Implementation of Universal Robots UR10 Robotic Arm for an Automated Sowing Robot with Customized End Effectors

A Technical Report
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By

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Approved: Date:

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Chapter 1: Background

Introduction:

The following is a project designed to take advantage of the existing capabilities of modern day multi-joint robotic arms with the intent to develop a comprehensive and autonomous platform that can be deployed in a multitude of scenarios without the need of in-depth knowledge of operation by the end user. Proprietary software or code controlled robotic arms exist in all types of environments and modern day manufacturing, warehouse operations, and even medical fields with all degrees of operator or end user involvement. In medicine, robotic arms can serve as the extension of surgeons reducing incision site and risk of infection by smoothing out the real time input of surgeons and reducing damage to soft tissue. In most industrial settings, automated robots move around warehousing operations following predetermined routes and finding their way to stacking and delivery locations. Multi-joint robotic arms are used in the automotive industry to reduce operating costs, and improve on safety as well as manufacturing operations by reducing the variability coefficient inherent to human labor and precision. Automation such as this, follows a preprogrammed tool path, and sequence with repetitive motion and increased fidelity of movement and manufacturing than that which could be achieved by human labor. In medicine we observe direct operation of the robotic arm as a real time appendage of the human user. In the automotive industry, we see the opposite end of the scale by way of completely human-disconnected robotic arms operated simply by a start and stop button. (AdventHealth University; Locus Robotics; Spatial)

Section 1.1: Universal Robots UR10

With six degrees of freedom, a 51 inch (in) reach, and a sub-30 kilogram (kg) weight combined with a 10 kg payload capacity, the Universal Robots UR10 model, shown in Figure 1, was the ideal base upon which this project could be developed.(Universal Robots S/A)

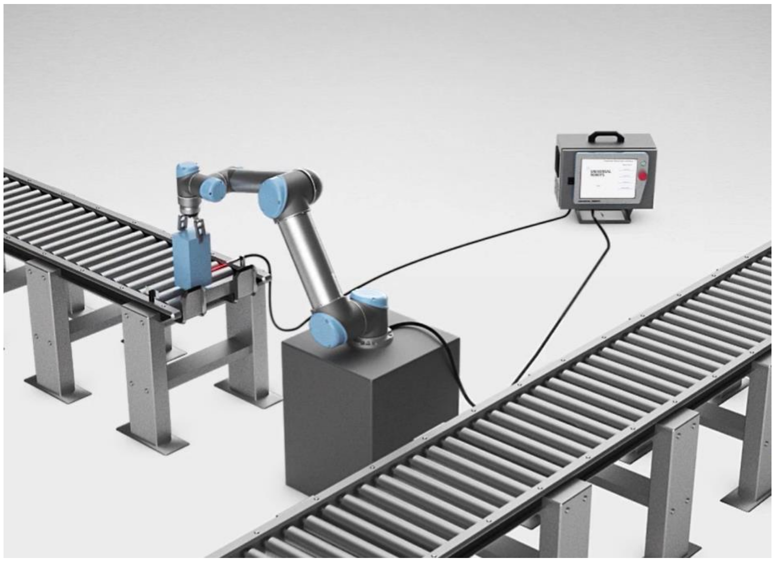


Figure 1: UR10 seen with included screen interface.

The UR10 platform includes a digital screen interface and proprietary software for programming of all operations, movements, waypoints, variables, and responses to feedback. Programming of sequences can be achieved by way of ‘pick-and-place’ movement of the physical robot that take into account the joint locations and orientation in reference to the base joint, or by way of double D-pad controls on the screen interface that operate all joints simultaneously depending on the chosen reference frame, that is from the point of view of the base, tool, or digital view shown on the screen.

Section 1.2: Current Commercial Seeder Solutions

A variety of modern automated or semi-automated seeding solutions exist for commercial mid-to-large scale applications. These seeders use a combination of hoppers, actuators, tubes, and rolling belt systems to move seed trays for large scale consumer needs for single crop harvesting. These machines, most commonly, move a 50 to 512 cell tray below a vertical soil and seed hopper that must be pre-filled with a predetermined monocrop of the end user's choice. These systems cannot be customized to deliver a variety of crops on a single tray, as they are designed to cater to commercial applications. One such provider of these smaller machines can be seen in Figure 2.(Seederman)

Figure 2: Seederman Model GS1 Needle Seeder.

Section 1.3: Project Application

By combining both technologies, the opportunity to develop a mobile application that is customizable to the individual needs of a single user is attained. A robotic arm that at the request of an individual consumer, can select from a variety of seeds to create a small scale seed tray containing one or many different crops. The potential application for such a device has been tailored to the individual UVA student living in school dormitories who desires to grow small scale vegetables, flowers, or legumes in the privacy of their rooms but lacks the ability or knowledge to take the first step in germination of a viable seedling.

Community gardens offer students the opportunity to grow their own crops, however, there is an inherent first step to this - the student must know how to grow the seedlings prior to planting in a large scale garden. Seed germination for a variety of crops can require specific soil volumes, moisture content, seed depth, temperature, sunlight exposure, and more. All these factors may prove challenging if not limiting to the average student population, and thus puts the access to a community garden such as one that exists by the Observatory Hill dining facility, Figure 4, far beyond their reach. But if a student could have access to an order system that removed the knowledge, skill, and time consuming barrier for entry, it may solve the problems inherent to poor diet outside of dining hall hours, and provide an incentive for greater community involvement. The location for such a tray planting device already exists in the UVA Greenhouse, where seeding of crops for research is painstakingly done by hand, Figure 3.

Figure 3: UVA Greenhouse and seed trays assembled by research students and faculty.

welcome to the
UVA STUDENT
GARDEN

THIS GARDEN IS OPEN TO ALL STUDENTS AND COMMUNITY MEMBERS AT ANY TIME TO DROP BY, GARDEN, HARVEST, OR ENJOY THE PLANTS! OR FEEL FREE TO JOIN ANY OF OUR SCHEDULED WORKDAYS WITH THE QR CODE BELOW.

SCAN THE QR CODE BELOW TO SEE A MAP OF THE GARDEN AND CURRENT WORKDAY SCHEDULE:

Figure 4: Sign for enrollment into UVA Student Garden.

Chapter 2: Design and Build

Section 2.1: Design Overview

All designing was conducted by way of SolidWorks CAD modeling. The guiding principle of the project was that of the limited reach of the UR10 robot arm, and the need for the entire system to be mobile - that is, the entirety of the robot and its workstation would need to be capable of being moved and set up by one or two users to be deployed anywhere on grounds. The UR10 base would be self-contained inclusive of the robot’s tools in order to allow for fixed coordinates in programming. The workstation would likewise need to be programmed to a locating protocol to ensure accuracy of the subsequent movements necessary to seed trays for the end user.

