Design and Development of a Robotic System to Simulate Autonomous Management in Plant Nursery

by
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Abstract

Existing plant management and harvesting approaches, such as visual scouting, ground-based proximal sensing, and manual harvesting, are labor-intensive, time-consuming, and do not scale quickly to large areas. Therefore, to facilitate more efficient farming methods, innovative technologies must be adopted to achieve optimal plant management as well as giving rise to the rate of food production. Inspired by the 2019 robotic design competition held by the American Society of Agricultural and Biological Engineers (ASABE), this project aimed to develop an autonomous robotic system to simulate plant management in a nursery. The mechanism discussed in this paper uses proximity sensors as the means of navigating its way through a 16 ft. by 4 ft. board that represents the plant nursery. Upon detecting a plant, it uses a custom-designed robotic arm to collect and distinguish it between the two categories of red and green using an RGB color sensor. Upon correct identification, the collected plants are then stored on a circular storage unit. Finally, with input from all the sensors, the system will navigate its way across the board to deposit the plants in their respective marked zones. The total run time of the system to execute the above tasks successfully was averaged at 58 seconds. With recent advancements in technology, agricultural producers now have the ability to use robotics in their field to eliminate the intensive labor required to accomplish simple, repeatable tasks and save time in collecting data to increase the rate of food production.

Keywords: Robotics, Mechanical Engineering, Plant Management, Agriculture, Autonomous System

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I. Introduction

United Nations has estimated that the current world population of 7.3 billion is expected to reach 8.6 billion by 2030 and 9.8 billion in 2050 [1]. Although recent reports by Food and Agricultural Organization shows the food production industry is growing by 1.2 percent every year, it is nowhere close to meeting the food demand, which is expected to increase anywhere between 59% to 98% by 2050 [2]. Therefore, to meet this demand, agricultural producers are embracing innovative technologies to increase food productivity. For farmers around the world to increase crop production, they must either increase the amount of agricultural land to grow crops or enhance productivity on existing agricultural lands through fertilizer and irrigation and adopting new methods like precision farming.

A. Background

Every year, ASABE Robotics Design Competition, held during the ASABE conference, intends to inspire young professionals to develop skills in robotic systems, electronics, and sensing technologies by simulating a fully autonomous robotics solution to a common agricultural process [3]. For the 2019 competition, participants were challenged to design a robot capable of conducting autonomous inventory management in a plant nursery simulated by a 4 ft. x 16 ft. board. During the competition, two teams would simultaneously compete with one another to correctly identify and arrange the most nursery plants in the shortest possible time within a five-minute time frame. Figure 1 shows the layout of the field. There are a total of 21 simulated red and green pot-plants located on the board. The robots need to autonomously identify these pots, collect and transport them to their respective storage area on the other side of the board. The pots must remain upright throughout the whole process. One plant, the “Golden Plant,” is placed in the center of the board and serves as bonus points for the team that collects it first. The robots are restricted to be within 12 in. x 12 in. x 12 in. dimension at the beginning of the competition. Figure 2 shows the two types of plants and the dimension of the pot. All the plants will be randomly placed with the exception of the golden pot that will always be placed in the middle. All plants will face the same direction with the leaves parallel to the south edge of the playing field [3].

