Development of an Automated Planter for Sweet Potato Slips

by

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Abstract

Fluctuating oil prices and the urge to reduce oil dependency has significantly increased US ethanol production. In 2011, approximately 28% of the corn market was used for fuel ethanol production. The expanding ethanol industry will require alternative feedstocks. Sweet potatoes provide a viable ethanol feedstock producing 2-3 times the carbohydrates compared to corn. However, one major drawback is the cost associated with planting sweet potatoes which depends extensively on manual labor with transplanters commonly used. Automation of sweet potato planting could provide a means to reduce planting costs while increasing planting capacity (ac/h). The objectives of this research were to: 1) design and evaluate a mechanism to automatically sort and singulate sweet potato slips and pine seedlings; and 2) identify physical characteristics of slips and seedlings which limit sorting performance. This automated sorting system utilized a hook mechanism to extract slips or seedlings from the bottom of a holding bin. Experiments provided quantitative and qualitative analysis to evaluated rear baffle designs, hook entry angle, and a grasping mechanism. Experiments using seedlings evaluated hook design and the rate at which seedling funneled to the bottom of the bin. The mean sorting rate (the frequency slips or seedling were removed from the bin) and singulation rate (the percentage at which single slips or seedlings were removed from the bin when slips were extracted) were used to evaluate design.

Qualitative results determined that a single, triangular shaped hook, 3.81-cm wide could effectively sort and singulate slips or seedlings. The bottom of the front and rear panels of the holding bin tapered together, the optimum angles to support slip or seedling feed were determined to be 51° and 46°, respectively to improve feed to the bin bottom. A two baffle system utilized a flat front along with a rippled rear baffle limited the volume of slips at the bottom of the bin and aided in slip feed. The flexible nature of slips required a grasping mechanism to physically secure slips prior to extraction, which ensured complete removal from the bin. Pine seedlings on the other hand had a larger diameter and were more rigid. Therefore, an open hook sorted seedlings more efficiently. The physical characteristics of slips and seedlings significantly affect the accuracy at which they could be automatically sorted. The highest sweet potato slip sorting accuracy was achieved projecting the grasping mechanism into the bottom of the bin at approximately 22.3°. This experimental setup yielded a sorting rate of 62.0% with 43.0% slip singulation. Pine seedling sorting performance was 49.0% with 51.0% singulation.

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Chapter 1 Introduction

1.1 Preface

The Energy Policy Act (EPA, 2005) and the Energy Independence and Security Act (EISA, 2007), along with fluctuating oil prices has created a tremendous interest and growth in ethanol production in the United States. Ethanol production increased from 3.9 billion gallons to 13.3 billion gallons between 2005 and 2010. According to EISA (2007), ethanol production is projected to reach 33.4 billion gallons by 2022 in the US. Increased ethanol production has effectively decreased the demand for gasoline however, its adversely affected agriculture with negative perceptions among the general US populous. The primary feedstocks used to produce ethanol in the US are corn and sugarcane. In 2011, 27.3% of the total corn production was used to produce fuel ethanol (USDA, 2010). Increased demand for corn, created from the continuous rise in ethanol production will increase costs throughout the corn market. Thereby, alternative fuel ethanol feedstocks are required to produce 33.4 billion gallons by 2022.

Ethanol is produced either from a high starch crop, (corn, sweet potatoes, cassava, other root crops) or a high sugar crop, (sugar cane, sugar beets, molasses, etc.). In the US, ethanol is commonly produced from starch crops, i.e. corn. While, corn and sugarcane are mainstream ethanol feedstocks, the sweet potato is alternate crop that can be used. Monday et al. (2002) showed that sweet potatoes yielded 2-3 times the carbohydrates needed to produce ethanol and contain 40%-50% more starch per pound than corn. Sweet potatoes also require less energy to produce ethanol compared to corn. Monday et al., (2002) indicated that sweet potatoes are a viable feedstock; however a major drawback related to sweet potato production is the high labor requirements during planting. Sweet potatoes are planted through transplanting vine cuttings, commonly referred to as slips. Commercial sweet potato producers use a semi-automatic mechanical transplanter, which plants up to eight rows simultaneously. Commercial transplanters (figure 1.1) require 2 people per row manually singulating slips, a tractor operator and 2-3 laborers trailing, filling missed pockets (Stoddard et al., 2006). Human operators manually singulate slips while the transplanter mechanically feeds individual slips into the furrow. Commercial transplanting can be performed at a mean rate of 62 slips per minute per single row (Way and Wright, 1987).

Figure 1.1. An 8-row sweet potato transplanter requires one tractor operator and two operators per row that alternate feeding slips.

Labor requirements during slip cultivation, land preparation and planting make sweet potato production costs high. Transplanting slips is the most popular planting method in the US. However, transplanting is labor intensive and requires manual skill to singulate slips. Stoddard et al. (2006) analyzed the cost related to sweet potato production and reported the average cost per acre was $4,317. Included in this cost were the cultural ($2,288), harvest ($1,014) expenses along with the total cash overhead ($1,015). Cultural costs shown in figure 1.2, includes land preparation, cover crops, irrigation and planting. Planting accounted for 40% of the total cultural costs. Planting sweet potatoes require 3.95 man hours per acre, which equates to about $251 per acre.

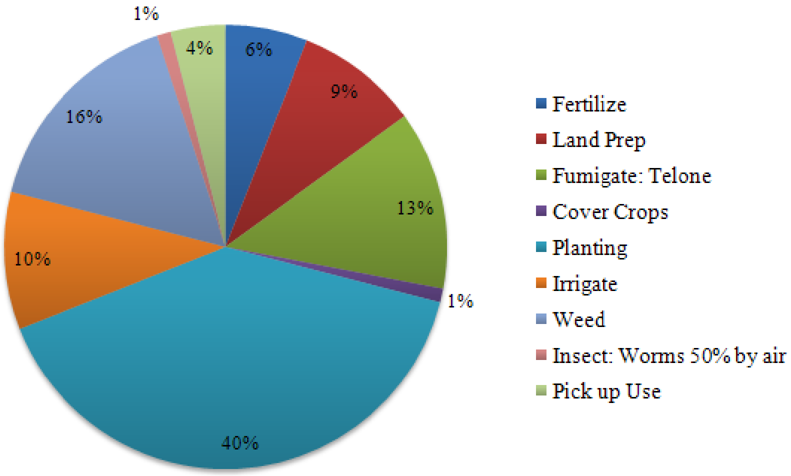


Figure 1.2. Break down by percentage of cultural costs of producing sweet potato which includes: land preparation, fertilizer, irrigation and plnating, (Stoddard et al., 2006).

In 2011, 129,700 acres of sweet potatoes were harvested, which produced 26,964,000 cwt/acre (cwt references weight 100 lb.) and $485,688,000 (USDA, 2012). The cost to produce sweet potatoes in 2011 was approximately $3,744 per acre, which is less than Stoddard et al. (2006) cost analysis. The cost to produce sweet potatoes, $4,317 per acre was significantly higher than the estimated $474 to produce an acre of corn (Purdue, 2011). In order to establish sweet potatoes as a feedstock for ethanol production; the cost of production/acre must decrease and the yield/acre has to increase. Labor requirements can be reduced through the development of automated planting technology, reducing or eliminating the need for manual slip singulation and feeding on a transplanter. A new transplanter could reduce labor costs associated with planting up to $175 per acre.