Section 2.2: Robot Components

2.2.1 UR10

The UR10 base was modeled in order to create a central reference point for all other measurements and dimensioning necessary. The base was also used in an assembly that contained the Tool Drawer which would contain all necessary tools and end effectors to complete the seeding of trays.

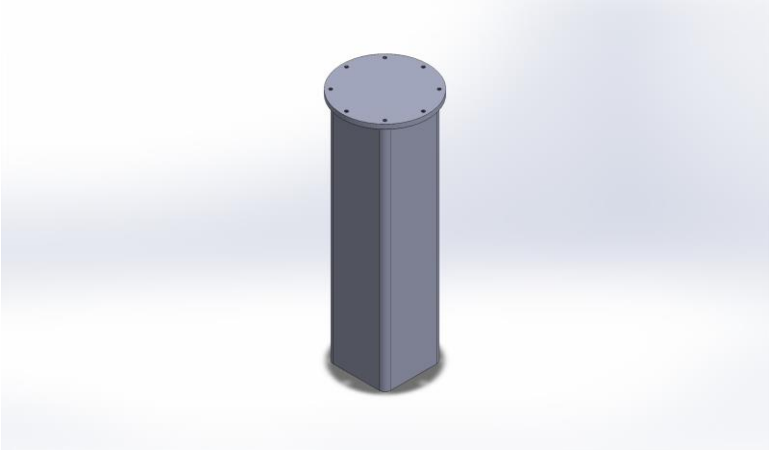


Figure 6: CAD model of UR10 Base.

The UR10 robot arm would sit atop the base shown in Figure 6, and the tool drawer is attached to the side of the vertical beam, by way of bolts that fasten it to the underside of the circular plate. This allowed for the design of the tool tray and all the necessary tools and end effectors to be functionally accessible regardless of the movement of the robot in the xy-plane as all components would sit safely out of the way without risk of interference with any of the joint movements.

2.2.2 Universal Receiver

The universal receiver was designed to be permanently fixed onto the tool appendage of the UR10 robot. It was initially designed as a stack of several layers of acrylic onto which the different tools would be magnetically held in place by three neodymium ¼ in. magnets arranged in a mirrored triangular pattern for tool alignment. The CAD model of the fork tray tool removed from the receiver and aligned for insertion can be seen in Figure 7.

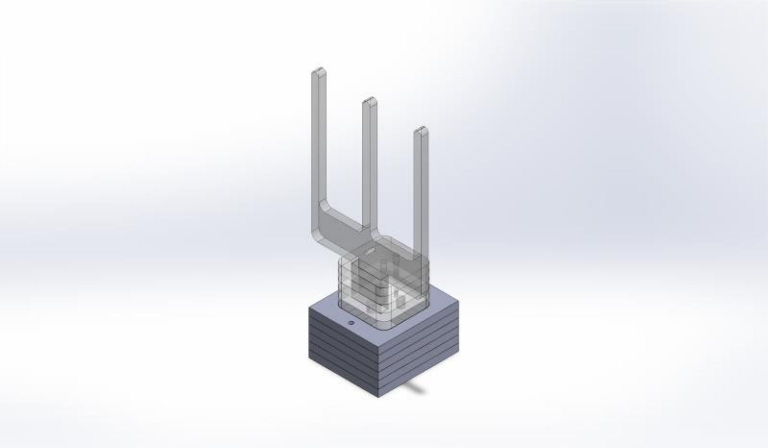


Figure 7: CAD model of Universal Receiver (gray) and aligned tray fork tool.

The completed prototype of the Universal Receiver worked as expected, but provided an opportunity to improve upon when it was observed that the tool interface, due to several miscut layers that lacked precision, would at times bind inside of the receiver, Figure 8. In order to provide a stable platform, multiple layers were needed, but as the number of acrylic layers increases, the tool would also be increasingly prone to jamming.

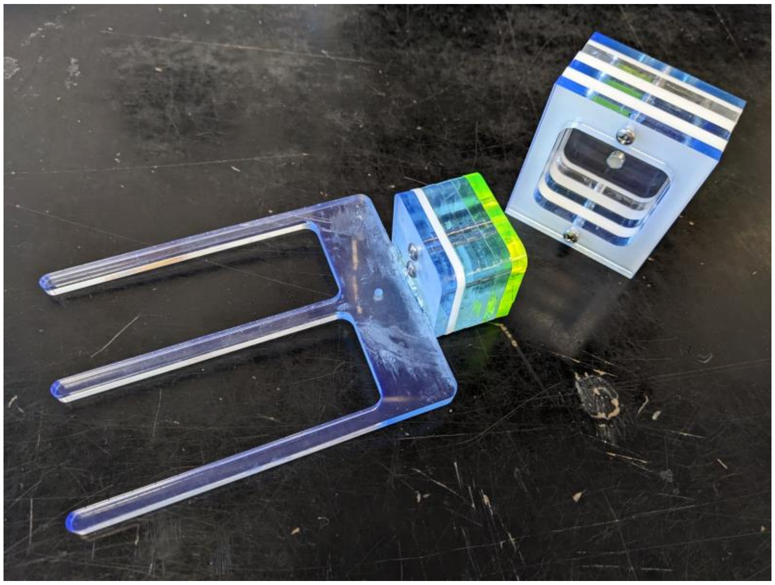


Figure 8: Completed Stacked Acrylic layer Universal Receiver V1.0

A new design was developed to be 3D printed, thus eliminating the potential for misaligned material that could cause a jam of the tools. The orientation of the magnets was also revised which allowed for shear separation of the magnets, instead of axial as was designed on the previous model, Figure 9. The relocation of the magnets also resulted in a reduction of the number of magnets needed to hold on to the tools within the receiver, and guided the subsequent programming of movement paths of the tool by favoring orthogonal forces on tool usage rather than axial which could result in the disconnection of a tool.

