PIPER: Pot-in-Pot Extracting Robot

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Abstract

Pot-in-Pot (PNP) has become a flourishing tree nursery production system due to its many advantages. However, this system has some complications surrounding the harvesting process, namely, the physical toll it takes on laborers and increased labor costs. To alleviate these issues, this project designed and prototyped a remote-driven robotic system named Pot-In-Pot Extracting Robot (PIPER). PIPER can navigate to a selected potted tree in the field and lift the production pot out of the socket pot without causing harm to the trees, pots, and robot itself. The box-shaped, metal chassis houses several components allowing for navigation to and lifting of the pots. Driven by two wheels in the front, PIPER has one large caster to the back of the chassis that allows for easy navigation amongst the rows. After navigating into position around a potted tree, PIPER grips the production pot using custom grippers for the pots' circumferences. At the same time, gripping electric linear actuators lift the potted tree from the socket pot installed in the ground. All while being powered by a gasoline generator. With the proper integration of these components, PIPER has the potential to become the go-to robot for harvesting nursery trees. With the implementation of this system, PNP farm owners will significantly benefit from decreased labor costs and reduced workplace injuries.

Acknowledgments

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Table of Contents:

1. Introduction

Pot-in-pot (PNP) is a nursery production system that allows nurseries to grow trees within a pot installed in the ground. This is done by semi-permanently installing a pot within the ground called a socket pot. Then, a second pot, the production pot, is placed within the socket pot. The tree will remain in the production pot until it is bought or grows out of the pot.

Figure 1. *Picture taken at Hale & Hines Nursery in McMinnville, TN showing the PNP system set up for 15 gallon pots. The 15 gallon pots can range in diameter from 17-22 inches and have an approximate weight of 60 pounds.*

Producers use this system for multiple reasons; the first is that the trees have access to their personalized nutrients via fertilizers, resulting in accelerated growth. This system also makes removing the trees from the ground easier and allows year-round harvesting. Despite several benefits, the PNP production system also contains some problematic factors, especially surrounding harvesting.

PNP tree harvesting can be a time-consuming and labor-intensive job. Harvesting can take up to six people, making labor a notable portion of total costs. It is estimated that the harvesting or extracting process alone accounts for 20% of total labor costs (Industry Contact). In addition to the fiscal considerations, harvesting is back-breaking work that is not conducive to a favorable long-term work environment. Therefore, a solution is needed to alleviate the tedious PNP harvesting process.

2. Project Definition

There is a need to design a chassis and lifting mechanism that will be able to navigate through a nursery that produces trees in a PNP manner such that selected potted trees can be extracted. Eventually, this mechanism is expected to be fully automated to increase the production rate, which must be primarily considered during the design process. Before further consideration can be given to the exact design of the chassis and lifting mechanism, a clear definition of success must be formulated.

Because no two tree farms are alike and do not follow specific standards or regulations for farm layout or design, this project has adopted standards to guide the design process. They are as follows:

- Pot Type: The Grip Lip 6900 pot style from Nursery Supplies Inc. (http://www.nurserysupplies.com/) will be considered the standard for this project. Frame measurements and gripping designs will be based on the GL6900. Additionally, the GL6900 will be used to determine if the final design is successful. The GL6900 comes in a range of heights and diameters. The standard version is 15.13 inches tall and has a top diameter of 17.25 inches.
- Spacing: Although nurseries do not have a required spacing for 15-gallon pots, the spacing will be, at minimum, a five-foot by five-foot grid pattern. This spacing is adopted by many tree growers due to the machinery used to install the pots.

- Road Conditions: While the road conditions (gravel, grassy, mulch, etc.) may vary, the design is based on a nursery with level rows and spacing with slopes no greater than 12% or 8.53°, as recommended.

3. Success Criteria

To be successful, the following criteria and constraints must be followed:

- Must not exceed a $5,000 budget.
- Must be capable of mechanically lifting the tree pots.
- Design weight of 90 lb. After weighing eight 15-gallon GL6900 pots filled with saturated soil, the average weighed 59.16 lb or approximately 60 lb (see 10.1 Pot Weights in Appendix). Using a factor of safety of 1.5, the design must be able to lift at least 90 lb.
- Limited human interaction.
- For the scope of this project, a person will position the robot around the potted plant. However, once the lifting process begins, no human interaction is allowed. In a future project, the robot will be autonomous, but is not within this project's scope.
- Robot will lift the production pot, leaving the socket pot undamaged and in the ground.
- Device will fit between the nursery rows when navigating and harvesting.
- Nursery row spacing for 15-gallon pots is on a 5 ft by 5 ft staggered or square layout.
- Robot can handle a range of pot diameter sizes.
- The GL6900 15-gallon pot comes in three different heights: squat, regular, and tall, and in a range of diameters. The robot's frame and lifting mechanism must accommodate diameters ranging from 17-22 inches and heights from 12-17 inches.

4. Design Approaches

4.1 Chassis

4.1.1 Small Forklift

The small forklift's main frame incorporates a lifting device in front of the mechanism's body. With this design, two main problems prevented it from being pursued. First, the chassis length would be too large, given the minimal spacing for the 15-gallon pot layout. The robot's body would hit the other pots making it challenging to navigate or could even lead to potential damage to the trees or pots. Second, this design would require a considerable counterweight on the chassis to ensure the lifted pot would not tip the machine over. The need for a heavier counterweight that essentially serves no other purpose makes the robot heavier and less efficient.