Ethanol production facilities in the US produce between 20 and 100 million gallons annually, averaging 61.4 million gallons (Nebraska, 2012). An ethanol plant that averaged 60 million gallons annually would needs approximately 22.2 million bushels of corn (corn yields approximately 2.7 gallons per bushel). If corn production averaged 150 bushels of corn per acre approximately 148,000 acres of corn is necessary. Tyler Monday et al. (2009) stated that sweet potatoes contain 2-3 times more carbohydrates than corn, so conservatively sweet potatoes can produce double the ethanol per acre than corn. The equivalent productivity would only require 74,000 acres of sweet potatoes. However, that is approximately 58.5% of the total US sweet potato production in 2012 (USDA, 2012).

1.2 Justification

Sweet potatoes generate 2-3 times more carbohydrates required to produce fuel ethanol compared to corn. However, high labor requirements during planting limit production. Currently, sweet potato slips are manually sorted and planted with a semi-automatic transplanter. Semi-automatic transplanters plants slips at an average rate of 62 plants per minute per row. Manually sorting slips is inefficient and plant survival depends on the accuracy of the operator that loaded the slip into the transplanter. On average it takes 3.95 hours and $251 per acre to plant sweet potatoes. Mechanizing slip sorting and singulation, to automate planting would increase efficiency and significantly reduce labor requirements. Mechanizing slip singulation would eliminate two operators per row which could reduce labor costs by $175 per acre, making sweet potatoes a viable feedstock for fuel ethanol.

1.3 Objectives

The goal of this research was to develop a means to automate the planting of sweet potato slips thereby, reducing labor requirements to plant and a new transplanter design. The research objectives were to:

1. Design and evaluate a mechanism to mechanically sort sweet potato slips and pine seedlings.
2. Identify physical characteristics of slips and seedlings (geometry, rigidity, leaf shape) that limit sorting performance of the designed automated sorting mechanism.

1.4 Thesis Organization

The Literature Review outlines information on ethanol expansion, sweet potato background and pertinent information about transplanters. Chapter 3, Design Criteria and Concepts establishes the design constraints and physical characteristics of sweet potato slips and pine seedlings. Chapter 4 presents the mechanical design and preliminary qualitative analysis for Prototype-1. Chapter 5 discusses the mechanical design of Prototype-2 along with statistical analysis of data. Chapter 6 provides the overall conclusions of this research along with suggestions for future research.

Chapter 2 Literature Review

2.1 Ethanol Production

The concern over the finite and unequal distribution of fossil resources, specifically petroleum oil, along with the desire for fuel independence has increased the US's interest in alternative energy. Legislators have established two bills, the EPA (2005) and the EISA (2007), to reduce oil dependency and motivate ethanol production. The EPA (2005) set an ethanol production goal of 28.4 billion gallons by 2012, which represented approximately 5% of the gasoline consumed in the US EISA (2007) revised ethanol production goals set by EPA (2005), setting out to produce 9.0 billion gallons of biofuel in 2008, with steady increase to 15.2 billion gallons 2012 and to reach 35.9 billion gallons in 2022 (Dicks et al., 2009). EISA (2007) was also directed toward automobile manufacturers, which required that their fleet of cars and light trucks to average 35 miles per gallon by 2020.

Ethanol, a clear colorless liquid containing a hydroxyl group (-0H) bonded to a carbon atom, is primarily produced through fermentation, the process which sugars such as glucose, fructose or sucrose are converted into cellular energy (Monday, 2009). Fermentation of sugar and starch to ethanol is a time proven technology that has provided substantial economics to the farming community. Currently, there are three primary raw materials used in the production of ethanol; sugars (sugar cane, sugar beets and molasses), starch (corn, sweet potatoes, and other root crops) and cellulosic material (biomass, woodchip, and perennial grasses) (Monday et al., 2002).

Corn and sugar cane are the two primary feedstocks used in the US in ethanol production. Hettinga et al. (2009), stated that corn-based ethanol accounts for 97% of the total ethanol produced in the US, which consumed 17% of the corn produced in the US. Figure 2.1 illustrates corn usage by segment in 2011, showing that 28% of US corn production was used for fuel ethanol (Jessen, 2012).

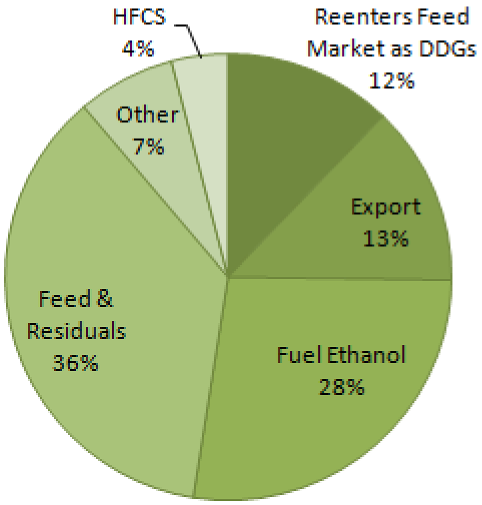


Figure 2.1. 2011 corn usage by segment (Jessen, 2012).

Increased ethanol production has positively and negatively affected the corn market. Dramatic growth of the ethanol industry has significantly increased the demand for corn which has resulted in more revenue (Westcott, 2007). However, increased demand for corn generates more competition between domestic industries and foreign buyers, ultimately inflating prices for consumers (Westcott, 2007). The USDA projects the increased demand for corn will motivate farmers to change crop rotations, to maximize corn acreage. Soybean production would decrease as a result of increased corn acreage. The increased demand for corn along with the reduced supply of soybeans would farther inflate prices throughout the agriculture sector. Alternative feedstocks for ethanol production are necessary before the demand for corn changes crop rotations.

Ethanol can also be produced through the fermentation of either sugar, starch or cellulosic material (Monday, 2009). Monday, (2009) built the argument that sweet potatoes are a viable feedstock due to their starch and carbohydrate content. Sweet potatoes contain 2-3 times more carbohydrates required to produce ethanol than corn, and can yield up to 900 gallons per acre while corn only yield 450 gallons per acre (Monday et al,. 2009)

Yencho et al., (2002), genetically engineered sweet potatoes to increase the starch content. The starch content correlates to ethanol yield. Thereby, increased starch content potentially could offset labor cost associated with planting. He created a hybrid sweet potato that had a 50 percent higher starch content than edible sweet potatoes; higher starch content equates to a higher ethanol yield. The starch and carbohydrate content makes sweet potatoes a viable alternative feedstock for ethanol production. However, a major drawback when considering sweet potatoes as an ethanol feedstock is the cost associated with planting an acre, which is about ten times that of producing an acre of corn (Yencho et al., 2002). Sweet potato production costs are high due to the labor requirements to plant the crop.