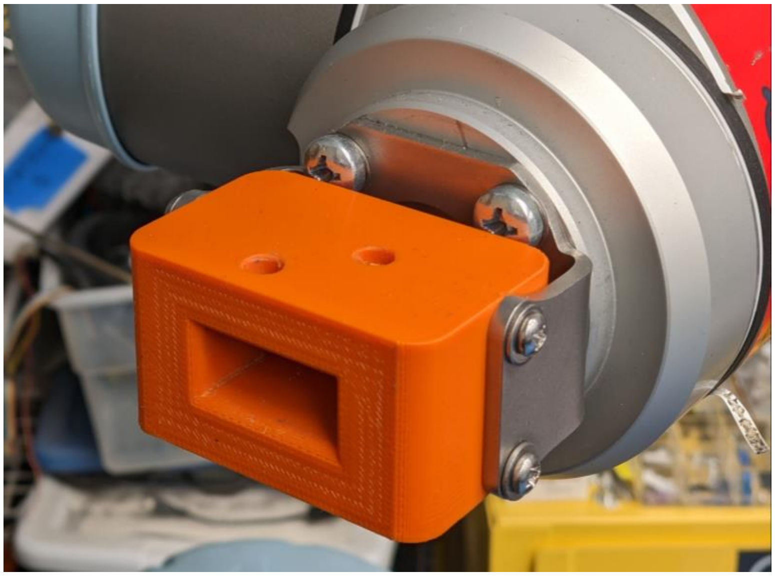


Figure 9: Final 3D printed Universal Receiver V2.0

2.2.3 Tool Drawer

The tool drawer, Figure 10, was developed to be cut out of ¼ in. acrylic with mounting 7/64 in. holes tapped for attaching onto the vertical faceplate of the tool drawer bracket seen in Figure 11.

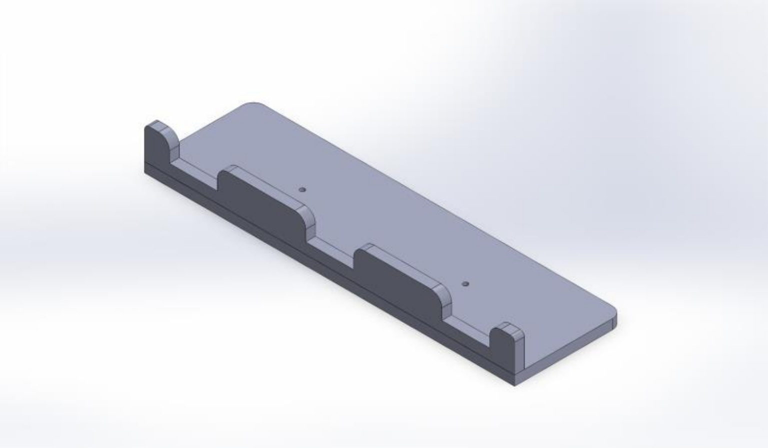


Figure 10: CAD assembly model of Tool Drawer.

Figure 11: CAD model of Tool Drawer Mounting Bracket.

Due to manufacturing constraints, the tool drawer mounting bracket was not able to be fabricated, so an improvised solution was developed from .055 aluminum sheets that were cut, bent, and riveted together in order to allow for the adequate amount of offset distance from the base of the UR10 robot, 12 inches, in order to limit the risk of joint pinching - that is, a position where the robot is not physically capable of reaching without causing damage to itself, this would then activate safety protocols and shut down the movement sequence. The final tool drawer and mounting bracket can be seen in Figure 12. In this image, the tool drawer can be observed with the accompanying Tray Fork and T-Tool, leaving one empty tool bay for further expansion of the system. The tools are held in place using magnets inserted into the vertical faceplate of the tool drawer.

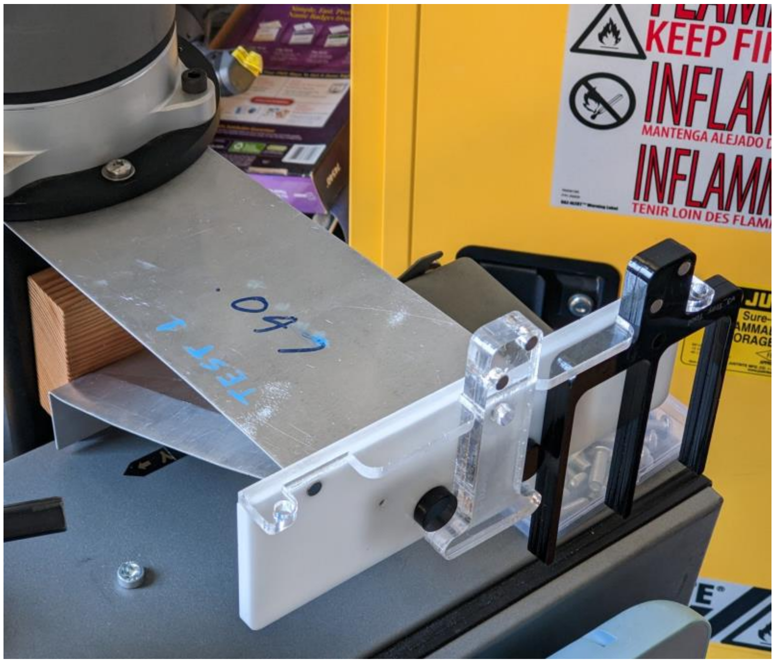


Figure 12: Tool Drawer and Improvised Mounting Bracket.

2.2.3.1 Tray Fork

The fork tool was designed as the primary moving agent of the tray itself. Accessing the tray was important because different parts of the operation resided in different places. Using a fork to pick up the tray (over a flat stage or some kind of hook) was the most intuitive design. The size of the fork was determined by the tray's dimensions which were a constant. The 0.25" holes are voids for magnets to connect the tool to the drawer and the end effector.

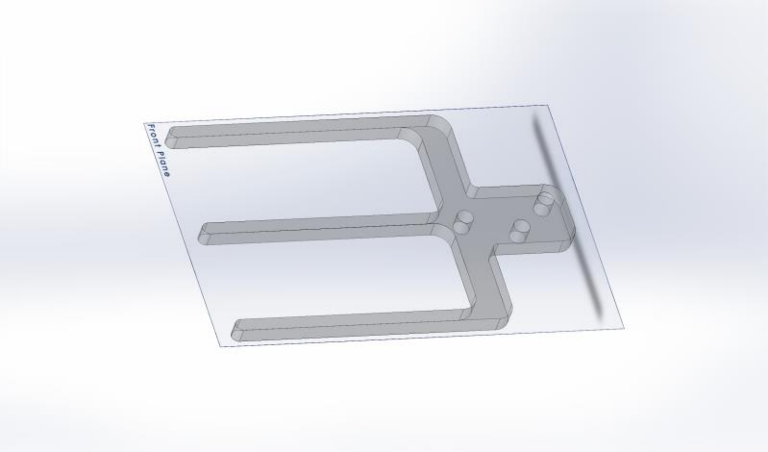


Figure 13: CAD model of Tray Tool single layer.

Because this part was made of acrylic, the cross section needed to be constant in one axis; otherwise, more of the edges would have been fileted for operator safety and ease of mating with the tray. The real tool is twice as thick (0.45") as that figure implies (0.225"). Due to Mill constraints, the acrylic part shown in Figure 13 needed to be cut twice and chemically "welded" together.

