Executive Summary

EXECUTIVE SUMMARY This progress report has been constructed to provide the foundational information regarding the initial development of the arborist robot for the 2026-2027 Ontario Tech Capstone Design course. The project aims to design and develop an arborist robot fit for cutting branches on a small tree; orchard trees have been noted for reference. The arborist robot shall be capable of climbing the tree, maintaining its position along the tree, operating a cutting mechanism to remove branches, and returning to the ground after the desired branches have been removed. This project has been developed to remove the hazards an arborist may face, as well as to improve the efficiency of tedious arborist tasks such as removing branches on tree farms or orchards. Nine customer requirements have been initially emplaced based on the assumption that the primary customer is businesses with repetitive industrial use; these are summarized with individual bases in Table 1. Twenty engineering requirements have been initially set in place based on background research and OMAFRA orchard dimensions, and are summarized in Table 2. Tree pruning exposes workers to falls, cutting-tool injuries, and electrical hazards, and remains labour intensive; pruning alone takes roughly 31 hours of skilled labour per acre and about 20% of pre-harvest costs in apple production. The prototype will attach to a 40-65 mm trunk, climb under remote control, stop at a selected height, position a cutter toward a branch of up to 20-30 mm, cut it, and descend. All numerical targets are preliminary and subject to change. In keeping with an under-promise, over-deliver philosophy, the committed deliverable is a reliable remote-controlled platform, while branch recognition, automated obstacle bypass, and semi-autonomy are treated as stretch goals. Concepts will be narrowed to one using a weighted decision matrix, and development will proceed in stages, in parallel across mechanical, electrical, and software workstreams.

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I. PROJECT SCOPE

The scope of this project is to design and construct a proof-of-concept arborist robot capable of:

(a) Attaching securely to a small tree or representative structure
(b) Moving vertically along the trunk
(c) Stopping and maintaining its position
(d) Position a cutting mechanism relative to a selected branch
(e) Cutting a small branch from the base of the trunk
(f) Using sensors to monitor position, movement, and system status
(g) Navigating around obstacles or unselected branches during vertical movement
(h) Returning safely to the ground after the operation is complete.

The prototype will be on a small scale to demonstrate the core functionality of the system, notably the scale may reflect the trees at an orchard. The robotic prototype may operate under human operator control, with consideration of autonomous capabilities for future development. The robot will not

The project will include constructing literature to document the design and development of the arborist robot, constructing literature to describe the operation of the arborist robot, and the physical prototype depicting the functionality. Success will be measured with feedback from experienced designers and educators, as well the operable success of the prototype.

II. BACKGROUND

Arborism refers to the practice of caring for individual trees and or other woody plants, focusing on their health, safety, and life cycle. An arborist acts upon the principle of arborism, this may include but is not limited to: cutting and removing tree branches, climbing trees, or trimming tree branches. Arborist's can be found in many environments from fruit orchards to forestry, each with varying hazards and inefficiencies with manual arborism. The working hazards of an arborist are exceedingly high due to the risk of falling branches, loss of grip/friction leading to an arborist falling from a dangerous height, and operating a cutting mechanism at elevated heights while supported by a fiber harness. Due to these hazards a new branch of industrial technology is under development focusing on arborist robotics, such robotics are capable of completing the tasks of an arborist while ensuring the human operator is away from risks of danger. This field focuses on developing robotic systems capable of climbing, cutting and trimming branches autonomously or under operator control, this is the field this project will reside in.

While the field of arborist robotics is broad, a notable arborist environment of interest is an orchard trimmer or small tree trimmer. Such tasks generally require a human worker to manually operate a cutting mechanism to remove or trim the branches they feel necessary, this risking operator safety of working closely with a cutting mechanism and risking a harmful fall depending on the height of the desired branch. Ideally this task could be automated with a robotic system placed on or around the tree by personnel, which is capable of maneuvering to and

cutting the branch of interest. Such a robot would remove the risk of an arborist falling and remove the risk of manually operating a cutting tool at close distances.

The field of arborist robotics is not a new topic with a few companies beginning to commercialize their own designs. Serpent Robotics has released the SR-1 which is a cable/rope driven arborist robot capable of cutting predefined branches and lowering them to the ground, this design requires a worker or system to set a hook point for the rope/cable for the robot to climb [1]. The concept of a MonkeyBot is underdevelopment at select companies and educational institutions, notably the utilized reference paper describes a walking mechanism to climb the tree trunk with a branch clamping mechanism, branch cutting/pruning mechanism, and object avoidance mechanism [2]. Another arborist robot under development is a manipulator based approach where the manipulator extends a cutting mechanism to a desired branch; such an approach has been developed with the concept of branch identification with machine vision [3]. An area of arborist robotics with little development is bio-inspired robotics, this view on how animal movements can be mimicked by robotics to perform the same or similar action. In terms of arborism and climbing trees, the movements of an inch worm or snake are of interest.