2.2 Sweet Potato

2.2.1 Background Information

The sweet potato (*Ipomea Batatas*) is a root crop that originated in the coastal mountains of Peru and Ecuador. (Kemble et al. 2006) Due to its tropical origin the optimum growing temperature range is between 70-85 degrees Fahrenheit, however they can tolerate temperatures as low as 65 degrees (Kemble et al., 2006). The adaptability if sweet potatoes enables farmers to cultivate anywhere there is a warm four month growing season, in the US specifically sweet potatoes can be grown from southern Alabama to southern parts of Michigan (Monday, 2009). Overall, the sweet potato is a highly adaptable crop that can be grown worldwide, tolerating low fertile soils, drought and a wide variety of climates.

Sweet potatoes are one of the most important starch-producing crops around the world. Globally they are the world's seventh most important food crop with an estimated 140 million metric tons produced annually (Monday, 2009). They are cultivated as an annual crop in over 100 countries and in approximately half of these countries it is the one of their top five commodities (Yencho et al., 2002). Historically sweet potatoes have been used either for human consumption or processed as animal feed and are currently becoming recognized as a crop well suited for bio-based or bio renewable plant products such as bio-fuels and high grade starches for the food and pharmaceutical industry (Yencho et al., 2002). Asia and Africa produce the world's largest volume; Asia single handedly produces approximately 85% of the world's production. In Asia, half of the sweet potatoes are produced for animal feed, in comparison the majority of produced in sub-Sahara Africa is for human consumption (Yencho et al., 2002).

The U.S. views sweet potatoes differently than most of the globe. In the US, sweet potatoes are an "occasional" vegetable (Monday et al., 2009). US sweet potato production in has increased from 87,100 acres in 1998 to 116,900 acres in 2010, the US only produces about 0.5% of the world's production. (USDA, 2012) Table 1 presents US sweet potato statistics.

Table 2.1. U.S. sweet potato production (USDA, 2012)

	2009	2010	2011	2012
Acres Planted	109,900	119,800	133,600	130,500
Acres Harvested	96,900	116,900	129,700	126,600
Production (cwt/acre)	19,469,000	23,845,000	26,964,000	26,482,000
Production ($/acre)	423,677,000	478,318,000	485,688,000	N/A
Yield (cwt/acre)	201	204	208	209
Yield ($/acre)	4,732	4,092	3,745	N/A

2.2.2 Land Preparation and Slip Production

The cultivation of sweet potatoes is very labor intensive and contains three vital parts: land preparation, the preparation of planting material and field planting (Keledek, 2012; Monday, 2009; Stoddard et al., 2006). Approximately 60 man-hours per acre are needed in sweet potato production. Cuttings and propagating slips takes approximately 15.6 man-hours which is approximately 26% of the labor requirements (Monday, 2009). The overall cost to grow sweet potatoes varies depending on the cropping plan and how they are propagated (VeggieHarvest et al., 2008).

Two methods are commonly used to propagate sweet potatoes; either through its tuber or by cuttings, (propagating sweet potatoes via cuttings is cheaper and easier) (Maazulla and Chen, 1994). Sweet potato slips, cuttings are harvested once they develop six to ten leaves and strong root systems. Slips are cut approximately 2.54 cm above the furrow and trimmed to 25.4 to 30.5 cm (Monday, 2009). Slips vary in length with respect to the growing season; slips harvested early with respect to the growing season tend to be shorter. Slip length ensures that slips can be planted deep, at least three nodes below the surface. Plant depth is important as it enables crops to develop strong root systems increasing yields (Monday, 2009).

Figure 2.2. Examples size and shape of typical sweet potato slips.

Land preparation is a critical step for sweet potato production. Sweet potatoes grown in well-drained, sandy loam soils produce the highest yields (Kemble et al., 2006). Prior to transplanting, land must be ploughed and turned over prior to creating beds (Keledek, 2012). Beds are 4-8 inches high and as wide as equipment will allow, narrower beds dry out faster. Bed height aids in drainage which protects root systems from water damage (Kemble et al., 2006). Farmers obtain maximum yield by transplanting slips approximately every 12 inches with a row spacing varying between 36-48 inches. Depending on plant and row spacing, 9,000-12,140 slips are required per acre (Kemble et al., 2006). The total number of slips needed per acre can be determined using the data presented in table 2.2.

Table 2.2. Sweet potato planting information (Olson et al., 2012).

Distance between rows (in.)	36-48
Distance between plants (in.)	10-12
Planting depth (in.)	3-4
Transplants needed per acre	9,000-15,000
Days to maturity from transplant	85-130
Plant population (acre)	9,000-15,000

2.2.3 Planting

The most common method used to planting sweet potatoes is through transplanting sweet potato slips. There are two primary methods commonly used; manual transplanting and semi-automatic mechanical transplanting. Manual transplanting, also known as setting slips, is performed by farmers manually placing the individual slips into the furrow. (A furrow is a trench made specifically for planting.) Manual transplanting can be performed at an average rate of 17 plants per minute, which means that it would take 17.5 hours per acre for one person planting (Way and Wright, 1987). Commercial sweet potato producers use semi-automatic mechanical transplanters, which requires a tractor operator, two people per row to manually singulate and place slips into pockets which are mechanically placed into the furrow. The key benefit to this method is that farm laborers perform less work, resulting in a faster metering rate. Mechanical transplanters can accurately set 31 slips per minute per person (Way and Wright, 1987). In comparison, if a farmer plants 12,450 slips per acre, a single row at a time, it would take one person 12.2 hours to manually transplant the acre. If the farmer used a mechanical transplanter it would take 3.4 hours. However three people are required to transplant a single row, which equates to 10.04 man hours. The improved efficiency of a semi-automatic mechanical transplanter is justifiable when three or more rows are transplanted simultaneously.

2.3 Vegetable Transplant Technology

Vegetable transplanting is the process, which transfers a seedling, slip, or young plant from a green house into the field. Transplanting is one of the most labor intensive field operations in the production of vegetable crops (Suggs et al., 1987). Dozens of transplanter designs have been developed over the past 15-20 years with the purpose to increase labor productivity or reduce labor requirements (Boa, 1984). Proposed designs can be categorized in two categories; improved manual machines and automated machines. Improvements are made to manual machines through studying how operators perform designated tasks. Through studying these tasks small changes to seat position or the angle and placement of seedlings with respect to the laborer are made to improve efficiency. Automated machines rely on control systems to perform all tasks, including placing the seedling into the furrow.

2.3.1 Manuel Transplanting

Vegetable transplanting has advanced significantly throughout the past two decades, however transplanting is still labor intensive. Every aspect of the operation has been improved via mechanization except the actual feeding of the seedlings into the machine (Suggs et al., 1987). Mechanization of the feeding of seeding required to automate transplanting has been slowed due to the biological, non-uniform nature of seedlings. Seedlings are a growing organism, which means every slip has a unique physical characteristics and geometry. The cell structure of the seedling makes them vulnerable to do damage, either crushing or breaking.