2.2.3.2 T-Tool

The general design for the T-Tool, Figure 14, was an artifact of a nascent concept for dirt and seed dispensing. While the details of that design are beyond the scope of this section, it would have required pushing and pulling against noticeable force and the T-Tool was the simplest method of achieving pushing and pulling in the directions needed without axially loading the tool (pushing or pulling against the magnets). It ended up being a perfect tool to rotate the dirt dispenser 360 degrees.

Figure 14: CAD model of T-Tool single layer.

Similar to the T-Tool, the magnets' locations and sizes, as well as the dimension of the interfacing part of the body, were determined by the end effector's design. It was cut from acrylic in two identical pieces and chemically welded together.

Section 2.3: Workstation Components

2.3.1 Work Table

2.3.1.1 Watering Station

Watering is a vitally important and realistically automatable part of germination. While a functional and plumbed watering station was out of the scope of this project, there was a designated paleting station that was the final destination for completed trays. While UR10's software enables automated paletting, our completed tray destination was chosen for its simplicity and lower clearance requirements than the paletting alternative.

2.3.1.2 Completed Tray Stacking

It was initially planned for a paletting station to include an area for completed trays to be placed after the preceding watering cycle was completed. Trays would be neatly organized side by side on several racks that would be labeled by pick up date corresponding to the expected germination date of the seeds planted. Under the scope of this project and its respective budget as well as logistical limitations of a permanent paletting rack, it was decided that a proof of concept would be substituted by way of a small scale stacking of completed trays in an open area of the existing workstation.

2.3.2 Tray Station

The tray station was developed as a means to mechanically replenish the trays for seeding. A slide, seen in Figure 15, was designed as proof of concept for the need to later develop a greater capacity tray delivery method. Due to the constraints of the tray materials, the priority for the slide was ensuring that trays would not become wedged as they would straddle a single edge, capable of holding 6 trays total which would be put in place by an operator at the beginning of running the UR10 seeding program.

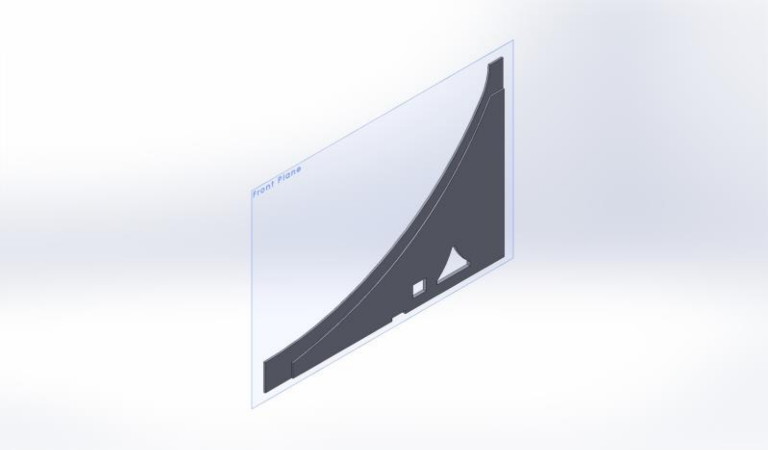


Figure 15: CAD assembly model of Tray slide.

The completed tray slide discharges trays onto the pickup location of the tray station ready for the UR10 equipped with the respective tray tool to pick up a single tray per seeding cycle. The tray slide and tray station location can be seen in Figure 16.

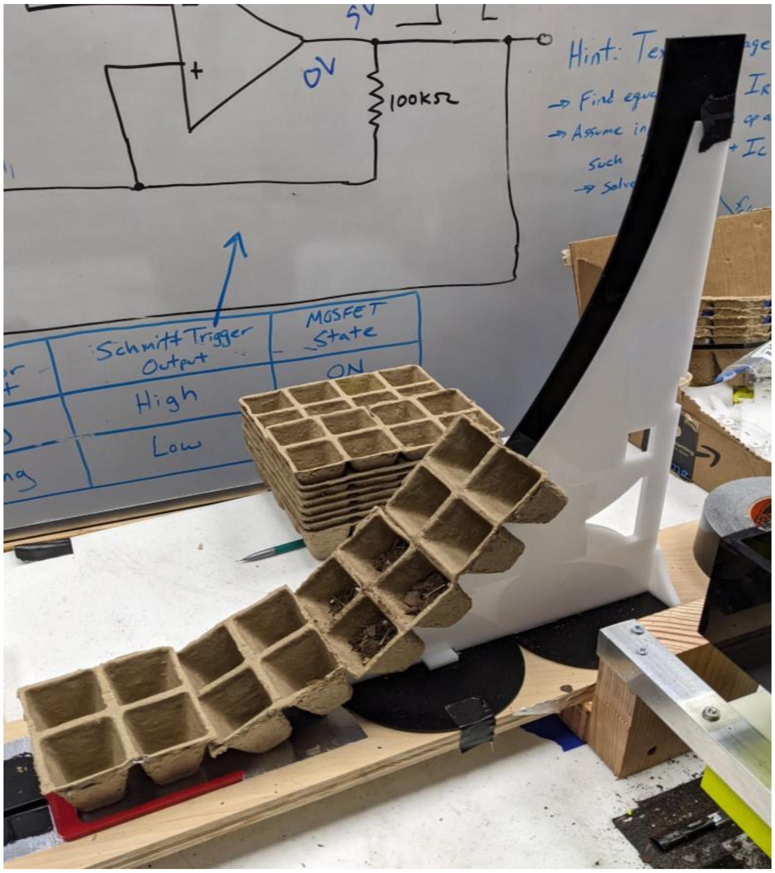


Figure 16: Tray station.

2.3.2.1 Future Tray Delivery

As can be seen in Figure 16 above, trays are currently placed by an operator prior to running the UR10 seeding program; thus, in order to accommodate upscaling of this project design, a mechanized tray delivery system must be developed to unstack and deliver trays to the designated tray pick up location. The use of a gate system may be necessary to ensure the delivery of a single tray at a time in order to ensure that processes farther down the assembly line are not interrupted due to the added height of multiple trays.

2.3.3 Dirt Dispenser

The dirt dispenser's initial design intent was to have two states (opened and closed) toggled by a hole for the T-Tool and to sift the dirt every time the dispenser was already being actuated (during the toggling). This initial goal of dispensing dirt and sifting it proved to be cursory, but it was a good starting point.

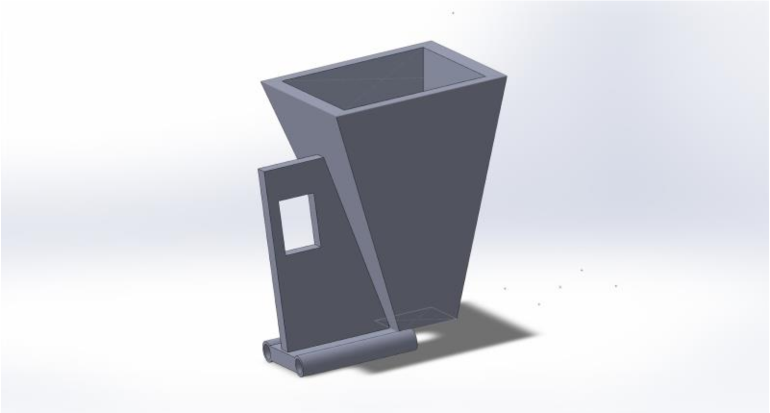


Figure 17: CAD assembly model of Dirt Dispenser V1.0.