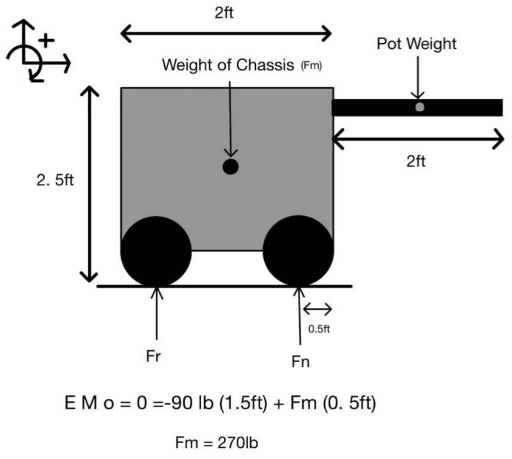


Figure 2. *This drawing demonstrates the tipping point of the chassis.*

4.1.2 Box Frame

The second approach was a box frame that opened up to encapsulate the tree and pot. It would use a lifting device on the edges of the mechanism's frame to pick the potted tree up. A linear actuator and motor would power the lifting mechanism. This box frame design met all requirements and constraints and was the pursued approach.

4.2 Gripping Mechanism

4.2.1 Engine Hoist

The engine hoist could grip the pot's rim and lift from above via a winch system. The gripping attachment would be hooks that grab the lip of the pots.

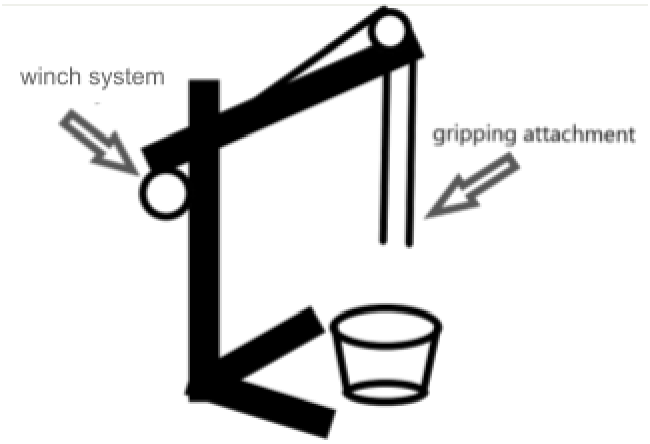


Figure 3. *Alternative gripping method. This idea is similar to a winch system used to lift car motors.*

This alternative was not pursued because designing sensors to grip the various-sized pots would be challenging. Also, the hoist design would also need to be tall and could easily damage the tree canopy. Hence, the hook design was not pursued because the sensors required would be expensive and add another layer of complexity to the project.

4.2.2 Claws

The claws are gripping mechanisms that fit around the lip of the pot that sits within the socket pot. The claws would have fingers that can pivot to conform to different pot diameters. The claws would grip the pot right beneath the lip to utilize the strength of the lip of the pot. The claw arms would need to be sufficiently long to grip evenly around the pot while being thin enough to allow the chassis to fit around the pot.

4.3 Lifting Mechanism

4.3.1 Hydraulics

The first option considered was hydraulic cylinders. The idea came from forklifts used in warehouses to lift pallets of products. Hydraulic cylinders are the driving force behind these machines' ability to lift this weight. If these cylinders are installed on PIPER, the robot can lift weights heavier than 90 lbs without a problem. However, hydraulic systems require many components to function correctly, such as pumps, motors, hydraulic fluid tanks, and gasoline tanks. Therefore, this system comes with two problems; firstly, the concern that all of the components required would make the entire system bulky and be unable to maneuver through the rows or even allow other parts to be attached to the chassis. The second problem would be the system's additional weight once hydraulics are connected. This weight could cause it to get stuck in the dirt or even fall over while maneuvering through the rows.

4.3.2 Electric Linear Actuators (ELA)

Electric linear actuators (ELA) are another possible lifting method. ELAs are compact yet have considerable lifting power. Such a mechanism would be better suited to fit the sizing constraints. Another benefit is having feedback from an ELA, which would help with future autonomization. Despite the many advantages, one downfall of ELAs is that they operate at a slower speed than hydraulics.

4.4 Design Selection

Using the pros and cons of each design approach to guide the design process, the overall design of PIPER is depicted in Fig. 4. It features a box chassis, two linear actuators, claw-like gripping mechanisms, and three wheels.

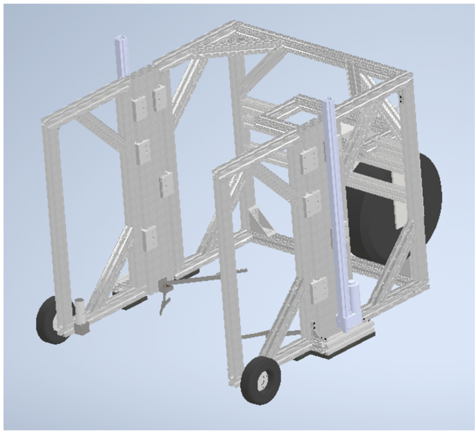


Figure 4. *Inventor Pro Drawing of chassis featuring linear actuators, grippers, and three wheels.*

5. Selection and Development of Design

5.1 Chassis

5.1.1 Sizing

The sizing constraints of the nursery were considered. The spacing between the individual rows of pots is 5 ft. The space is typically a 5ft by 5ft square or staggered pattern for the 15-gallon pots. It is important to note that this spacing is measured from trunk to trunk or pot center to pot center. A measurement or distance from pot lip to pot lip was found to determine the limitations put on the chassis. The largest pot diameter for a 15-gallon of 22 inches was used to determine the minimum spacing allotted for the chassis. From here, the

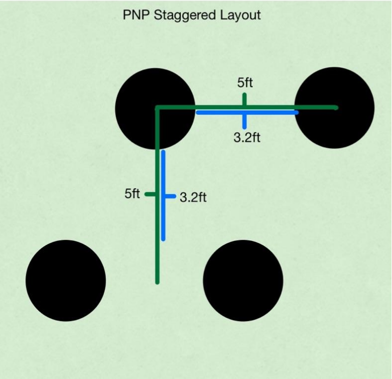


Figure. 5. *Layout of PNP system for 15 gallon pots. The spacing dimensions are shown.*

space from pot lip to pot lip could be calculated, as shown in Fig. 5.

