineering technology design process. We decided to use an expanding and retracting motion to climb trees and a combination of arms that can grab and grip onto the trunk of the tree the device is working on.

The natural next step is tying our ideas and the information we've collected and designing the product itself and a controller. We expect to start with basic mechanics since stability, maneuverability, and weight distribution will all be important factors to consider when creating a product that will need to resist falls while also being light enough to hold its own weight. This phase involved iterative CAD modeling, component selection, and preliminary layout verification to ensure compatibility between mechanical, pneumatic, and electrical subsystems. In February, students finalized the design and started to research on how to implement the pneumatics into the robot. The main focus was working on the circuits and acquiring the parts necessary to create the circuit and arm. By the start of spring break, students had successfully printed the core component of the robot they would need to start assembly. These milestones culminated in tangible deliverables, including finalized design drawings, fabricated components, assembled subsystems, and an operational prototype suitable for functional testing and demonstration.

6. Project Management and Bill of Materials (BOM)

This project was one of the nine senior design projects completed in the 2024-25 academic year. A project proposal including problem definition, literature review, conceptual design, modeling, simulation, Gantt Chart, and proposed bill of materials was prepared and approved in a 1 credit hour of Senior Design I course in fall 2024. The 3 credit hours Senior Design II course in Spring 2025 included finalized design, 3D prints of the mechanisms, required purchases, construction, implementation, and testing. With the senior design timeline, a significant portion of the work will involve iterative designing, printing, and troubleshooting to identify the most effective construction techniques for the robot. Throughout, there are milestones to hit which will allow us to look at the project piece by piece rather than as a single integrated task. Each member of the team provided the necessary information to report, design, build, and progress the building week by week. This milestone-driven approach supported effective project management, teamwork, and accountability within the engineering technology capstone experience.

The use of pre-built parts provided by Sam Houston State University allowed the team to effectively budget as best as possible. Most component costs are expected to be estimated using commercially available parts commonly found in engineering technology laboratories. Many of the resources the University offers are extremely useful in the building of our prototype, through 3D-printing, machining, soldering, coding, and so on. Access to these institutional resources reduces overall development costs while enabling hands-on fabrication and testing. The project requires a variety of engineering techniques to complete its task, ranging from coding, designing on SolidWorks, and building with multiple tools. Safety concerns are at an all-time low, being on par with the project and the desired outcome of creating a safer environment for arborists and workers.

Table 1 exhibits the total cost of the project as $990.22, not including 3D printing materials as well as the cost of any software, computers and other machines used in the machine shops of the Department of Engineering Technology. This cost represents the projected direct hardware expenses required to develop a functional prototype. If we manage to stick around this price range, it would be advantageous over manual labor, as the Robot can be reused and does not risk human life. It is a reusable machine, so at a greater upfront cost than an arborist, it is possible to use the robot many times more.

Table 1. Bill of Materials (BOM) of the TCTR project

Bill of Materials			
Item	Unit Cost	Quantity	Extended Cost
Raspberry Pi 4	$70.00	1	$70.00
Arduino	$27.00	2	$54.00
3 Pack Stepper Motors	$60.00	1	$60.00
Pneumatic Cylinder CG5EA32TNSR-100	$92.70	4	$370.80
Pneumatic Cylinder CQMB40-75	$119.00	2	$238.00
Upstepper 12v-5v	$15.00	2	$30.00
Controller	$10.00	1	$10.00
1/4" Push Connect Pneumatic Fittings	$14.99	1	$14.99
Pneumatic 1/4" 2-way Hand Lever	$17.95	3	$53.85
Cordless Mini Chainsaw	$40.00	1	$40.00
4 Motor Driver	$30.59	1	$30.59
1/4" NPT Air Hose Fittings	$17.99	1	$17.99
		Total	$990.22

7. Assessment

ETEC 4199 Senior Design I and ETEC 4399 Senior Design II courses at Sam Houston State University include all the student learning outcomes (SLOs) developed in the Electronics and Computer Engineering Technology and Mechanical Engineering Technology programs. SLO3 requires students to function effectively as a member as well as a leader on technical teams. The corresponding Performance Indicators (PIs) for SLO3 are (a) Use appropriate context, conventions, and mechanics, (b) Use credible sources, evidence, and structure, and (c) Demonstrate oral presentation skills. The senior design project presented in this paper is one of the nine senior design projects completed in the 2024-2025 academic year. Three in-class presentations in Senior Design I provided valuable feedback from other student teams and faculty to the project design and implementation. The multidisciplinary team members met with both faculty advisors weekly, either face-to-face or via Zoom, outside of regular class hours for reporting progress and resolving design challenges. Engineering Technology programs contain five Student Learning Outcomes (SLOs) and their corresponding fourteen Key Performance Indicators (KPIs) that are all measured for completed capstone projects. Out of five SLOs, assessment results for SLO3 entitled as “Apply written, oral, and graphical communication in broadly defined technical and non-technical environments; and an ability to identify and use appropriate technical literature” is shown on Table 2. The full and completed assessment for all SLOs will be available after ETEC 4399 at the end of the Spring 2025 semester. Some of the Industrial Advisory Board (IAB) Members attend both the midterm and final Senior Design Seminars to evaluate the projects and provide very effective feedback.

Table 2. Sample assessment selected for SLO3

Key Performance Indicators	**Unsatisfactory < 60%**	**Developing 60-69%**	**Satisfactory 70-79%**	**Exemplary ≥ 80%**
a) Use appropriate context, conventions, and mechanics (Pre-Proposal + Mid-Report)	0%	0%	10%	90%
b) Use credible sources, evidence, and structure (Final Technical Report)	0%	0%	20%	80%
c) Demonstrate oral presentation skills (Final + Mid Presentation)	0%	0%	15%	85%

8. Conclusion

The main challenge that this senior design project seeks to address is the large safety risk that comes with trimming trees, with secondary problems being accessibility and the cost of operation. The benefit of the proposed TCTR is that it is intended to eliminate the need for a human climber, therefore significantly reducing the safety risk associated with an arborist; it is also expected to be easier to train someone to use a robot instead of the lengthy process of becoming an arborist. As a work-in-progress project, the proposed system is focused on validating these anticipated safety and operational benefits through continued development and testing.

Thus, the proposed design consists of a small robot capable of inch-worming its way up the tree to reach high limbs; it will have a chainsaw or other cutting device attached to a robotic arm capable of three-hundred-and-sixty-degree motion along three axes. Other designs considered during the development process include using wheel-based bases commonly used in a coconut harvesting robot or using electric motors to control an extendable centerpiece, allowing flexibility. The main applications envisioned for the Tree Trimming Robot are industrial/commercial environments. In the lumber industry, trimming the branches off growing trees, is expected to allow the tree to use more resources for vertical growth. Another advantage is that TCTR is designed for multiple uses; this is expected to lead to a lower cost in the long run, as the robot can be reused with routine maintenance rather than requiring repeated deployment of human crews. In addition to its technical objectives, this project provides a multidisciplinary, hands-on learning experience that reinforces engineering technology competencies in system integration, safety-driven design, and practical problem solving. The robot is ultimately intended to reduce the need for companies to assign personnel to the hazardous task of climbing trees.

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