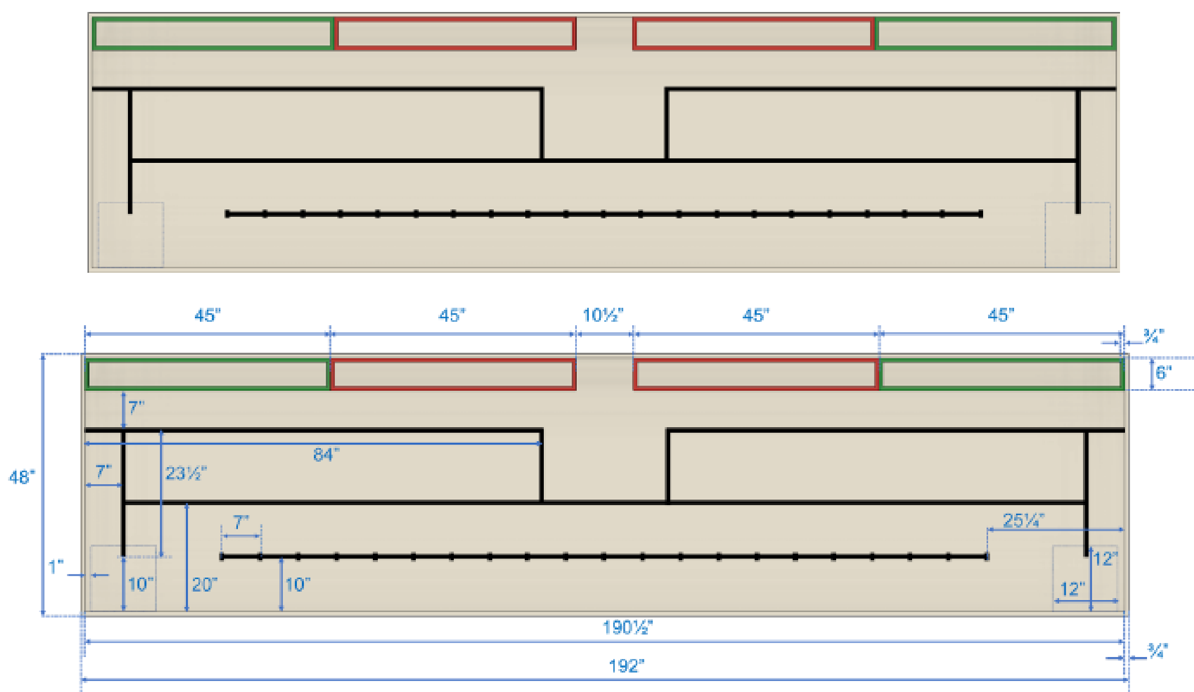

Figure 1. Dimension of the plants used

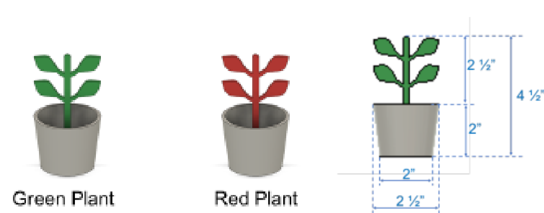

Figure 2. Layout of the field

B. Project Goal

Since this project was inspired by the annual ASABE Robotics design competition, the implemented autonomous system was primarily used to participate in this challenge and represent the University of Nebraska Lincoln. However, upon completion of the challenge, the built system is planned to be used as a teaching instrument to train new students in the field of robotics and prepare them for the following year's challenge as well as paving the way for similar projects that can be used in a real-life environment.

Since this system is to simulate the enhancment of food productivity by improving the task of autonomous management within a plant nursery, one can categorize this project under precision farming. Farming is highly land and labor-intensive. Farmers are driven to use technology to increase efficiency and manage cost. One way to understand precision agriculture is to think of it as everything that makes the practice of farming more accurate and controlled when it comes to the growing of crops and raising livestock. This project can be used to contribute to improving the autonomous management of a plant nursery in the agricultural sector. However, if modified accordingly, it can be found useful in almost any field that works with the task of classification, collection, and transportation. As a recent study by Hexa Reports suggests, precision agriculture is set to grow to $43.4 billion by 2025 [4]. By utilizing such projects, one can put the University of Nebraska at the forefront of developing the latest agricultural technologies and a name to be remembered around the world.