The commercial development of arborist robotics generally focuses on large-scale forestry, or large-scale tree branch removal. The development of an arborist robot capable of trimming/cutting/pruning trees on a smaller scale, such as an orchard, will use the experiences and lessons learned from large-scale projects, while involving the innovation of new promising techniques. Note orchards are of primary reference as they provide a more structured operating environment than a large, mature forest or urban trees. In Ontario, these orchards usually contain about 900-1300 trees/acre, with 1000 being the sweet spot [4]. Pruning remains a significant manual operation within apple production. Pennsylvania State University reports that apple tree pruning requires about 31 hours of skilled labor per acre and accounts for about 20% of pre harvest costs [6]. Orchard pruning is also selective rather than simply removing every branch. OMARFA recommends removing branches based on a number of factors such as size, position. vigor, and relationship to the central leader [7] [8]. These characteristics make high density orchards a suitable application for robotic pruning while still presenting challenges related to mobility, positioning, sensing, and selective branch removal.

III. CUSTOMER REQUIREMENTS

The customer requirements are set in place given that the customer needs are trimming, cutting or pruning small tree branches. The robot is expected to be industrialized and assumes the primary customer to be businesses which periodically require multiple days use of the arborist robot. The primary customer requirements are presented in table 1.

Table 1. Customer Requirements

ID Number	Requirement	Requirement Basis
CR #1	Ease-of-Use	The customer should be able to secure the robot around or on the desired tree, the customer should also be able to remove the robot from the tree after use.
CR #2	Light Weight	The customer should be able to move the robot tree to tree without the need for heavy machinery.
CR #3	Safety	The customer should be safe when operating or moving the robot, this considering pinching, interfaces and sharp edges.
CR #4	Accuracy	The robot should only trim or cut the branches specified by the operator or appropriate program.
CR #5	Low Cost	The customer may request multiple units for a large orchard or tree farm, the cost should be kept minimal.
CR #6	User Friendly	The customer should be able to understand the system and operate the device in such a way where their safety is not at risk.
CR #7	Longevity	The product is expected to operate for an extended period of time to support the cases where the robot will be used during every hour of the day for multiple days
CR #8	Reliability	The customer should feel comfortable using the robot and have trust in the operation.
CR #9	High Quality	The robot should not significantly damage the tree trunk and should perform clean cuts on the desired branches

IV. PROBLEM DEFINITION

Tree trimming is a labour intensive and hazardous task. Arborists are often exposed to various risks such as falls, cutting equipment, and electrical hazards. Powerlines, faulty equipment, and working with a chainsaw are

major hazards associated with the job [8]. Working at heights with such hazards all around can create additional consequences if an arborist has a sudden medical emergency. In 2021, the Occupational Safety and Health Administration documented a fatal incident where an arborist experienced a heart attack while pruning a tree and had fallen off [9]. This project aims to investigate ~~a scaled~~ robotic arborist platform that is capable of travelling along the tree trunk, getting positioned near a selected branch, and cutting it without direct involvement from the professional. This would greatly reduce the risk professionals face from the many dangers that come with the job.

While many arborist robotic systems are intended for large mature trees or forestry applications, this project focuses on orchards and similar environments. These orchards provide a more structured environment where trees are arranged in somewhat uniform rows, making it more suitable for the development of a scaled robotic pruning system. A representative Tall Spindle orchard configuration described by OMAFRA uses about 0.9 m spacing between trees and about 3.6 m between rows, with a top support wire about 2.75 m above the ground[10]. OMARFA also states that a five year old Tall Spindle tree should contain fruiting wood throughout the 0.6-3 m region of the tree [7]. These dimensions provide an initial reference for the vertical operating range and available working space of the robot.

Despite the structured layout, individual trees are not geometrically uniform. An eight year old study of dwarfing “Honeycrisp” apple rootstocks reported trunk cross sectional areas of about 13.2-17.6 cm^2 [11]. Assuming an equivalent cross section, this corresponds to about trunk diameters of 41-47 mm. A separate stuffy of dwarfing “Granny Smith” apple trees reported trunk cross sectional areas of about 25.1-32.4 cm^2 for several M.9 rootstocks after seven growing seasons [12], corresponding to an equivalent diameter of 57-64 mm. Together, these studies can be used to determine an initial trunk diameter design range for dwarf apple trees, however would still require further verification.