Feeding slips into a transplanter requires three sub-operations; singulation, isolating a seedling from a bulk sample, aligning and transferring the seedling with respect to the transplanter mechanism (Suggs et al., 1987). Each sub-operation depends on the physical characteristics of the seedlings which are naturally are non-uniform, fragile and tend to tangle (Suggs et al., 1987). Vegetable transplanters are classified by the technique used to grab seedlings. There are currently several types which include clamp-type, chain clip-planting machine, disk clip planting machine, basket-type planting machine, belt planting machine and guide tube seedlings transplanting machine (Wan and Wang, 2011). An important statistic when comparing transplanters is the damage ratio; “clip” type, chain clip and disk-clip designs have the tendency to crush seedlings therefore they are not suitable for young plants, while the guide tube and flexible-disk transplanter have relatively low damage ratios (Wan and Wang, 2011). Sweet potatoes, cassava and tobacco fall into the category of crops that still require mechanical transplanting. These crops are cultivated by planting a section of plant from the previous crop. For example, sweet potatoes require the planting of a 10-12 in. vine cutting. Thereby, several engineers have conducted countless experiments to increase the productivity and efficiency of mechanical transplanting (Suggs et al., 1987, Wright and Way, 1987, Wan and Way, 2011). Efficiency has been improved through optimizing the seat position for laborers and through evaluating the speed of the transplanter to reduce damaging or mis-loading cultivars.

Way and Wright (1987) published an article, **Human Performance in Mechanical Transplanting of Sweet Potatoes,** where they evaluated and compared manual transplanting and mechanical transplanting. They discovered that hand transplanting on average was performed at a rate of 17 plants per minute per worker, while a single row, two person per row semi-automatic mechanical transplanter increased production to 31 plants per minute per person (Way and Wright, 1987). Throughout the study, a five loading station transplanter simulator and a conventional transplanter were used to determine their effects on operators', ranging from plant loading performance, comfort and difficulty. They modified a Holland BASIC planting unit to make it function while remaining stationary, a variable speed simulator to control the operating speed of the transplanter. These modifications enabled them to study the effects of transplanter speed on the operator. Data was collected through photoelectric sensors, which allowed the beam to shine beyond the path followed by the end of the pockets, so when a slipped filled a pocket the beam was interrupted and when the pocket was unfilled there was no interruption. Experiments concluded that the best transplanter type had five loading stations and a horizontal loading station area. A loading station refers to where an operator places a slip into a pocket. The operator faced so the middle of the loading station was 60 degree to the right of the direction he faced and the pockets moved from his left to his right, (all operators in this experiment were right handed) (Way and Wright, 1987).

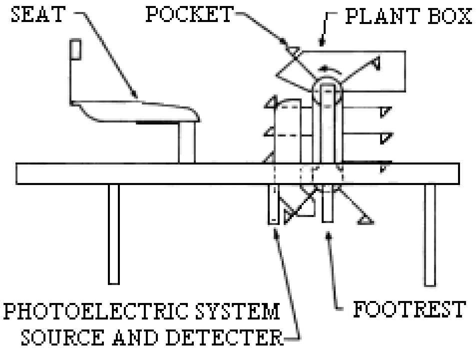


Figure 2.3. Side view of Basic Holland transplanter used in the Way and Wright (1987) study.

2.3.2 Automated Transplanting

Advancements to robotics and automation systems have made the leap from industrial applications into agriculture machinery. The use of robotics in automatic transplanters has reduced labor requirements by executing repetitive tasks in an accurate and reliable manner (Ryu et al., 2001). Stoddard et al., (2006) presented the labor requirement per acre to plant sweet potatoes averaged 3.95 man hours and $251. Reduction in the number of laborers need to plant slips could significantly reduce production costs.

Automated feeding currently utilizes either on a chain, tape or similar device holding plants in a single file or a tray holding plants in a grid to circumvent the natural non-uniformity of the plant with respect to size, shape and location by attaching it to an element (Suggs et al., 1987). Two distinct groups of automated transplanters have emerged over the past two decades. One machine feeds a strand of plants into chain pots between a pair of feed rollers into a rapidly rotating pair of accelerator rollers which broke the strand between plants and propelled the plant into the drop tub (figure 4). The second method grips plants between a pair of hands, that rotate the plant into the furrow, release it (Suggs et al., 1987). Gripping plants directly from plant trays can be successfully performed at a rate or 100 plants per minute while transplantation the utilized the chain pot technology was performed successful at 140 plants per minute (Suggs et al., 1987).

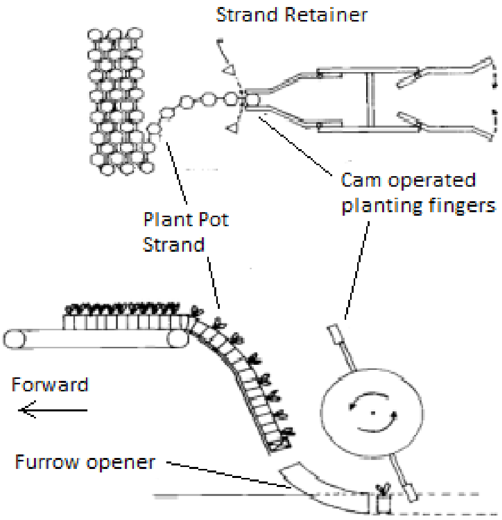


Figure 2.4. Suggs et al,. (1987) chain pot transplanter representation.

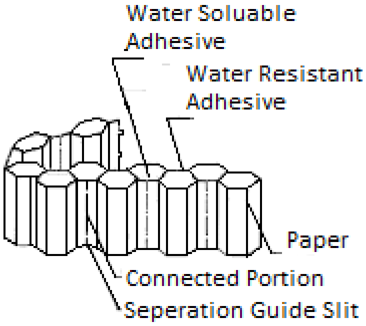


Figure 2.5. Suggs et al., (1987) chain pot automatic transplanter.

As technology, specifically transplant technology continues to move forward, engineers must continue to design solutions which deal with the natural variability of seedlings. As mentioned, this has been accomplished for seedlings that can be grown in an individual pot or tray, however innovation are needed for crops that are cultivated from larger plants like sweet potatoes, tobacco and cassava. Each of these plants are transplanted by grafting a section of a plant into the ground.

2.4 Processes Required for Automation

Automation is the use of a control system to reduce the need for human intervention as much as possible, effectively improving efficiency, lowering rate of errors, and reducing the cost of labor requirements (Zhang et al., 2007). Advancements in technology has enabled the automation of numerous mechanical processes used in industry. Automation in agriculture, specifically vegetable planting has developed slowly in due to working environment and manual skills required to perform tasks. Automation routinely consists of three general assignments; this includes sorting, assembly and transporting raw materials. Each general assignment includes multiple subsystems. For example, automated sorting includes at least three subsystems: ejecting system, transporting system and packing system (Zhang et al., 2007).

Two factors that have allowed automated technology to develop faster in industrial sectors than agriculture are the environment in which the technology would operate in and the physical properties of raw materials. The working environments in manufacturing sectors are relatively constant with respect to lighting conditions, humidity and ambient temperatures. The environment at which a machine used in agriculture fluctuates greatly in comparison. Light fluctuates from low to high intensities and temperatures can range from below freezing to above 100^0F. Environmental conditions are drastically different due to industrial technology typical location in either a warehouse or factory while agricultural technology must be built to with stand use outside where it must withstand harsh environmental conditions. Agricultural technology and machines will be subjected to harsh weather condition and a variety of ground conditions. Another factor that has adversely affected the progress of automation within the agriculture sector is the biological nature of raw materials (Lee and Kok-Meng, 1999). The development of an automated process or the improvement upon a pre-existing mechanical process in agriculture or industry the way at which materials are handled is important. Raw materials are vastly different between industrial and agriculture sectors. Often in industry materials are rigid and durable, which enables grasping, guiding and sorting of machines to be crude. Sorting biological materials must be more precise, a mechanism that can clamp onto steel with a moderate force when applied to a seedling will most likely damage or potentially kill the plant.