II. Approach

The main task in this study was to design and develop an autonomous system capable of finding the pot-plant, distinguish if it is red or green, and place it in the correct storage location. The first step towards building this system was to brainstorm different concepts and construct the initial mechanical design. With the restrictions imposed for this challenge, various design options were proposed, some of which included a conveyor belt system and circular multi-arm robot. Although these early concepts are further discussed in the discussion section, as the main challenge for this project revolved around collecting must pot in the shortest time, simplicity was of most importance. Hence, for the final design, shown in figure 3, it was decided to implement simple proximity sensors in the system for it to navigate its way through the field. Then, once the robot reaches the pot plants, it would use commercially available color sensors to identify the color of the pots. Upon correct identification of the plants, it then uses a custom made robotic arm to collect and store the pots within the system so they can be transported and dispatched at their corresponding storage area on the opposite side of the field. The design methodology used in the aforementioned approach can be separated into four main categories. These are as follows:

A. Detection
B. Collection
C. Storage
D. Transportation

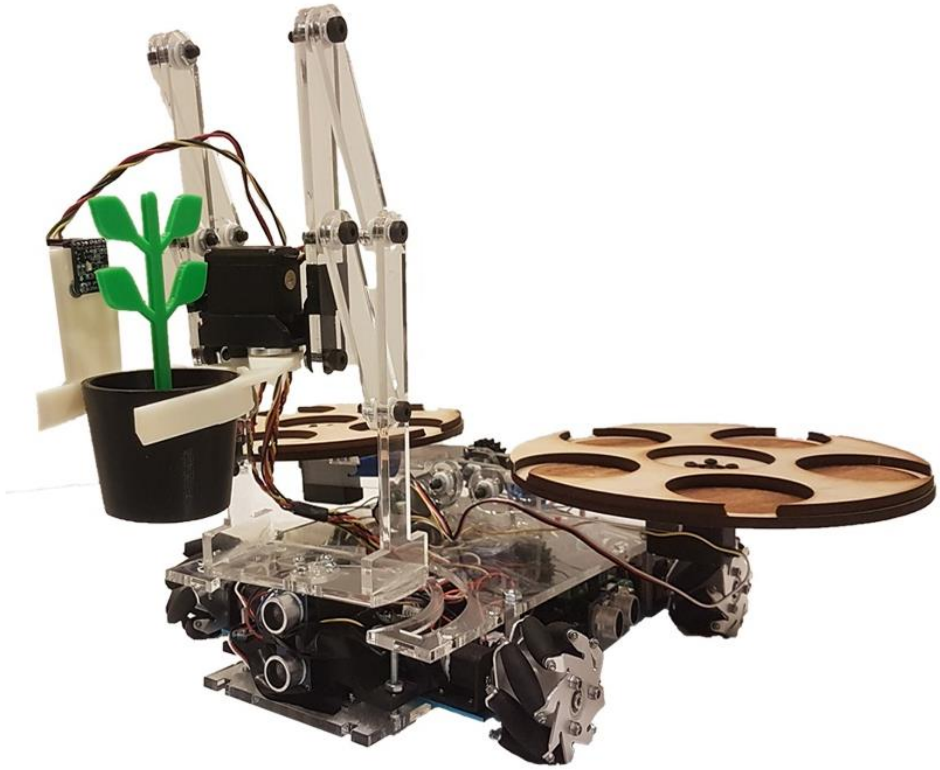

Figure 3. Final design

A. *Detection*

In order to implement the plant identification process, the Adafruit TCS34725 RGB sensor was selected. This sensor comes with an RGB clear light sensing element equipped with an IR blocking filter, which minimizes the IR spectral components of the incoming light and increases the accuracy of color measurement [5]. This sensor is capable of sensing colors located within the 1.5 inches of the sensor. Hence, with its low price, it was an ideal choice. Figure 4 show these compounds. Further specifications of this piece include 3.3V regulator in order to power the breakout with 3-5 VDC safely level shifting for the I2C pins so they can be used with 3.3V or 5V logic. Moreover, it has a neutral 4150°K temperature LED with a MOSFET driver onboard to illuminate the object that is to be sensed; in our case, the petals of the pot-plants [5].