The design shown in Figure 17, which had a static funnel and a latch that moved along two guide rails achieved the design intent but further consideration introduced a different issue: the latch would have been prone to multiple modes of failure (dirt between too rubbing surfaces, the latch being too hard to close, the closed state not being entirely closed, dirt not dispensing evenly across tray, and probably more that would have made themselves apparent had we built this prototype).

For the second iteration of the Dirt Dispenser, it was theorized that clumps of soil could become lodged in any moving parts and thus halt the delivery of soil or become fixed in the open position. From this hypothesis, a second design was developed which eliminated all moving parts downstream of the dirt container. It was further improved upon, by segmenting the entire system into sections that could be taken apart to clear blockages, perform repairs, or swap out parts for newer iterations as long as the mounting points and bolt holes remained the same. As seen in Figure 18 below, the two primary components of this new system would gather the soil being dumped from an overhead container into a single stream in a funnel designed to break apart larger clumps of dirt while simultaneously collecting the sifted dirt near the center. The soil would then cascade over a cone inside of the Cell Splitter which ensures the volume of dirt being delivered to each cell of the individual tray is evenly distributed throughout.

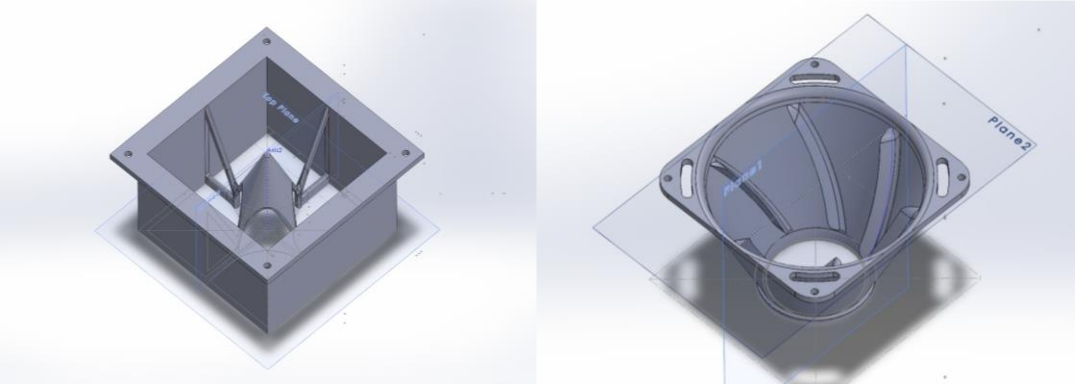


Figure 18: CAD model of Tray Cell Splitter (left) and Turbine Funnel (right) for Dirt Dispenser V2.1.

The sections above are then stacked vertically. Additionally, the design included a redundant system designed to sit atop the Turbine funnel. This spike was developed to break apart the largest of soil clumps that may occur from stationary soil becoming packed under vertical pressure in larger containers. This system was not manufactured for the purpose of this scaled down version of the project as the dirt container used was limited to a single tray volume of dirt approximately 4 in^3.

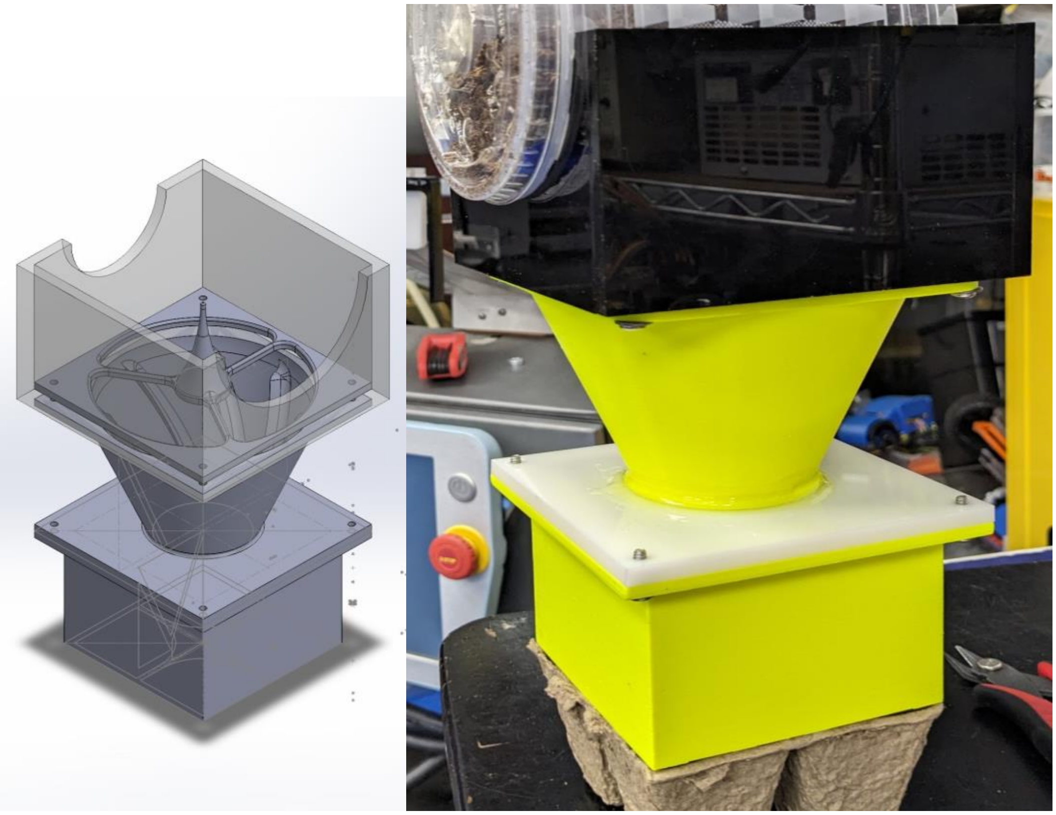


Figure 19: CAD assembly model (left) and completed (right) Dirt Dispenser V2.1.

The completed dirt dispenser as seen in the above Figure 19, sits atop a seeding tray, and houses a small scale specific soil delivery system.