Branch geometry creates another significant design challenge. A study of Tall Spindle apple trees reported an estimated height of 3.5 m, with about 30 primary branches distributed around the central trunk and branch junction diameters of 10-35 mm [13]. These branches may obstruct the robot’s vertical movement even when they are not intended for removal. Therefore, the system must be able to navigate around or bypass these branches while staying attached.

Selective pruning further prevents the robot from simply removing every branch that obstructs its path. OMAFRA recommends removing scaffold branches that exceed about 50% of the diameter of the central leader, in addition to competing, dead, forked, and excessively vigorous branches [6]. Previous robotic apple pruning research has demonstrated successful cutting of branches about 25 mm in diameter over various ranges of orientations [14].

The system must maintain sufficient support and stability during movement and cutting while minimizing unnecessary damage to the tree. It must accommodate variations in trunk geometry, move vertically through the

required pruning region, navigate around unselected branches, position itself around the trunk, and accurately position the cutter relative to selected branches. Remote control, localization, sensing, and appropriate safety systems must be also integrated with mechanical and electrical subsystems.

The core design question for the project is: How can a robotic system securely attach to a tree, move vertically along the tree, get positioned around branches, and remotely perform selective cutting while minimizing risk to the operator and tree itself?

The main engineering challenge is integrating:

- Secure attachment to the tree
- Vertical mobility
- Positioning around the trunk
- Remote operation
- Branch cutting
- Localization and sensing
- Safety systems
- Mechanical, electrical and software subsystems

V. ENGINEERING SPECIFICATIONS

The engineering requirements presented within the section are subject to change with the design and development of the arborist robot; these engineering specifications ~~as seen~~ in table 2 are ~~to be preliminary.~~

Table 2. Engineering Specifications

ID Number	Specification	Target	To Be Determined
ES #1	Supported trunk diameter range, mm	40-65 mm*	Actual diameter of the intended test tree/equivalent object
ES #2	Vertical Travel Distance, m	0.6-3 m*	Minimum travel distance needed for demo; scaled relationship to orchid tree height
ES #3	Vertical Travel Speed, m/s	0.01-0.02 m/s*	Desired climb time, motor/actuator speed, gearing, total robot mass
ES #4	Vertical stopping/positioning error, mm	5-15 mm*	Accuracy of the cutter stopping relative to the branch
ES #5	Circumferential access around trunk, °	360°*	Whether true 360° is needed or would satisfy for orchard access
ES #6	Circuferential positioning error, °	1-5°*	Required accuracy based on cutter size, branch diameter, and manipulator reach

ES #7	Maximum branch diameter cut, mm	20-30 mm*	Final branch size for demonstration; cutter's capability
ES #8	Cutting success rate, %	70-80%*	Number of trials and acceptable failure rate
ES #9	Maximum unselected branch branch bypassed	3-7*	General orchid branch diameter/geometry the robot needs to pass
ES #10	Robot/support slip while stationary, mm	7-15 mm*	Acceptable movement during cutting
ES #11	Holding/loading capacity, N or kg	0.5-2.5 kg*	Robot mass + cutter + dynamic cutting loads
ES #12	Structural Factor of Safety	5-8 kg*	Maximum expected loads from weight, motion, and cutting
ES #13	Tree damage	Criterion TBD*	Criteria for assessing damage to the tree and the acceptable quantities
ES #14	RC Range	4-7 m*	Expected distance the operator can be away
ES #15	Communication loss safe stop time, s	50-300 ms*	Controller latency and risk analysis requirement
ES #16	Emergency stop response time, s	50-300 ms*	Acceptable stopping time from hazard assessment
ES #17	Localization/position estimate accuracy, mm	1-3 mm*	Sensor choice and positioning accuracy needed on branch approach
ES #18	Operating time per charge, min	10-40 min*	Expected demo cycle time, motor/cutter power consumption, battery capacity
ES #19	Complete pruning cycle time, s	4-7 min*	Desired productivity
ES #20	Robot mass, kg	1-4 kg*	What can be carried/installed reasonable by 1 person

*Not verified; based on preliminary discussions and subject to change

VI. PROJECT PLAN

The project will use an iterative engineering design process to develop a proof-of-concept arborist robot that attaches to a tree, moves vertically, positions around the trunk, and performs a controlled cut on a targeted branch. The plan is organized around development stages and their dependencies rather than fixed task dates, because dates will be refined at each progress report. The design philosophy is to keep the initial system simple,

demonstrate reliable basic functionality first, and add autonomy and advanced features only after the core platform works (under-promise, over-deliver).