It was calculated that 38 inches or about 3.2 feet was the space to drive the chassis through the PNP system. Thus, the decision was made for the footprint of the chassis to be a 3ft by 3ft frame, leaving a total of 2 inches of clearance; or one inch on each side between the chassis and pot lip.

5.1.2 Material Selection

Steel and aluminum are the best and most commonly used materials for structures supporting a 90lb 15-gallon PNP tee. Aluminum alloy has a yield strength of 125 MPa which equals about 18,000 psi, and steel has a yield strength of 250 MPA, which is about 36,000 psi. Therefore, the strength of both of these materials should be sufficient to support the weight of the pot. Although steel is cheaper and stronger, aluminum is of lighter weight and rust-resistant. From a previous year's project, 80/20 aluminum T-slot extrusions were available (80/20, Columbia, Indiana). Therefore, this material was selected for building the frame in the spirit of recyclability. The 80/20 extrusions were made out of 6105-T5 aluminum with a yield strength of 35,000 psi, comparable to A36 carbon steel with a yield strength of 36,000 psi (www.internetimage.ca, n.d.). Additionally, aluminum is one-third of the weight of steel. Therefore, a frame built from aluminum extrusions could support lifting 90 lb tree pots. Also, the extrusion bars are covered in a transparent anodized material that helps to prevent oxidation and corrosion. This characteristic makes the material well suited for being outside in the elements, which is a needed feature.

5.2 Wheels

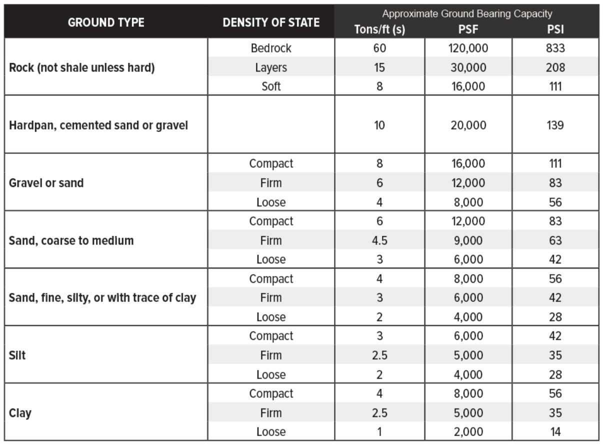
5.2.1 Sizing

The most prominent consideration when selecting appropriate wheels for the robot is how the tires interact with the ground. More specifically, it is essential to determine if the tire's footprint contacting the ground’s surface will supply ample support for the robot’s load. If the tires are too small, the wheels can sink into the ground, resulting in the frame struggling when moving across various types of terrain, such as grass, or even over irrigation hoses, commonly found in nursery settings. Thus, it is important to calculate the needed tire dimensions. The necessary dimensions can be determined using Eq. 1, which relates the ground pressure, weight, and tire footprint area for a rubber tire:

$$P = \frac{W}{0.78*A} \tag{1}$$

P= ground pressure
w= width of tire
A = area of tire contact patch or footprint

To solve for the area of the tire’s footprint, a calculated load, and an assumed ground pressure must be used. Using a tool in CAD Inventor Pro to calculate the weight of the chassis and components, the load was calculated to be 200 lb. Using a factor of safety of 1.5, a weight of 300 lb was used in the following calculations. Given that the weight will be distributed amongst three tires, this total weight is divided by three to get a load of 100 lb, and this value was then used in Eq. 1. A ground pressure must be selected based on the ground coverings seen in PNP tree nurseries.



GROUND TYPE	DENSITY OF STATE	Approximate Ground Bearing Capacity		
		Tons/ft (s)	PSF	PSI
Rock (not shale unless hard)	Bedrock	60	120,000	833
	Layers	15	30,000	208
	Soft	8	16,000	111
Hardpan, cemented sand or gravel		10	20,000	139
Gravel or sand	Compact	8	16,000	111
	Firm	6	12,000	83
	Loose	4	8,000	56
Sand, coarse to medium	Compact	6	12,000	83
	Firm	4.5	9,000	63
	Loose	3	6,000	42
Sand, fine, silty, or with trace of clay	Compact	4	8,000	56
	Firm	3	6,000	42
	Loose	2	4,000	28
Silt	Compact	3	6,000	42
	Firm	2.5	5,000	35
	Loose	2	4,000	28
Clay	Compact	4	8,000	56
	Firm	2.5	5,000	35
	Loose	1	2,000	14

Figure 6. *Range of ground pressures based on ground types*

Various ground conditions can be used in nurseries, including grass, mulch, and gravel. However, the ground conditions are uncontrollable; therefore, it was best to design conservatively and use ground pressures for soft surfaces. Soft surfaces pose the most significant problems as the tires are more susceptible to sinking. Using the table in Fig. 6, the softest soil pressure could be determined (Ground bearing capacity table 2021). The pressure of 14 psi was selected for the following calculations. Since the load and assumed ground pressure was determined, rearranged Eq. 1 can be used to calculate the required tire footprint area.

$$14psi = \frac{100lbs}{0.78*A}$$

$$A = 9.2\,in^2$$

After calculating the total area of the contact footprint, the width and diameter of the tire could be determined using the relationship shown in Fig. 7. Note that the relationship for soft surfaces is what is being considered. To determine the needed wheel diameter, a wheel radius must be selected. Given the size constraints of the chassis, as mentioned in previous sections, the width of the tires must be 2 inches at maximum. This allows the chassis to still be 30 inches wide and gives a one-inch clearance between the wheels and chassis. Therefore, using a 2-inch width, the required minimum diameter can be found using Eq. 2.