Figure 4. Adafruit TC3472 sensor

B. Collection

To pick up and deposit the pots, a custom-designed robotic arm that consists of a pair of parallel 4 bar linkage was developed. The reasoning behind the implementation of a parallelogram 4 bar linkage was due to the fact that the pots must remain upright during the entire process. This robotic arm is controlled by two hobbyist servos-one for rotating the arm horizontally and the other to move it vertically. A 360-degree rotation servo (Parallax Feedback 360° High-Speed Servo) was implemented for ease of movement during the placement and removal of the collected pots in the storage unit. Figure 5 shows the implemented arm assembly. The direct collection and deposition process is handled by a High-Torque 2BB Metal Gear Servo-Hitec HS-645MG. This allows for unconstrained movement and smooth operation. These servos are directly controlled by a Lynxmotion servo controller Lynxmotion SSC-32, and commands are sent to this board via serial communication from the Arduino Mega.

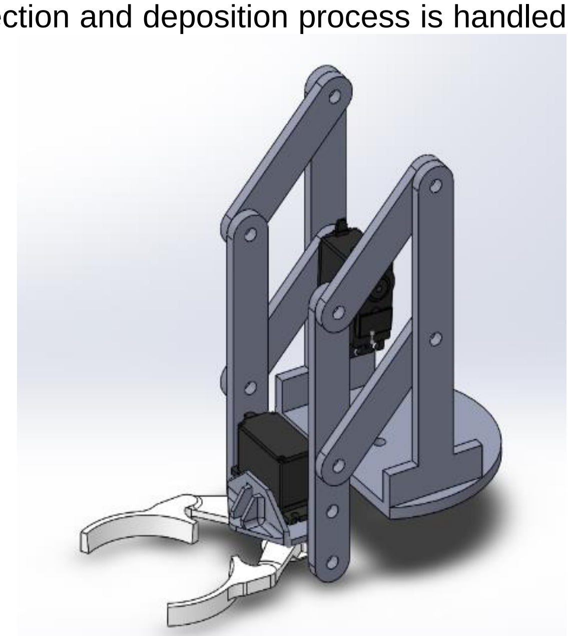

Figure 5. Arm assembly

C. Storage

In order to store the collected pots, two circular symmetric units capable of storing five pots were designed. As shown in figure 6, each holder was engraved to a small depth in order to keep the pots firmly in place. Each unit is driven by a 360-degree rotating servo, which enables a continuous rotation. As the robotic system must be within the restricted dimension at the beginning of the match, the plates are initially in a folded position. Upon the initiation of the system, the plates will open simultaneously, a process which is utilized by a dc motor. This design was inspired by the process of Biomimetics, which is known as the transfer of ideas and analogies from biology to technology [6]. More specifically, this design is to replicate butterfly wings. Moreover, the plates were designed in a way to allow the robotic arm to place the pots with ease and maintain the upright position of the pots while being transferred across the board.