Table 3. Development stages

Development Stage	**Activities / Task**	**Resources**	**Deliverables / Outputs**	**Time Frame**
Stage #1 - Research and requirements	Research existing arborist robots, tree climbing practice, cutting mechanisms, sensors, and standards. This refines the engineering specifications and design constraints	- Research papers and technical references - existing arborist robot designs - engineering standards - CAD/software tools - faculty guidance	Engineering requirements and design constraints	September - October 2026*
Stage #2 - Concept development and selection	We will compare multiple concepts using a weighted decision matrix based on safety, stability, mobility, cutting capability, manufacturability, cost, weight, and reliability. One concept will be selected and refined into a detailed system design.	- CAD software - design software - engineering calculations - decision matrix - faculty/team expertise	Engineering requirements and design constraints	October 2026*
Stage #3 - Parallel workstreams after selection	(i) mechanism, covering attachment, drive, and motor sizing; (ii) power and electronics, covering battery, motor drivers, emergency stop, and wireless link; (iii) software and control, covering remote control, sensor reading, and coordinated control of all actuators; (iv) vision and operator interface, covering the touch interface and, as a stretch goal, branch detection.	- motors - motor drivers - sensors - battery/power components - wireless communication hardware - CAD Software - programming tools - simulation/ calculation tools	Subsystem designs and prototypes	October - November 2026*
Stage #4 - Skeleton prototype	Integrate the attachment and climbing mechanism and demonstrate basic remote-controlled climbing, targeted before the winter break.	- structural materials - motors - wheels - motor drivers - microcontrollers - battery - wireless controller - 3D printer(or other fabrication)	Basic climbing prototype	November - December 2026*
Stage #5 - Cutting and positioning	Integrate the cutting mechanism and circumferential positioning.	- cutting mechanism - actuator - motors - motor drivers - positioning sensors - microcontroller - test branches	Controlled cutting and positioning capability	January - February 2027*

		- fabrication equipment - safety equipment		
Stage #6 - Sensing and localization	Add sensors for movement, positioning, and system monitoring.	- encoders - distance/proximity sensors - current sensors - limit switches - microcontroller - computer wiring - communication hardware - software development tools	Integrated sensing system	February - March 2027*
Stage #7 - Full minimum viable prototype sequence	Attach, climb, stop, position, cut, descend.	- complete prototype - battery - control system - sensors - cutting mechanism - test tree - safety equipment - data collection tools	Functional proof-of-concept prototype	March 2027*
Stage #8 - Stretch goals	Obstacle bypass, branch detection, and semi-autonomous features.	- camera - computer/ embedded processor - computer vision software - additional sensors - testing equipment - existing prototype	Optional advanced functionality	March - April 2027*

*~~Not verified;~~ based on preliminary discussions and subject to change

The key dependencies consist of: concept selection being completed before detailed design and build work begins. The attachment system must hold reliably before the cutting module is integrated. Communication, emergency stop, and safe stop on signal loss must work before any powered test on a tree. The control architecture must coordinate the actuators as one system rather than as independent control loops, since the drive, positioning, and cutting mechanisms interact. Simple electronics can be tested on a breadboard or proto board before custom circuit boards are made. The full costs cannot be determined at this stage but will be added in later progress reports.

Table 4. Estimated Cost

Resources	Examples	Estimated Cost
Mechanical Components	Motors, wheels, structural materials, bearings	TBD
Electrical Components	Battery, motor drivers, wiring, emergency stop	TBD

Sensors	Encoders, proximity sensors, current sensors	TBD
Computing/Control	Microcontroller, embedded computer, wireless hardware	TBD
Cutting System	Actuator, guarded cutting mechanism	TBD
Fabrication	3D printing, machining, fasteners	TBD
Testing/Safety	Test fixture, safety equipment	TBD
Total	**-**	**$1000**

Based on preliminary discussions, table 5 below outlines a high level breakdown of each member's strengths and roles assigned at the current stage of development. Once further progress is made, these roles are subject to change as the team will have a better understanding of what is needed.

Table 5. Team Roles

Team Member	Discipline	Suited For
Isabella Herrera-Casco	Mechanical	Mechanism design, motor sizing, structural analysis, prototype assembly
Ibrahim Ahmed	Mechatronics	Power system, motor control, electronics integration
Connor Armstrong	Mechatronics	Electronics, wireless communication and emergency stop, wiring and circuit boards
Jonathan Leaper	Software	Control architecture, sensor fusion, localization
Drew Glover	Software	Branch detection (vision), operator interface

VII. References

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