2.3.3.1 Continuous Dirt Supply

In order to increase the scale of this project, a continuous supply of soil is required to accommodate an increased demand of trays to be seeded. Above the current Dirt Dispenser, a gate valve system fashioned from two plastic cups is found. This system was created with the intent of modularity to a large scale soil container to be added. The two-cup system works similarly to a rotary valve with a 90° offset. As the inner cup rotates, the openings align with the through holes of the outer cup every 180°. Above this rotary gate, a larger container could be connected to the current system, permitting large-scale expansion.

2.3.4 Seed Dispenser

2.3.4.1 Mobile Seed Dispenser

The first iteration of the seed dispenser was designed around the concept of being picked up and dragged across the germination tray like Johnny's Selected Seeds' machine with the same purpose. There were two separate bodies: the cabinet (and window pane, here shown in red but ideally clear), and the roller. The seeds poured into the top of the cabinet would be singulated by the roller. Each rotation dropped 1 seed. The roller had a small cavity on the outside of the roller body that was sized to kale seeds.

Figure 20: Image of Prototype of Seed Dispenser V1.2.

Testing this prototype displayed its mistakes: the axis that the roller is sitting on (a 6-32 bolt) takes all of the force and isn't very easy to actuate. The next iterations did a better job of distributing the load and were built bigger. Additionally, the following iterations kept the seed dispenser static and moved the tray to actuate the rolle: this proved much more efficient because it removed an unnecessary tool change.

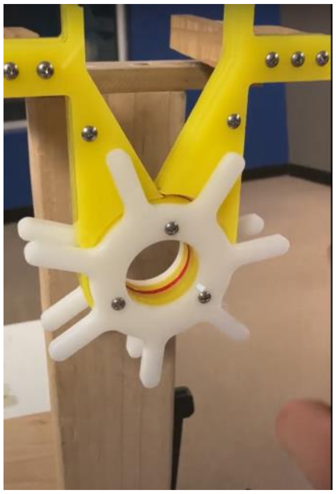


Figure 21: Image of Prototype of Seed Dispenser V8.2.

After 9 design iterations, the seed dispenser was made entirely out of acrylic and had much longer cleats than the original dispenser. The change to acrylic was because an ABS part of a similar geometry wouldn't rotate smoothly enough due to friction between the roller and the cabinet. The longer cleats allowed us to program the actuate the rotation at a diagonal path that made for a good fit between the cleats and the tray structures via a guess-and-check. Shorter cleats would have given us less optionality later in the process, which we found out the hard way. The mounting bracket is made of scrap wood. A metal bracket to fix the seed dispenser would have been significantly more sturdy and preferable, but much more expensive and time consuming. The biggest technical challenge was the tendency of sticky seeds to lodge together at the opening of the funnel above the roller, but that was sufficiently mitigated by using tape and thin plastics to create an ad-hoc leaf spring into the roller that jolted the lodged seeds right before the cavity and the openings were co-located. The final roller had 7 cavities unlike the first roller which only had 1. That was because the number of cavities, diameter of the roller, and distance between tray structures (1.7" for our trays) are linked together by the equation $3.14D = 1.7n$ where n is the number of cavities. Cavities need to be located in between cleats, and 4 was the minimum number of cleats possible to use.

Chapter 3: Workflow and Programming

Section 3.1: Sowing Workflow Overview

From the perspective of the UR10, the procedure was a loop that included picking up each new tray, dispensing dirt, dispensing seeds, and placing the completed product in its resting place.

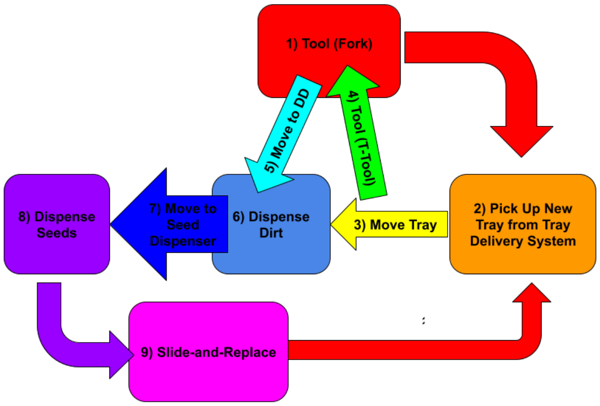


Figure 22: Simplified Diagram of Sowing Workflow

Section 3.2: UR10 Programming

The GrowBot was a unique project in how frequently our decision was to solve problems mechanically or solve them logically. All movement and power operations were done by programming the UR10 software which spared us dependency from external electronics or motors. Programming the software was relatively trivial from a language perspective, but we still faced important decisions in how we solved problems.

3.2.1 MoveJ vs MoveL

Although the capabilities of the UR10 robot are vast, the most important capability for our program was the discretion UR10 allows between moving quickly or moving precisely. MoveJ is what machinists might think of as a “jog” movement, but MoveL is a linear move. The distinction is that the arm is articulated by rotating motors, so the fastest way to get from Point A to Point B is with a curved path. Oftentimes, though, a user may need the arm to move in a linear pattern. The GrowBot needed to utilize this during tool changes and precise tray control, however the Jogging functionality was very important to reduce cycle time for longer movements.

3.2.2 Paletting

One great example alluded to earlier was where and how to place the completed trays. Although there is designated pelleting functionality built into the UR10 that we know how to use, we decided to solve the challenge by moving the completed stack of trays before each next tray was placed. Both options required a full understanding of how the UR10 would use our script to function the GrowBot. While paletting provided a more elegant solution, it required much more clearance than the single-path slide-and-replace pattern that we chose.

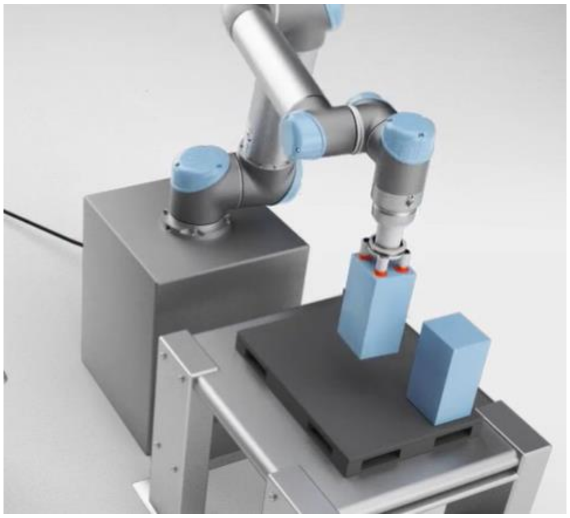


Figure 24: Paletting Software Alternative

3.2.3 Movement and Destination Tolerances

Presently, GrowBot's operational speed is restricted due to precision loss, hindering its efficiency. One possible remedy involves the adoption of 3D printing for components currently cut from acrylic. This shift could replace sharp corners and orthogonal faces with rounds for larger tolerances, potentially enhancing the robot's operational speed.