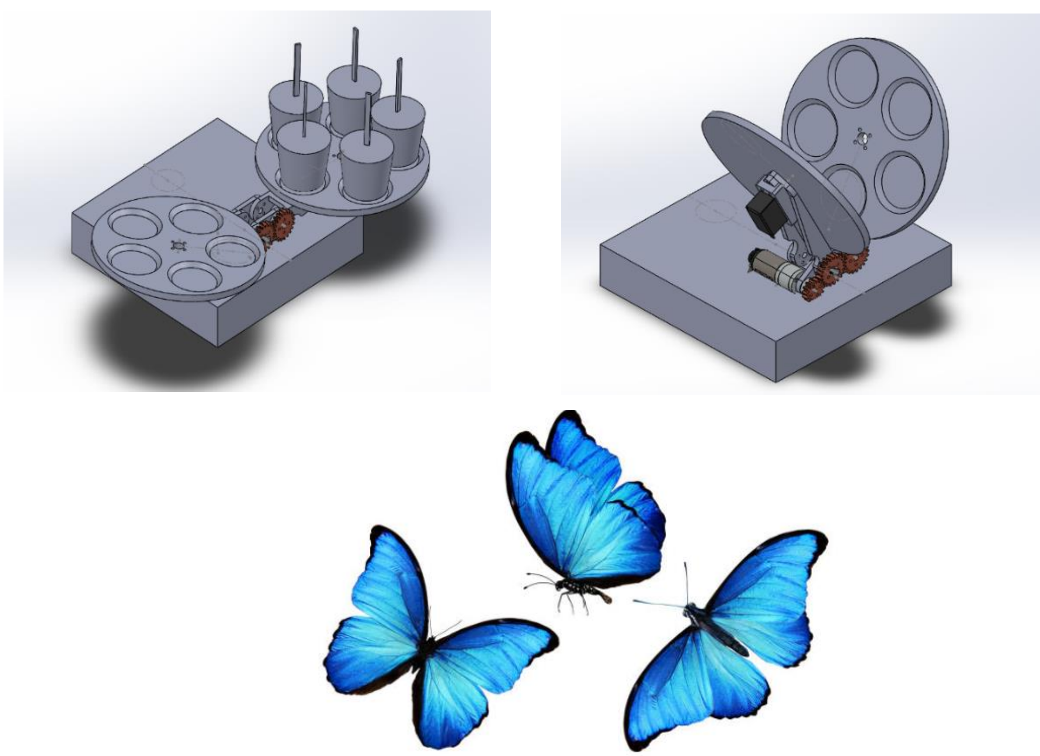

Figure 6. Storage units and the inspiration behind it

D. Transportation

The mobile platform used to transport the entire assembly around the board is built on a 4WD 60mm Mecanum Wheel Arduino Chassis. Mecanum wheels were specifically chosen to allow the robot to move in all directions without having to turn to the respective angle, thus reducing the time required for the successful completion of its task. The platform is controlled by high-reduction geared DC motors to enhance motion smoothness. Adafruit HC-SR04Ultrasonic sensor, one at the front and one at each side of the robot were implemented in order to navigate the chassis around the board. These sensors have a detection range of 2 to 400 cm (approxiamely 0.80 in. to 160 in.) and are commercially available at a low cost [7]. Moreover, a line following sensors was also used to track the pots along the line where they were set up. Figure 7 shows the chassis that was used for this project.

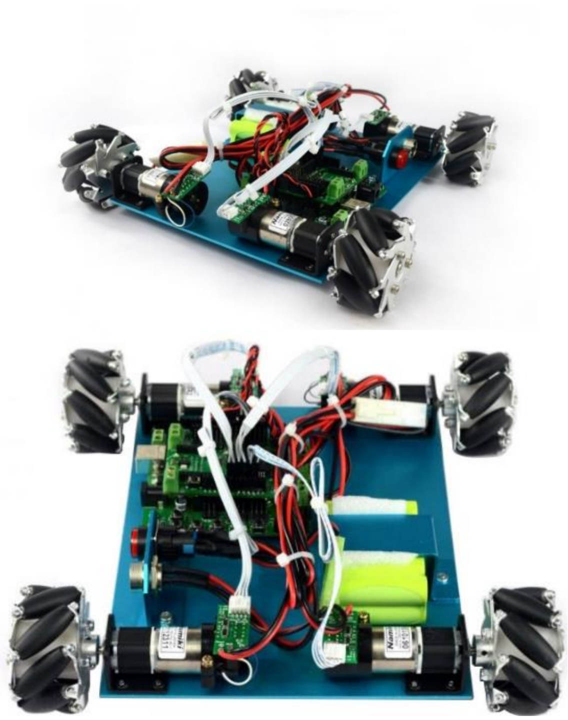

Figure 7. Chassis

III. Results & Discussion

The robotic system at hand utilizes ultrasonic sensors to navigate its way through a 16 ft. x 4 ft. simulated environment, which represents a plant nursery. As soon as the robot starts running, it first positions itself along the row where the pots are placed, unfolds the storage units, and steers forwards until the ultrasonic sensor detects the first pots at the 10-inch distance. The mechanism will then pause for the custom-designed robotic arm to reach the pot. The gripper of the arm is initially open to allow the arm to position itself around it. The gripper then closes, allowing the RGB sensor to get closer to the plant and detect its color. Once the correct colors have been identified, the arm transfers the pot plants to either the right plate, which holds the green pots or the left plate, which is to store the red pots. Finally, with the assistance of the mecanum wheels, the system smoothly rotates and steers towards the storage area to dispatch the pot plants in the two marked zones. Multiple runs were conducted to measure the average time it takes for the system to accomplish the above tasks. The average time recorded for the successful collection or dispatch of a pot was measured to be 12 seconds. This is measured from the period the system is positioned correctly in front of the pot all the way to the correct placement of the object in its correct storage unit or the reverse process. The total time to collect all the pots successfully, starting from the corner of the board until the robot reaches the center of the simulated area was averaged at 137 seconds. This time also accounts for to initial positioning of the system as well as allowing the unfolding process of the storage plates. The average time taken for the robot to rotates from the center, travel to the other and, and complete the dispatch process was 132 seconds. Therefore, the total time taken for a ture successful run was found to be 269 seconds (4 minutes and 48 seconds), which was within the five-minute time frame of the competition.