Automation can improve the efficiency of most mechanical processes, but it is not suitable for processes that require manual skill. The economic benefits related to automation are offset by higher initial costs along with higher maintenance costs (Raji and Alamutu, 2005). Replicating manual skill through automation requires advance sensors, software programming and measuring systems. The two skills that human operator possess that are most complicated to reproduce in automation is the ability to feel and grasp raw materials and the ability to identify and locate objects.

2.4.1 Identifying Objects

Machine vision represents technology used to acquire and analyze the image of a real scene through the use of computers and other devices to obtain data or control machines or processes. (Sun et al 2003) The theory and application of image analysis has experienced tremendous growth, as technology has progressed (Raji and Alamutu, 2005). Basic systems include a camera, a computer equipped with an image acquisition board and a lighting system. There are three levels of visions systems (Raji and Alamutu, 2005). Low-level processing systems include image acquisition and pre-processing, (pre-processing includes applying filters that can remove the background, specific colors). Intermediate level processing includes both steps mentioned in low level processing then goes on to segmentation, representation and description of the image. High level processing includes all steps mentioned thus far and then executes recognition and interpretation of the image. The figure 6, presents the progression of each level of processing.

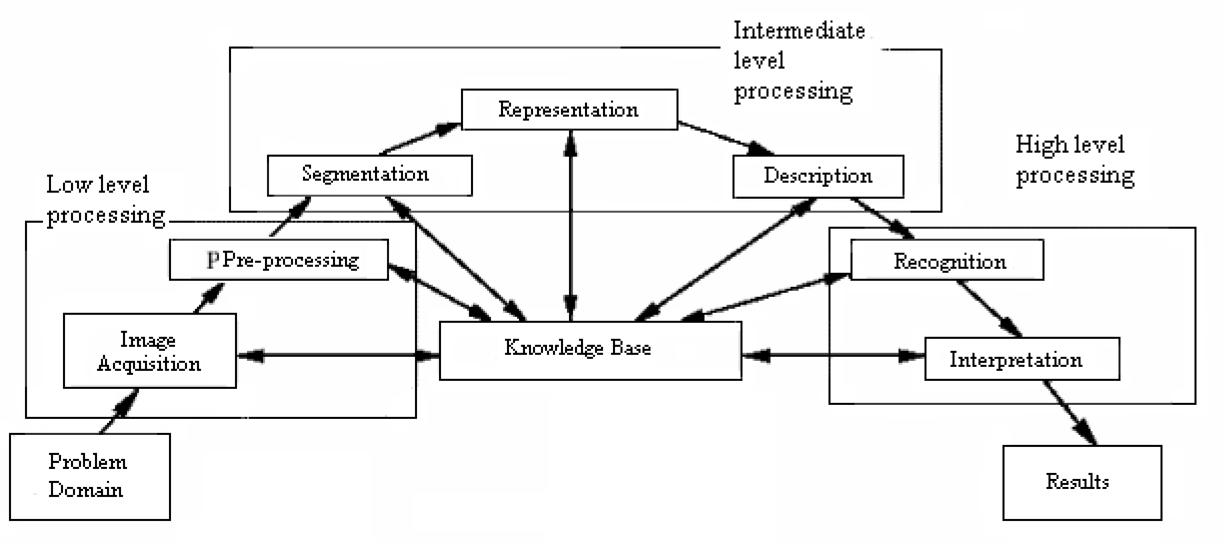


Figure 2.6. The three levels of computer vision analysis. (Raji and Alamutu, 2005)

There are two key components in image acquisitions, the illumination system and image capturing device. Proper illumination systems within vision systems cannot be overstated. The performance of the illumination system greatly influences the quality of an image and plays a significant role in the efficiency and accuracy of the system (Raji and Alamutu, 2005). The lighting type, location and color quality will present the objects or scenes in the optimal way to be recognized or analyzed. Light sources commonly used include fluorescent lamps, incandescent lamps, lasers, X-ray tubes and infra-red lamps. Image capturing devices are used to generate images and can include scanners, ultrasound, X-ray and near infrared spectroscopy, however in machine vision, solid state charged coupled device (CCD) are used to generate images (Raji and Alamutu, 2005). Recent technology has enabled digital cameras to be used to capture images, which eliminates the need to convert CCD image to a digital format.

Image preprocessing refers to digitizing the images captured to make them readable by a computer. Preprocessing enables the computer to improve image quality by suppressing undesired distortions by enhancing important feature in the image (Raji and Alamutu, 2005).

Low level vision systems would be sufficient to sort or singulate raw materials. The main objective of the vision system would be to locate raw materials. This vision system would enable a control system to know the precise location to project a grasping mechanism or suction mechanism to extract an item from a group or cluster. To singulate sweet potato cuttings the vision technology would be subjected to multiple light intensities every time it functions. The accuracy of the vision system would be affected when operating in low light conditions. Another item that would affect the illumination system is the variability of slip color. Some slips are dark, with purple tenting which in low light may appear black to the vision system. Machine vision was not a good fit for this application.

2.4.2 Grasping Raw Materials

The second skill that human operators possess that is difficult to generate through mechanical mechanisms is the ability to grasp objects. Grasping raw materials, especially seedlings, is currently one of the key obstacles slowing down the advancement of automation in agriculture. Technology used in industrial settings includes pneumatic suction and the use of magnets or mechanical hands; where grasping technology in agriculture is limited to the use of mechanical hands. Mechanical hand designs are separated into two categories: simple hands and complex hands (Rodriguez et al., 2010). Simple hands utilize fewer actuators and sensors which provides simple control strategies compared to complex hands (Rodriguez et al., 2010). Simple hands are designed and controlled for particular tasks due to their basic construction however complex hands are designed for general functions.

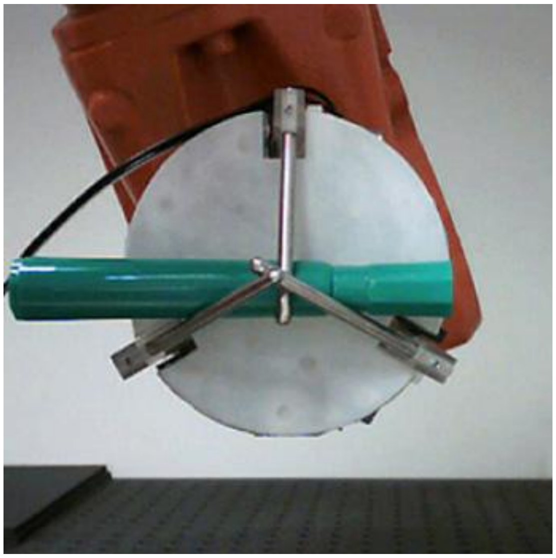


Figure 2.7. Simple hands can be designed to pick up or separate objects, the complexity of the hand depends on the task being performed (Rodriguez et al., 2010).