3.2.3.1 Business Focus - Speed and Reliability

GrowBot's primary strength lies in its ability to swiftly and consistently execute tasks once programmed. Minimizing the cycle time is a pivotal goal for all industrial applications.

3.2.3.2 Challenges with Speed and Precision

GrowBot ideally maintains consistent precision across different speeds, but in trials there has been a noticeable decline in accuracy beyond 60% speed. This poses a problem as it caps the robot's cycle time. Importantly, this precision issue is likely common among most industrial robot arms.

3.2.3.3 Proposed Solution

Addressing the precision drop at higher speeds could involve adjusting system tolerances surrounding the tool change process. This modification might enable a faster yet slightly less precise robot to efficiently sow seeds.

3.2.3.4 Constraints with Current Components

The existing limitation of acrylic components, due to restrictions in laser cutting, confines their design to constant cross-sections. Consequently, this constraint impacts the ability to achieve optimal filleting along both axes. In other words, the tools cannot be filletted along the axis they're cut from.

Chapter 4: Conclusion

Section 4.1: Recommendations for Improvement on Current Model

Although the growbot is functional, there are multiple parts of the system that could be improved: the seed dispenser mechanism, the tool drawer, and the end effector are the four most important to fix. Because none of these prototypes are even a month old, and because it's a sunken cost fallacy anyway, we are open to solutions that include entire first principles redesigns (for example: seed dispenser) as well as small adjustments to functional components (for example: end effector).

Section 4.1.1 Seed Dispenser

The seed dispenser needs to be more consistent with respect to moving seeds from the funnel to the roller cavity. The goal is for it to dispense 2 seeds per roller (but 1 or 3 are fine as well). Currently though, the seed dispenser dispenses inconsistently and often dispenses zero. One solution is to entirely redesign it to be spring activated. In this example, pressure would line up a hole in the outer body with a void in the inner body that is full of seeds. The size of that overlap would determine how many seeds come out. A benefit is that the seeds would be dropped deeper into the soil rather than just on the surface.

Figure 25: Seed Dispensing alternative design

Section 4.1.2 Tool Drawer

The tool exchange works flawlessly 60-80% of the time, but bigger fillet radii where possible and larger tolerances between the tools and the drawer would increase this in future models. The fillets were made with constant radius and symmetric tangency by default. However, to more adequately meet the design intent of guiding tools into their slots, the geometry should be asymmetric with a longer run on the face parallel to the direction of motion during re-staging. Reducing the error is vitally important because in an industrial setting, a statistic below 99% would be entirely unacceptable: "For example, in the automotive industry, to meet the requirement that delivered product must meet Six Sigma metric (3.4 defective parts per million), the quality level of automotive components supplied by robots must reach 99.99966% level."

Section 4.1.3 End Effector

Similarly, the end effector would benefit from a bigger and less symmetric fillet radius that is more intentionally designed to guide the tool. This could reduce the instances of tool exchange accidents. This radius needs to be done thoughtfully because the tool needs to be firmly in the end effector's grip during operation, and that relies on a tight tolerance on each side. Big radii threaten to reduce the integrity of the end effectors' control of the tools. The best way to achieve a bigger tolerance on tool exchanges without sacrificing integrity during operation is to increase the depth of the end effector in the axial direction.

Section 4.2: Overview of Future Physical Components

Section 4.2.1 Watering System

The watering system needs to be capable of automatically plumbing water in different increments at different times depending on the seeds in the tray. The watering system would be located in the same place as the completed pallets. While there are many ways to solve this problem, one solution would be to organize the serially placed completed trays by seed because they will all have the same watering requirements. Depending on the seeds, the watering system could be a stagnant shallow pool of water for the permeable germination trays to sit in. If the seeds require top-down irrigation, the watering system would need to be plumbed to water trays in batches with similar timelines. Because the UR10 is only capable of one logical program at a time, the sensing and actuating of the watering system would need to be externally controlled by a separate waterproof mechatronic system.

Section 4.2.2 Dirt Reservoir

In order to run without the need for constant refills, the dirt dispenser should be refilled by a large reservoir of dirt above the dispensing mechanism. This was covered under section 2.3.3.1 above.

Section 4.3: Future Software Integration

For this solution to be industrialized, the infrastructure around a student's request needs to be built. The form we see this taking is a Qualtrics survey that can be accessed by the end user from anywhere. The technician would need to approve or deny the requests individually for them to be moved from the pending request list to the queue. The technician would confirm the queued items before each run to make sure that sufficient seeds, dirt, and trays are available for the requested function, and would mark the task as completed. The submitters of completed tasks would be notified that their germinated trays are awaiting pickup. The software infrastructure is required for this tool to be usable by students.

References

AdventHealth University. (2022, February 10). *Robotics in Healthcare: Past, Present, and Future*. https://www.ahu.edu/blog/robotics-in-healthcare

Bi, Z. M., Lang, S. Y. T., Shen, W., & Wang, L. (2008). Reconfigurable Manufacturing Systems: the State of the Art. International Journal of Production Research, 46(4), 967–92. DOI: 10.1080/00207540601064773

Goff, J. [JohnnysSeeds]. (2023, June 12). Manual Cell Tray Seeder from Johnny's Selected Seeds [Video]. YouTube. https://www.youtube.com/watch?v=yEgaqMzDxtQ

Seederman, G. (2023). *Welcome: Seederman Products*. Greenhouse Tray Needle Seeders | Seederman Products. https://seederman.com/index.html

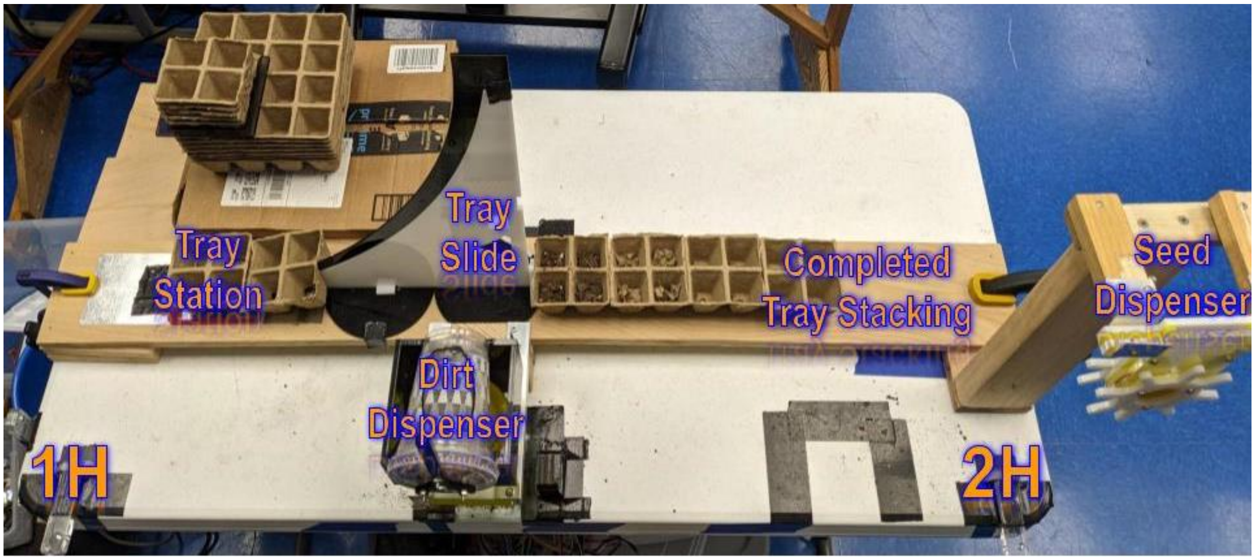
Team, S. (n.d.). *Automotive Robots: Everything you need to know*. https://blog.spatial.com/automotive-robots#:~:text=That%20spirit%20of%20automation%20and,perform%20other%20intricate%20assembly%20processes.