A. *Alternative designs*

The first step towards building this system was to create the initial mechanical design. As was mentioned earlier, other design concepts were examined. One of which is a conveyor system, which is shown in figure 8. As shown below, the robotic arm is located in the middle and a conveyor belt on each side of the arm. Initially, the position of the robotic arm was decided to be in the middle to allow access to both conveyor belts. As there are only 2 categories of plants (Red and Green), each conveyor belt would store and hold the respective color. Not shown in the figure, there is an RGB sensor attached to the robotic arm to detect the color of the pot. This design was not proceeded with due to the restrictions it imposed with regards to the dimensions requirements for this project.

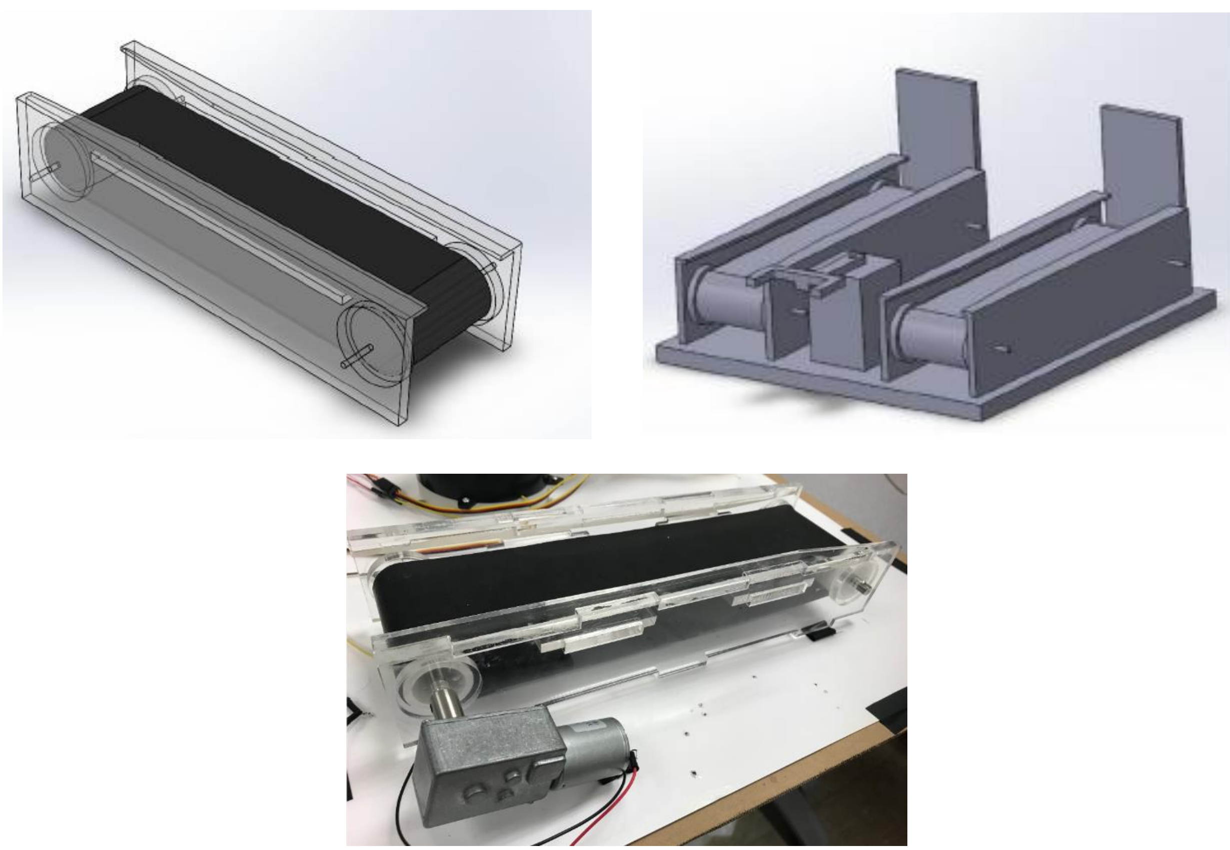

Figure 8. Conveyor belt design

Furthermore, there were various challenges faced during the design process. For example, as shown in figure 9, the initial idea was to use a robotic arm with two degrees of freedom to pick up pots. However, it was found that this design will not maintain the plants upright during the collection process and would result in disqualifying the teams.

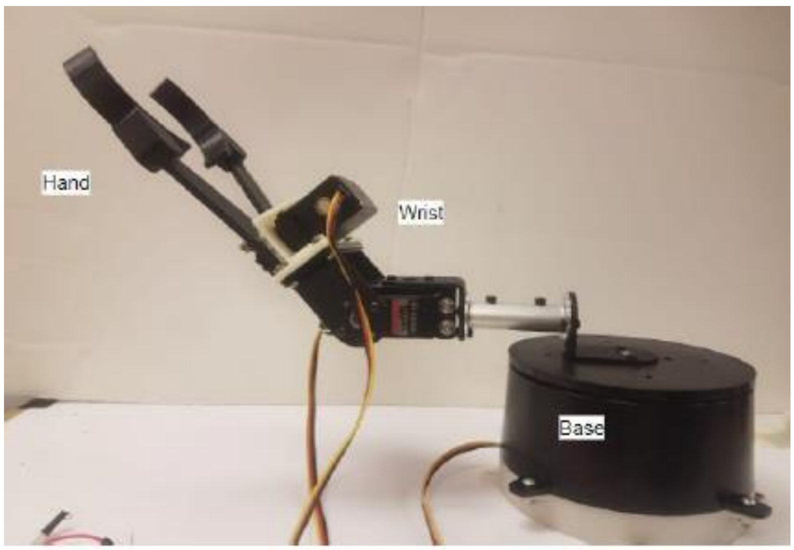

Figure 9. First iteration of the robotic arm

B. Assembly

After designing the preliminary components, an iteration of the design for each category was made. Various materials were used in this process. The majority of components, such as the links for the arm, the assembly to open and close the plate, and the upper part of the chassis, were laser printed on the acrylic sheet and utilized a slot and tab design. Some of the advantages of a slot and tab design included the fact that it allowed the alignment of parts to be achieved easily, and it provided a more secure connection between parts. Components such as the grippers for the arm and the gears which require a higher strength and precision were 3D printed.

IV. Conclusion

In conclusion, the implementation of this project was successful. The main task in this study was to design and develop an autonomous system capable of finding the pot-plants, distinguish if it is red or green, and place it in the correct storage location all within a 4 ft x 16 ft board that represents a plant nursery. The total time required for the system to complete the above tasks successfully was measured to be 269 seconds (4 minutes and 48 seconds), which is within the 5-minute time frame of the competition. Moreover, upon participating at the ASABE robotics design competition, various challenges were faced that prevented the assembly from performing to the desired level of expectations. For instance, both left linkages (main and spare) for the robotic arm were fractured due to extended practice runs in order to optimize the system further. Despite this setback, the system was able to position itself correctly and collect the majority of the pots during the main run. Overall, with the difficulties faced, the team was able to secure the 4th position in the competition. Following the completion of the challenge, the built system is now used as a teaching instrument to train new students in the field of robotics and prepare them for the upcoming robotic competitions. This project can be used to contribute to improving the autonomous management of a plant nursery in the agricultural sector if scaled appropriately.

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