Rodriguez et al., (2010) published *Manipulation Capabilities with Simple hands,* where he defined two strategies were to control simple hands; “let fingers fall where they may” and put the fingers in the right place”. The first method enabled the range of motion to rely on the details of the grasping process. The thought process that motivated this method involved the idea that if they closed the hook, “all the details of the grasping process to be determined by the mechanics of the emergent interactions between hand and object” (Rodriguez et al., 2010). The second method they experimented with was, “put the fingers in the right place.” This method relied on knowledge of object size, location and the mechanics of stable grasp (Rodriguez et al., 2010). Method two relies on accurate sensors, models and controls, therefore small error can cause failure.

To automate the sorting and planting of sweet potato slips, the philosophy “let the fingers fall where they may” would produce the best results. The second method requires knowledge of the size, shape and location of the objects being grasped, due to the variability of sweet potato slips the size and location of the slip will change with respect to every grasp attempt. Generating a range motion, to produce collisions and interactions of groups of slips that will create separation within a group creating space between slips will be crucial. The correct range of motion will determine the success or failure of the grasping mechanism.

2.5 Summary

In 2011, 97% of the total U.S. ethanol production was corn-based, which consumed 27.3% us the total corn grown in the U.S. Increased production and projected goals for ethanol production has left researchers searching for alternative feedstocks. Monday (2009) showed that sweet potatoes could be a viable feedstock producing 2-3 times the carbohydrates need for fuel ethanol compared to corn. However, there are two major drawbacks; increased labor cost and the labor requirements to plant sweet potatoes. Currently sweet potatoes are mechanically transplanted at an average rate of 31 plants per person per row. It takes two people per row and a tractor operator. Stoddard et al., (2006) cost analysis, showed that planting sweet potatoes requires approximately 4 man hours and costs about $251 per acre. The best way to decrease cost is to decrease the labor requirements through automating the planting of sweet potatoes. If commercial grower planted three rows simultaneously, an automated transplanter eliminates the need for five operators.

Chapter 3 Design Criteria and Concepts

3.1 Preface

Vegetable transplanting is a labor intensive task that involves three main processes: sorting, transferring seedlings to a transplanter mechanism and placing the seedling into the furrow created in the soil. This chapter outlines the design criteria and concepts for sorting and singulating slips and seedlings. The physical characteristics of seedlings were found to be a key limiting factor in the design of an automated seedling sorting and singulation mechanism. Design limitations are described within the in design constraints and parameters. Measured and observe physical characteristics of sweet potato slips and pine seedlings are presented. Finally, alternative slip and seedling sorting and singulation preliminary design concepts are then discussed.

3.2 Design Constraints

Design constraints represent quantifiable or qualitative characteristics that provide design limitations or establish specific needs. For this study, three categories of design constraints existed; economical, environmental and technical. The economical design constraints established were:

1. Minimum sorting rate of 62 plants per minute per row. The minimum sorting rate had to equal the planting rate of existing commercially available transplanter technology.

2. Sorting and removal from the holding bin must be performed with a minimum accuracy of 70%, slips or seedling should be secured and removed from the bin on at least 70% of hook extractions. A sorting efficiency of 70% is acceptable due to multiple slips being extracted on a single hook extraction which creates a surplus of slips available for planting.
3. Fabrication costs. The cost to develop and fabricate this product must remain in a threshold that allows a producer to justify the purchase.

Technical constraints:

1. On-board slip storage. Planting sweet potatoes requires 9,000 to 15,000 slips per acre. Commercial sweet potato producers utilize a four row transplanter. The Design would include 8 bins holding, 2 per row, each holding 1,500 slips. Two holding bins would feed each row to maintain efficient metering. Therefore, an acre could be planted without loading additional slips.
2. The design sorting mechanism must overcome the non-uniform geometry of slips and seedlings. The durability of slips specifically, or lack thereof must also be taken into account during the sorting process.
3. Slips averaged 25.4 -30.5 cm in length thereby the width of on-planter storage was established.
4. Electrical components must operate on 24Vdc due to the electrical output system on modern tractors.

Environmental constraints:

1. The design will operate in an outdoor environment, where sun light intensity, humidity and precipitation varies. Therefore, mechanical and electrical components must be weather proof.
2. Electrical components have to be durable and operational when exposed to dust, dirt, mud, fertilizers and other elements.

3.3 Design Parameters

Design parameters are the qualitative and quantitative aspects of the physical or functional characteristics of a design, component or system that provides input to the overall design. Similar to design constraints, parameters can be divided into the same categories; economic, technical and environmental. Potential economic benefits of an automated transplanter include improved planting efficiency through reduced labor requirements and increased metering rates. Automated sorting and singulation and delivery to the furrow eliminates to laborers per row. Technical parameters required knowledge of knowledge of transplanting. For example, sweet potato slips must be transplanted deep, at least two nodes underground and perpendicular to the surface. Technical and environmental parameters overlap. Mechanical and electrical components have to be durable and weather resistant. The design will be subjected to a multitude of vibrational frequencies generated from the tractor's engine, driving over rough terrain, getting pulled through the soil and from the sorting mechanism.

3.4 Sweet Potato Slip Characteristics

The physical characteristics of sweet potato slips were a significant limitation in the design of a mechanical sorting and singulating system prototype. The geometry, flexibility, elasticity and leaves varied significantly for each variety of sweet potato. Beauregard, Jerusalem and an industrial variety of sweet potato were compared. However, Beauregard sweet potato slips were primarily used to through this research. Literature (Olson et al., 2012; Kemble et al., 2006: Stoddard et al., 2006; Monday et al., 2002) has stated that slips vary in length from 25.4 to 30.5 cm. Slip length is dependent on the growing season; slips harvested early in the season are shorter, closer to 25.4 cm. Along the length of each slip, leaves protrude from nodes. The leaves often caused larger groups of tangles, adding to the challenge of mechanically sorting. However, all leaves, except those protruding from the top two nodes could be removed prior to transplanting.

Sweet potato slips grown in large raised bed. However, slips primarily used through this research were grown in pots at Auburn University. Slips grown and harvested from pots had 2 to 3 times the nodes compared to slips grown in beds. Potted slips also were more complex in geometry, they curve around multiple axis. Slips varied greatly in rigidness, shape and size. The flexibility was observed by manually bending slips into a semicircle. Most slips could reach a nominal diameter of 3.8 cm prior to breaking, while thicker slips broke prior to reaching 5.1cm. A Mitutoyo Absolute SuperCaliper (model number CD67-S6"PS) was used to measure Beauregard slip diameter in three locations; near the cut end, the center and directly below the first node with leaves (Figure 3.1). The diameter varied 1.3 mm across the length of the slip (Table 3.1). Overall, slip diameter averaged 3.6 mm.

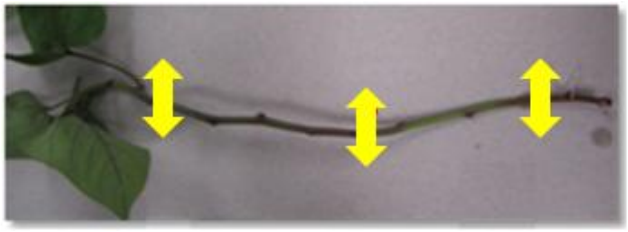


Figure 3.1. Illustration of the three locations in which slip diameter was measured; near the leaves, at the center and near the cut edge.