Universal Robots A/S. (2014, October). Technical Specifications UR10 - Universal Robots. https://www.universal-robots.com/media/50880/ur10_bz.pdf

Why locus. Locus Robotics. (2023, September 15). https://locusrobotics.com/why-locus/?utm_source=google&utm_medium=cpc&utm_campaign=GAW.US.04&utm_content=Warehouse-GAW.WARE.04&keyword=warehouse+automation+system&utm_sitelink=&gad_source=1&gclid=CjwKCAiAmsurBhBvEiwA6e-WPJukfkpjErfzb6N7czguIywQwUPjVKPZcOP6sakR3_M4XWvwZgZBRxoC9KYQAvD_BwE

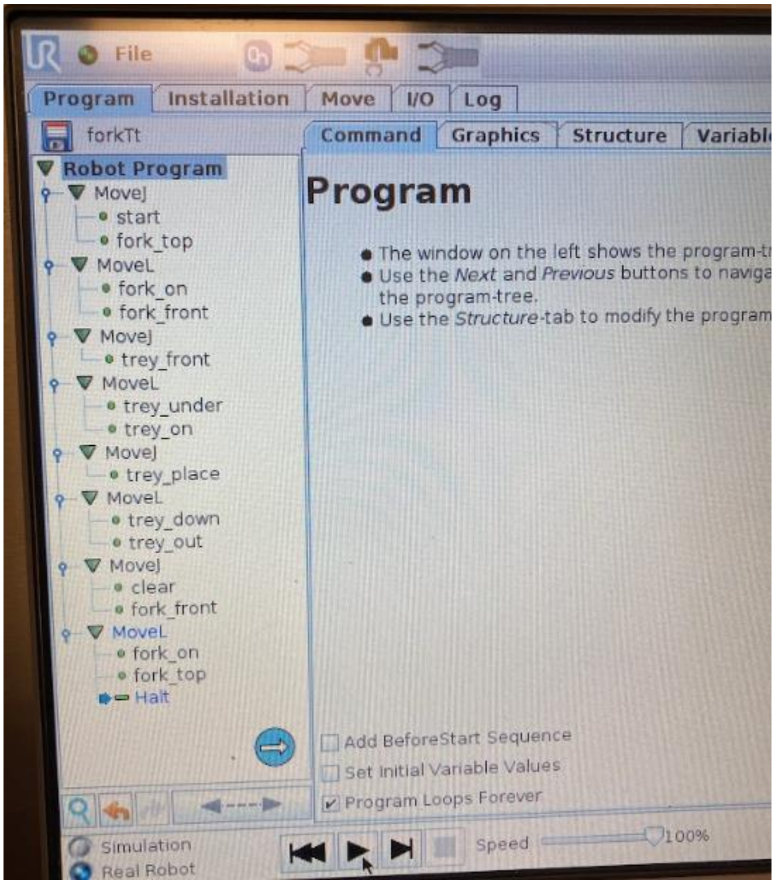
Appendix A

1. UR10 - Starting Procedure:
    a. Move robot cart to desired position, 51 in. horizontal radial clearance needed.
    b. Extend wheel chocks to lock into position.
    c. Plug in.
    d. Press the green screen pad button.
        i. Follow on-screen instructions for initialization
2. Workstation Positioning Procedure:



    a. On screen (user 1):
        i. File > Load Program > locateTable > Load
        ii. “Play”
            1. Press “automatic” to move robot to starting position
        iii. “Play”
        iv. Hover thumb over E-Stop button
    b. On workstation (user 2):
        i. Locate table a safe distance from UR10 base
        ii. Wait for position 1H, user 1 will signal by following steps on screen
            1. Robot will wait 5 seconds
        iii. With both hands, firmly move table locator tab 1H, inserting into Universal Receiver
            1. Robot will retreat and move to position 2H
            2. Robot will wait 5 seconds
        iv. With both hands, firmly move table locator tab 2H, inserting into Universal Receiver
            1. Robot will retreat
            2. (ii) will repeat
            3. Adjust if needed
        v. Robot will return to compact start position

3. Seeding Program:



```
Robot Program
  MoveJ
    start
    fork_top
  MoveL
    fork_on
    fork_front
  MoveJ
    trey_front
  MoveL
    trey_under
    trey_on
  MoveJ
    trey_place
  MoveL
    trey_down
    trey_out
  MoveJ
    clear
    fork_front
  MoveL
    fork_on
    fork_top
  Halt
```

- The window on the left shows the program-t
- Use the *Next* and *Previous* buttons to naviga
  the program-tree.
- Use the *Structure*-tab to modify the program

☐ Add BeforeStart Sequence
☐ Set Initial Variable Values
☑ Program Loops Forever

a. On screen (User 1):
   i. File > Load Program > forkTt3 > Load
   ii. "Play"
      1. Press "automatic" to move robot to starting position
   iii. "Play"
   iv. Hover thumb over E-Stop button

b. On workstation and perimeter (User 2):
   i. Keep persons from approaching robot when in motion
   ii. ***Robot precision is directly proportional to the maximum speed of operation***
      1. Watch for dropped tools, and other equipment interferences
   iii. Wait for robot to complete program or for User 1 to stop program

CAUTION: UNDER NO CIRCUMSTANCES SHOULD EITHER USER OR SPECTATORS ATTEMPT TO INTERFERE WITH THE MOVEMENTS OF THE ROBOT DIRECTLY. DISREGARDING THIS CAUTION MAY CAUSE SEVERE HARM TO PERSONS AND/OR GREAT DAMAGE TO ROBOT.