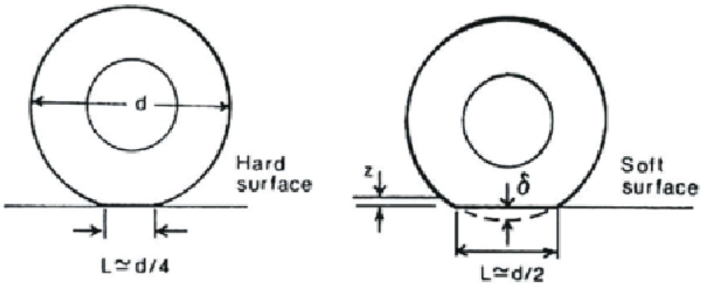


***Figure.* 7.** *Visual depiction of the relationship between the wheel diameter and the length of its footprint.*

$$A = base * width \tag{2}$$

$$9.2\ in^2 = \frac{diameter}{2} * 2\ in$$

$$diameter = 9.2\ in$$

5.2.1.1 Tire Selection

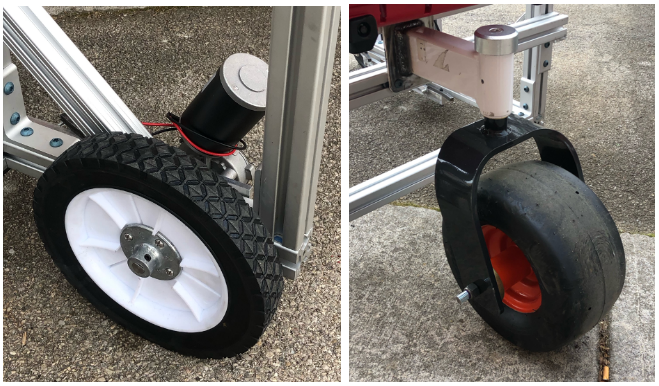


Figure. 8 & 9. *To the left is a photo of the driven wheels. They have a 10 in diameter and are 1.75 in thick. To the right is the caster wheel that sits in the back of the chassis. The wheel has an 11 in diameter and is 6 in thick. The setup of the driven wheels and caster wheels allows the robot to drive similar to a forklift.*

5.2.2 Motor

The motor selection was an essential part of the design process for the wheels and mobility of the robot. To select the motor, two calculations were considered, torque and speed.

5.2.2.1 Torque

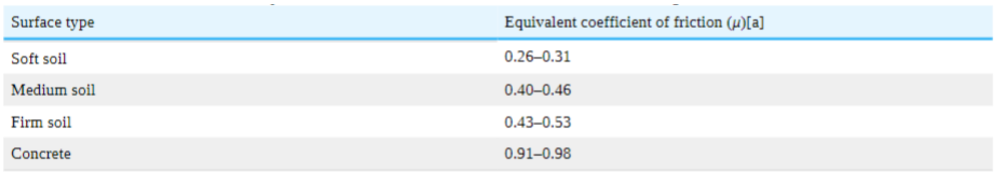
To find the required torque, the maximum slope needed to be considered to represent normal force. As determined by asking an expert in the horticulture field, the maximum slope that will be encountered was estimated as an 8.53-degree incline. This value can be used in Eq. 3 to determine the normal force on such an incline.

$$\text{Normal Force} = \frac{Weight}{cos(\theta)} \qquad (3)$$

$$\text{Normal Force} = \frac{300lb}{cos(8.53)} = 303.4\ lb$$

Now, this adjusted normal force can be used to calculate the new tractive force using Eq. 4. To perform the calculation, the friction coefficient for soft soil was selected from Table 1.

Table 1. *Equivalent coefficient of friction for a tractor wheel working on different surfaces*



Surface type	Equivalent coefficient of friction (μ)[a]
Soft soil	0.26–0.31
Medium soil	0.40–0.46
Firm soil	0.43–0.53
Concrete	0.91–0.98

$$T = \mu_f \bullet F_N \tag{4}$$

T = Tractive force

$$\mu_f = friction\ coefficient = 0.31\ soft\ soil\ type$$

$$F_N = Normal\ Force = \frac{303.4 lb}{2\ wheels} = 151.7\ lb$$

$$T = 0.31 * 151.7 = 47\ lbf$$

After calculating the adjusted tractive force, a torque requirement can be calculated. To determine the torque on 10-inch diameter tires, Eq. 5 was used.

$$Torque = T \bullet radius \tag{5}$$

$$Torque = 235\ in - lb$$

Converting the value of torque to ft-lb:

$$Torque = 19.6\ ft - lb$$

5.2.2.2 Speed

Based on operation speeds of similar equipment found at nursery sites and as mentors suggested, the chassis's maximum travel speed was set to be 0.5 mph. This horizontal speed can determine the required rotational speed that the motors must supply to each chassis' wheel.

First, the speed can be converted into inches per minute. Then, the circumference size of each wheel can be used to determine the number of rotations performed per minute. The diameter used to calculate the circumference was the diameter of the selected tires.

$$Circumference \ = \ pi \bullet diameter \ = \ 20.11\, in \tag{6}$$

$$\text{rpm of wheel} = \frac{528\frac{in}{min}}{31.4in} = \ 16.8\, rpm$$

Thus, the required rotational speed of the motor was found to be 16.8 rpm.