Table 3.1. Mean Beauregard slip diameter (mm) measured in three locations across individual slips along with mean diameter.

	Root	Middle	Leaf	Average
Average (mm)	4.2	3.8	2.9	3.6
Standard Deviation	0.6	0.7	0.5	0.5

Design of an automated planter for sweet potato slips requires knowledge of the transplant process. The tropical nature of sweet potatoes allows them to thrive in warm climates, while planted in sandy loom soils. Sweet potatoes slips are planted deep, requiring at least two nodes under the surface of the soil in raised beds. Raised beds prevent water damage during heavy precipitation, while maintaining moisture during droughts. Tyler Monday (unpublished data, 2010. Auburn, AL.: Auburn University) did a field study(Appendix D) that evaluated how slip orientation affected survival rate and yield. The study utilized three treatments with two variations of sweet potatoes; Beauregard and X-167, a high starch industrial sweet potato (table 3.2). Treatments 1 and 2 utilized conventional slip orientation. However, slips were transplanted in bedded soil in treatment 1 while, slips in treatment 2 were transplanted in non-bedded soil. Lastly, slips in treatment 3 were transplanted in bedded soil, in a “U”-shape. Statistical analysis, ANOVA test with a 95% confidence interval, of the survival rate showed that treatment 1, conventional and treatment 2, new slips transplanted in non-bedded soil, were not significantly different for either variety of sweet potato. However, the survival rate of treatment 3, the “U”-shape transplants was significantly lower than both treatments 1 and 2. The field study showed that raised beds did not significantly affect the survival rate of slips, but slip orientation could significantly decrease survival rate.

Table 3.2. Results from 2010 field study, which evaluated three sweet potato slip transplant procedures; slip transplanted into raised beds (conv.), slips transplanted into flat soil (new), and slips transplanted in a ”U”-shape (U) (Tyler Monday, unpublished data, 2010. Auburn, AL.: Auburn University).

TRT	Survival	Survival (%)	Yield (lbs)	Calculated Yield (lbs/A)
X-1617 Conv.	19.3	77.0	81.3	47190.0
X-1617 New	16.3	65.0	77.9	45258.8
X-1617 U	9.0	36.0	62.6	36372.6
Beau Conv.	21.8	87.0	78.5	45592.8
Beau New	20.0	80.0	73.0	42376.6
Beau U	13.3	53.0	60.1	34906.1

3.5 Pine Seedling Characteristics

Pine seedlings, unlike slips, are more rigid. Seedlings arrived ranging in length between 35.6 to 50.8 cm, tightly packed in a preservative gel. Seedlings were trimmed to match the average length of sweet potato slips to utilize the same holding bin. Two methods were used to trim seedlings; the top, the pine needles or the root was trimmed to obtain the desired length (figure 3.2). Once trimmed seedlings were grouped and randomized prior to them being loaded into the holding bin. Figure 3.3 illustrates how seedling geometrically varied. Overall, seedlings were relatively straight. The thickness and amount of pine needles also varied. Similar to slips, branches protruded from seedlings. Branches either caused tangles or separation among groups of seedlings depending on the rigidity of the branches. Through the duration of testing, seedlings were repeatedly recycled causing them to dry out. The mass of individual seedlings decreased on average 2.4 grams through testing (table 3.3). Repetitive contact with the bin and hook mechanism removed the gel preservatives and sand from seedlings causing pine needles to separate and become bushy. Lighter seedlings fed through the holding bin at a slower rate compared to fresh, heavy seedlings. The slower feed rate negatively affected performance of the sorting mechanism.


a
b

Figure 3.2. Image illustrates where pine seedlings were trimmed to achieve the desired length; (a) the pine needles at the top and (b) the roots.

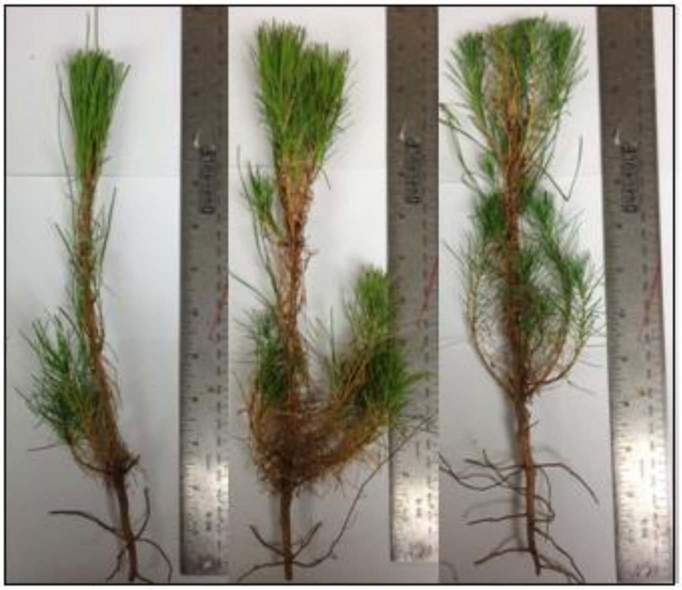


Figure 3.3. Three examples of relatively straight, post-cut pine seedlings. Note branch orientaion and number of branches varied between slips.

Table 3.3. Summary of seedling mass before (pre) and after (post) the sorting tests.

	Pre (g)	Post (g)	Difference (g)	Percent Difference
Average	10.0	7.60	2.40	27.3%
Standard Deviation	2.60	1.39	1.21	

3.6 Alternative Design Concepts

The Design of an automated transplanter required three sub-systems. The first sub-system focuses on the slips singulation or sorting. Sorting is the removal of 3 seedlings or less from a bulk sample, while singulation is the removal of a single seedling from a bulk sample. The second sub-systems transports sorted slips to a transplant mechanism where it is later, placed into the furrow. The final sub-system, places the plant into the furrow, closing soil around the plant.

Automated transplanters, like the Pearson Fountain AutoPlanter (Pearson AutoPlanter, 2006), have been developed for crops propagated from seed plugs. Seeds are either propagated in grid trays or chain pots to give seedlings a location (x,y) relative to the transplant mechanism. These specialized pots eliminate the limitations associated with the non-uniform plant geometry. Crops transplanted from vine cuttings (e.g. sweet potatoes) or from larger seedlings (e.g. pine seedlings) cannot be grown in special pots and require manual singulation prior to transplanting. Currently, sweet potato slips are transplanted using a semi-automatic mechanical transplanter, where slips are singulated manually and fed into an automated transplanter.

A review of planters, specifically corn planters, seed is loaded into a holding bin. Holding bins provide sufficient on-board storage. Slips average 30.5 cm in length thereby the holding bin can be designed to have a width of 35.6 cm, permitting slips to lay flat while limiting the potential lateral displacement.   The holding bin had to hold enough slips to plant an acre. Limiting the time spent loading the holding bin, reduces labor requirements. The first sorting concept explored extracting individual slips from bundled groups. A metal hook moved back and forth extracting slips on the outer edge of the bundle. This concept was eliminated due to the labor requirement necessary to bundle slips. Another concept for a hook mechanism was developed through manually extracting slips from a group of slips bundled on a workstation. Manually pinching slips between the thumb and fore-finger worked efficiently. Slips could be removed from the group utilizing a target specific, a slip that had separated itself from the bundle, range of motion and curled fore-finger. Slips were secured and lifted perpendicular to the station, gravity was used to separate leaves. Observation of all preliminary concepts provided a foundation that lead to the concept of pulling slips through the bottom of a holding bin.