5.2.2.3 Motor Selection

Figure 10. *Motor selected to drive two driven wheels. The selected motor is a 12V DC gear motor. It is rated to supply 6 ft-lb of torque. The motors will be attached to the wheels via a steel shaft. Additionally, the motors will be mounted to the 80/20 with a fabricated motor mount.*

5.3 Lifting Mechanism

Figure 11. *Picture of the ELAs used from Progressive Automations*

Due to the issues previously mentioned about hydraulics, it was decided to find a mechanism that works similarly to hydraulics but without size and weight constraints. This led to the consideration of electric linear actuators (ELA), which can lift an immense amount of weight. The ELA (Progressive Automations) selected for the design can lift 450 pounds of force each, totaling 900 pounds, and are also small in size and only weigh approximately 5-7 pounds each. Some other benefits of ELAs are the weatherproof ratings that allow them to work in wet or dusty conditions without malfunctioning.

Also, the ability to work electrically rather than powered by gasoline or diesel, thus, alleviating any concern of possible leakages. One last advantage to ELAs is their lock-and-hold capability; if, for whatever reason, ELAs lose power while lifting a pot, the rod that is extended will lock in place and hold the pot where it last raised it. This is unlike hydraulics; if hydraulics lose power, the cylinder's rod will recede. Thus, making ELAs the better choice for this design.

5.4 Sliding rail

The siding rail is a crucial element to the success of the robot's lifting. The sliding rail is a three-piece extrusion bar or a 4.5 inches wide piece of 80/20 that fits within linear bearings on the chassis. The sliding rail is where the gripping mechanisms attach, and the linear actuators attach to the other side of the sliding rail, which is used to lift the pot. The sliding rails are attached to the linear actuators via a bolt and nut through the piston shaft of the linear actuator. A three-piece wide piece of 80/20 was selected to add structural integrity along with giving enough space to mount the grippers.

Figure 12. *3-piece sliding rail with linear bearings*

5.5 Gripping Mechanism

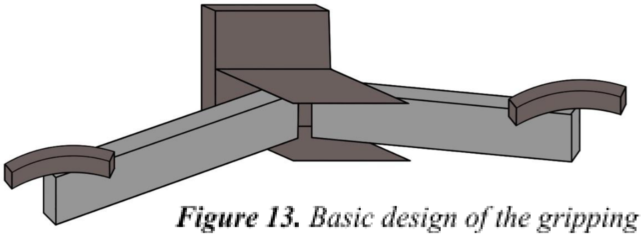


Figure 13. *Basic design of the gripping mechanism*

The gripping mechanism's design was based on the mechanics involved in harvesting one of the GL6900 15-gallon pots. To harvest, two people work together to lift the pot by using both hands to grip the pot's rim and then lift it. Thus, the team proposed using two claw-like gripping devices featuring two arms and a finger-like piece at the end of each arm. A basic depiction of this design is shown in Fig. 13.

The general idea of the fingers is to allow the robot to form and lift up on the pot's lip, similar to how a person's hand would. In order to ensure the gripping mechanism works properly for the range of pot diameters and that there will be enough gripping force, the pieces of the design must be sized accordingly.

5.5.1 Sizing

The two gripping mechanisms designed to grip around the pot consisted of two identical mechanisms. Each gripping mechanism had a mounting unit and two arms with two fingers on top. The mounting unit was made up of three steel plates attached to a back plate to mount onto the triple piece of 80/20. Within the mounting unit were two arms made from rectangular aluminum bar stock that was 1 inch by ½ inch and 6 ¾ inches long. Aluminum bar stock was selected for the arms because of availability and strength. Stress analysis was conducted on the arms to gauge the size of the bar stock needed to withstand the force of the pot. The arm length was determined by finding the length of a line tangent from the mounting unit to the edge of 22 inches, and this process is depicted in section 9.2 of the appendix. The arm was positioned 1 inch away from the chassis, and the chassis was 2½ inches away from the closest edge of the pot. Using 2-D CAD, the length of the tangent line was determined to be 6¾ inches from the mounting plate to the pot. If the arms were any longer, the finger would no longer be able to close underneath the lip of the pot.

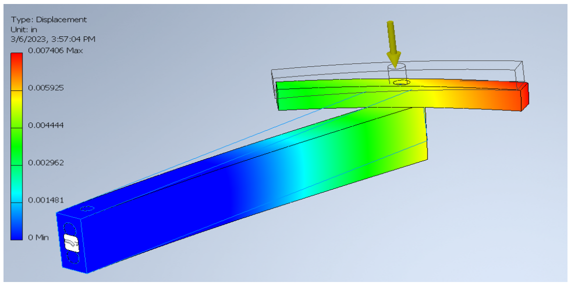


Figure 14. *This image shows the stress analysis done via Autodesk Inventor and the left scale shows deformation in inches*

The finger was made from ⅜ inch square steel bar, allowing the finger to fit underneath the lip when lifting. The finger was 4 inches long and bent to a radius of 10 inches, allowing the fingers to be adjustable for pot diameters ranging from 17 to 22 inches. The fingers were mounted at the end of each arm using a shoulder bolt to allow finger rotation. Fingers were gripping around the pot, and the arms were used to rotate and enclose the pot. The back of the aluminum bars was attached to the mounting unit via a 5 mm (0.2 inches) pin with a flat side and multiple set screws. The pin went through a gear, then through the top part of the unit into the gear plate and a washer, the aluminum bar, another washer, and out the bottom. Because the pin will be under shear stress due to the moment of the arms under load, the pin was held in place via multiple set screws. The calculations were as follows:

$$Force\ of\ the\ pot\ per\ Arm\ =\ 22.5\ lbf$$

$$Arm\ length\ =\ 6.75\ in$$

$$shear\ strength\ of\ pin\ =\ \frac{50{,}000 lbf}{in^2}$$

$$Torque\ =\ arm\ length\ \bullet\ Force\ of\ the\ arm\ per\ pot \tag{7}$$

$$Torque\ =\ 6.75\ in\ \bullet\ 22.5\ lbf\ =\ 146\ lbf\ -\ in$$

$$coupled\ forces\ on\ pin\ =\ 1\ in\ apart$$

$$146\ lbf\ -\ in\ \div\ 1in\ =\ 146\ lbf$$

$$C/S\ area\ of\ pin\ =\ 0.0308\ in^2$$

$$146\ lbf\ \div\ 0.0308\ in^2\ =\ 4814\ \frac{lbf}{in^2}$$

$$50,000\frac{lbf}{in^2} \geq\ 4814\frac{lbf}{in^2}$$

It was calculated that the pin will hold because the shear stress exceeded the applied force. The washers will allow for free rotation of the arms, and the gears will be controlled by a motor that allows for remote control of the gripping mechanism.

5.5.2 Motor

5.5.2.1 Torque

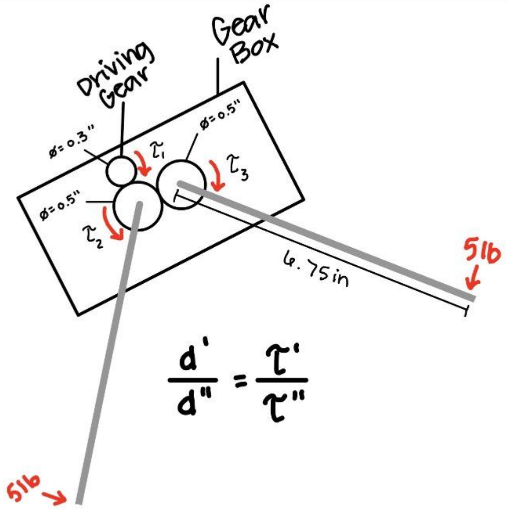


Figure 15. *Torque on Gears*

In order to select an adequately rated motor for each claw mechanism, the torque required to apply the gripping force had to be calculated. However, before this torque could be calculated, the gripping force applied to the pot from each claw needed to be determined. Based on empirical testing of gripping the pots, a force of 5 pounds from each claw was selected. Since the majority of the lifting will be based on lifting on the pot's lip, calculating the grip strength of the grippers around the pot is a secondary concern. For example, if the lifting relied solely on the friction force of gripping, as seen in the appendix, the gripping force would need to be higher. Thus, it was decided to use only a fraction of that force and 5 pounds of force from each arm. In Fig. 15, the arms, gears, and forces applied can be seen. Having selected the force, the torque on the second driven gear can be determined with Eq. 8.

$$\tau = Force * length \tag{8}$$

$$\tau = 5lb * (6.75in/12\frac{in}{1\,ft}) = 2.8\,ft - lb$$

With the gear’s torque determined, a gear ratio formula was used to determine the gear’s torque. Since both of the driven gears were the same diameter, there was a 1 to 1 gear ratio. Therefore, the torque of the first driven gear was the same value, 2.8 ft-lb. However, the additional torque needed to move the other arm must be added, resulting in an overall torque of 5.6 ft-lb for the first driven gear. To find the torque of the driving gear, another gear ratio formula was used as shown below:

$$\frac{g1}{g2} = \frac{\tau 1}{\tau 2} \rightarrow \frac{0.3\,in}{0.5\,in} = \frac{\tau}{5.6\,ft{-}lb}$$

$$\tau = 3.4\,ft - lb$$

Lastly, the transfer of torque from the gear to the motor’s shaft must be considered. Since the motor’s shaft was approximately 0.21 inches, this can then be used in another gear ratio formula to transfer the torque. Thus, it was concluded that the motor needs to supply at least 2.4 ft-lb of torque.

5.5.2.2 Rotational Speed

After finding the required torque, a required rotational speed must be determined to size and select a motor properly. This was selected through the process of calculating rotational speed and then determining how long it would take for the arms to close. If this time were considered reasonable, then this would be selected as the rotational speed. The following proportion was used:

$$\frac{rotations}{60\,sec} = \frac{angle\ of\ arm\ rotation}{time\ to\ grip} \tag{9}$$

The final selected rotational speed requirement is 3 RPM. Based on the smallest pot or one with the longest travel time, the claws can grip the pot within 3 seconds. This is found to be a reasonable time and is, and thus, 3 RPM was the decided minimum rotational speed requirement.

5.5.2.3 Motor Selection

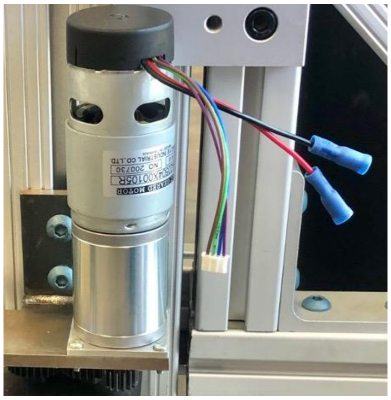


Figure 16. *Selected motor to drive arms of gripping mechanism. 24 DC gear motor. Rated to supply 2.2 ft-lbs of torque. Mounted on the gripping mechanism as seen in photo.*

5.5.3 Gripping Mechanism Assembly

An overview of the final design is presented in Fig 17. It features a back plate in which the motor, gears, and arms are mounted. The arms are attached to the gears via pins that run through both components. Attached to the two arms are the robot's fingers which are shaped to fit the pot type. These mounting plates are then mounted on the sliding rails.

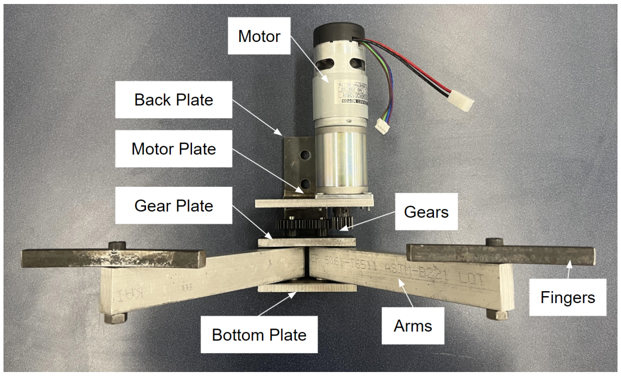


Figure 17. *Full gripper assembly*

5.6 Power Source

In order to determine the type of power source required to sustain the system throughout a day's work, the power needed to operate the chassis and lifting mechanism must be considered.

Table 2. *Power Needs of System*

Component	**Power (W)**	**Time (s)**	**Power-Time (W-s)**
Linear Actuators(x2)	144	180	25,920
Wheel Motors (x2)	21.6	20	432
Claw Motors (x2)	88	6	528
Total	253.6	206	26,880
			7.47 W-Hour

Based on the power calculated for each major component, the maximum power required for the whole system at a given moment is 253.6 W, or for a total cycle the power needed is about 7.5 W-Hours (Table 2).

The power source will be selected based on the wattage of each component. A need of 254 W meant a small generator could power the robot. Small generators can produce up to 1000W of energy, which is sufficient for the motors' needs. Furthermore, the generator can run for 3 hours at a full load of 1000W or 6.8 hours at a quarter load which would be closer to the power usage of the robot assuming 75% efficiency.

Figure 18. *1000 Watt Honda generator*

5.7 Control System

The long-term goal for this project is to be completely autonomous, so no human interaction is required. The first step to meet this goal is to limit human interaction via a wireless remote control similar to that used for drones and RC cars.

To meet this goal, a schematic was created to outline the electrical parts to control this system appropriately. To create a schematic, the system was viewed from a high level starting with the input power being a 1000W generator with an output current of AC. Next, the motor components for the wheels, linear actuators, and grippers needed a DC input current. Thus, an AC to DC Power supply, also known as a transformer, with 50A was used. The next step was adding a motor controller to each component to control the motors with a joystick on a remote control. Each component required a specific voltage motor controller to meet the specifications of the motors. For example, the wheels, linear actuators, and grippers required 12V, 24V, and 12V, respectively. A wireless receiver was used to connect the wireless remote control to each motorized component. All of these connections can be seen in Fig. 19.

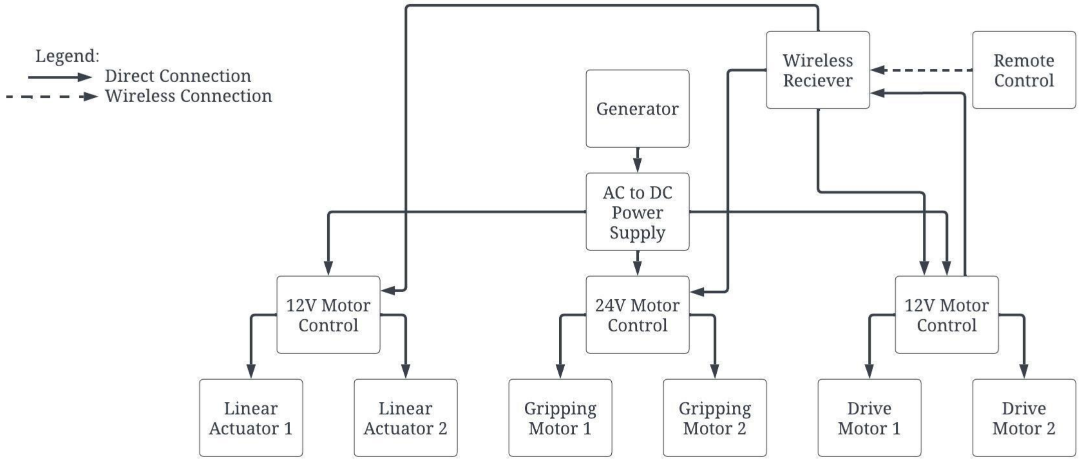


Figure 19. *Communication paths for robot's motors and remote*

5.7.1 Remote control commands

The remote used for this system was a Radiolink AT-10. This remote is typically used for drones, helicopters, and RC cars, and due to this versatility in possible usage, this is an excellent choice for PIPER. The AT-10 allowed us to not only drive the wheel motors while also simultaneously and individually controlling the grippers and ELAs, respectively. A different mechanism on the remote controls each component; the drive wheels are controlled by Joystick 1, the ELAs are controlled by Joystick 2, and the grippers are controlled by Switch C. These mechanisms are labeled in Fig. 20.

Figure 20. *Image of the Radiolink AT-10 remote control. Label 1 is the joystick used for the drive wheels. Label 2 is the Joystick used for the ELAs. Label 3 is the switch for controlling the grippers.*

5.7. Full Assembly

Figure 21. *Fully assembled PIPER excluding the wiring and electrical components*

Once all of the components were selected, the task of building commenced. The process started by building and fortifying the chassis. From here, the linear actuators were attached and secured using steel plates and 80/20 pieces. Then the grippers were attached to the 3-piece 80/20 slider. Next, the two driving wheels were attached to the chassis with their respective motors and the large castor wheel. Finally, the electrical system was put together using 16 gauge wire to connect all of the components used for the control system. This leads to the final result, as shown in Fig. 21.

6. Testing

Testing was a two-phase process to test out the different components of PIPER. Phase 1 was to test the maneuverability of the wheels and the chassis through the row spacing of trees. This testing was done using a 2D testing site, which is shown in Fig. 22. During phase 1, it was proven that the system could maneuver through the rows of the 2D site and get to a pot without hitting it or the pots around it.

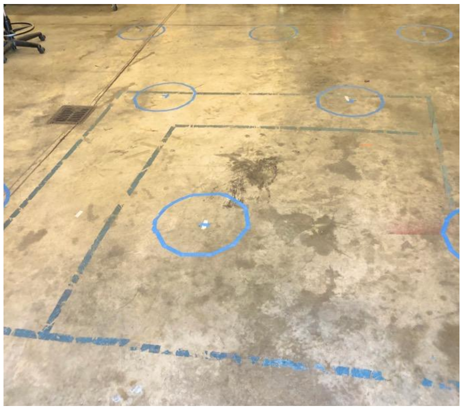


Figure 22. *The site used during testing in phase 1. The blue circles are where the potted trees would be in a PNP staggered spacing*

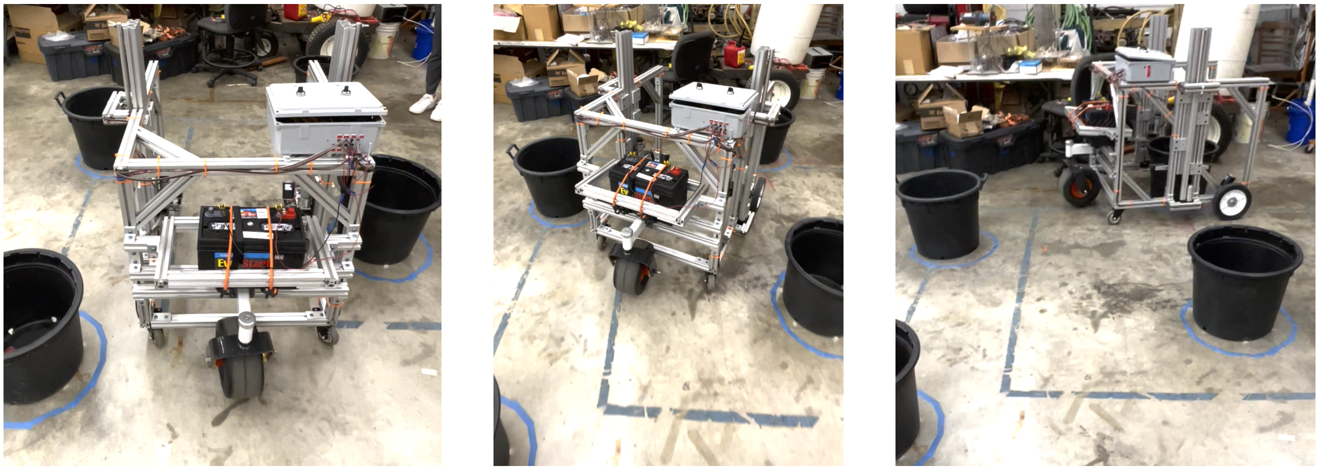


Figure 23-25. *Pictures of PIPER navigating through the PNP staggered spacing. Fig. 23 on the left depicts PIPER being driven down the row. Fig. 24 in the middle shows the approach to a pot. Lastly, Fig. 25 shows PIPER surrounding a pot ready to grip and lift.*

Then, phase 2 of testing was done to test the linear actuators and the gripping mechanisms. This testing was done by creating a miniature pot-in-pot site on campus with three semi-permanently installed socket pots, as shown in Fig. 26. During phase 2, the process of gripping and lifting the potted maple tree was carried out multiple times to test the system's consistency. It was found that the systems could safely lift a maple

Figure 26. *This Miniature PNP site utilizing three potted tree areas was used for phase 2.*

tree growing inside a 15-gallon pot. Additionally, PIPER was found to be able to lower and release the pots as well. Fig. 27 shows the success of this second phase.

Figure 27. *PIPER successfully gripping and lifting a 15-gallon potted maple tree in UT Nursery Complex.*

7. Results and Conclusions

Following a year-long design project, the team is pleased to report that the resulting design fulfills all initial criteria. The chassis and wheels are seamlessly integrated to accommodate a staggered tree spacing of 5ft by 5ft, enabling the equipment to navigate to any tree within a field. Importantly, the design is able to securely grip and elevate a potted tree weighing approximately 90 lbs without causing any damage to the tree, pots, or the robot itself. All this was achieved while keeping the cost under $5,000, coming in at approximately $4,200.

Looking to the future, the team has identified some areas for improvement in a potential second iteration of this design. Firstly, we propose changing from a three-wheel design to a four-wheel design with four independently driven motors. This modification would enable the robot to move in one spot without turning in a large circle like the current design. In addition, the driving motors and wheels would have to increase in torque and diameter, respectively, making it easier for the robot to drive on more rocky terrain such as gravel. Finally, weatherproof all the motors and wiring components to ensure they remain protected in all weather conditions. These changes, once implemented, would enable further testing and optimization of the project and potentially open up opportunities for its use in the PNP industry.

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9. Appendix

9.1 Pot Weights

To get a better and more accurate value for what the lifting needs will be with a 15 gallon pot, several measurements were taken on eight young maple trees kept in the 15 gallon GL6900 pot. These trees were measured after being water, so the weights should depict a more realistic maximum weight that is expected to be lifted.

Pot	1	2	3	4	5	6	7	8	Avg.
Weight (lbs)	57.82	61.56	64.58	55.70	58.70	57.10	60.68	57.12	59.16

Based on the found average, the 90 pound weight requirement is well above the realistic need. However, by using a 90 pound weight requirement, a 1.5 factor of safety is applied which further proves the design's ability to realistically lift the 15 gallon pots.

9.2 Arm Sizing Image