Chapter 4 Prototype-1

4.1 Preface

An initial prototype, Prototype-1 was designed and fabricated to evaluate holding bin design and multiple hook designs. This prototype provided a small scale test platform to evaluate fundamental sorting and singulation concepts which could then be used for subsequent designs. The front and back panels of the holding bin remained adjustable to determine the angles necessary to maximize slip feed rate, while hook geometry, contact configuration, and range of motion (ROM) provided the qualitative data required to assess sorting efficiency. The holding bin, two hook contact configurations and five hook designs were evaluated during this initial effort.

4.2 Mechanical Design

4.2.1 Holding Bin

Planters and transplanters used throughout the agriculture industry require on-board seed or seedling storage. The majority of planters utilize a hopper, or holding bin, while currently, all automated transplanters require specialized pots. Sweet potato slips and pine seedlings were not considered viable options to be grown in specialized pots, since slips are vine cuttings from bedded plants. Therefore, the initial design step was to develop a holding bin to properly store sweet potato slips or pine seedlings that would minimize the negative effects associated with the non-uniformity of slips. Since slips average 30.6 cm in length, the bin was designed to be 34.4-cm wide. The width allowed slips adequate space to lay relatively flat inside the bin without excessive space for lateral movement. The height or depth of the bin was established to produce a 15 to 30 slip storage volume for preliminary testing. The holding bin was designed to allow slips to be extracted from the bottom. The main design focus was the shape and opening at the bottom of the bin in order to grasp and remove individual slips. The front and back panels were tapered such that they formed a V-shape to provide a slip feed rate at the bottom of the bin. The bottom angles of the front and back panels restricted the volume of slips or seedlings at the bottom of the bin, while aiding the feed rate of slips supplied to the bottom. Figure 4.1 illustrates how the front and back panels were assembled while showing the opening in which slips could be removed.

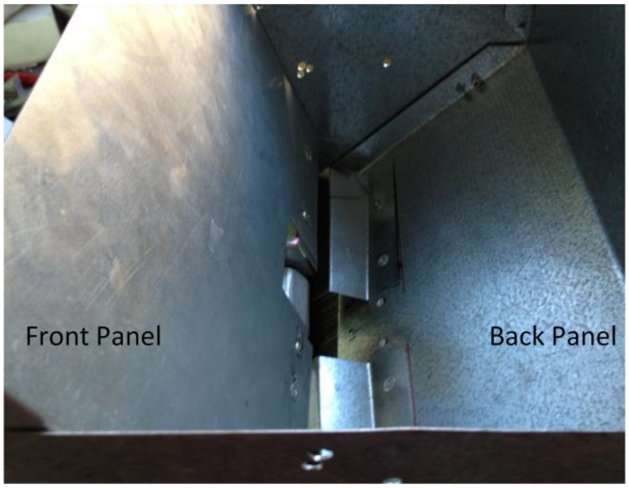


Figure 4.1. A look inside the holding bin of Prototype-1, the bottom angles of both the front and back panels were adjustable to determine the angles that maximized slip feed rate.

The side panels mounted directly to a rectangular steel frame, which provided a rigid substructure. Front and back panels were fastened to the side panels remaining independently adjustable. The bottom angles of the front and back panels were adjusted throughout testing to determine a feed rate that would minimize tangles among groups of sweet potato slips. The bottom angles of the front and back panels directly affected the rate at which slips fed to the bottom of the bin. Larger angles allowed for a direct path to the bottom of the bin. Nylon bristles attached to both the front and back panels to retain slips in the holding bin while permitting removal with the hook mechanism. Figure 4.2 illustrates the slope required to feed slips and where the nylon bristles were attached to the back panel.

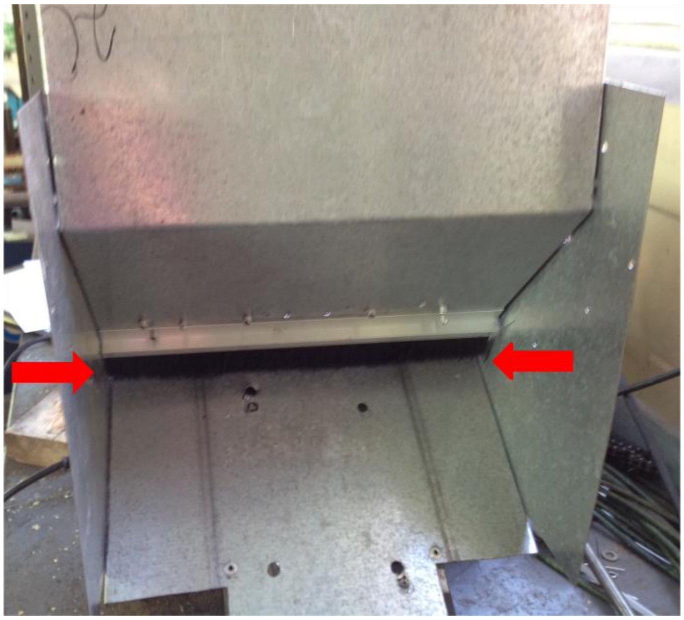


Figure 4.2. Illustration of Nylon bristle (marded by the red arrow) mounted to the back panel, which prevented slips from falling out of the bin.

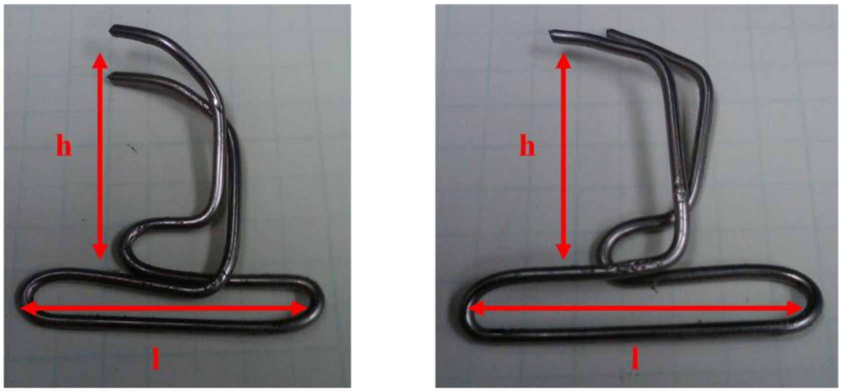
4.2.2 Hook Design

The mechanization of slip or seedling singulation was the first step required to design an automated transplanter. Singulation is an act of sorting; removing a single object from a group or large sample. The goal in this research was to singulate slips or seedlings. However, sorting slips into small groups, three slips or less was acceptable because singulation of small groups, is a simpler task compared to singulation of slips from a large (50 or more) sample. The physical characteristics of slips and seedlings were a driving force of hook design. Slip size, geometry and rigidity affected hook design. Two contact configurations, where slips were grasped; 1 versus 2 points of contact (figure 4.3) and five basic hooks were designed.

Figure 4.3. Illustration of the two contact configurations evaluated for singulating sweet potato slips; two contact points (a) versus one at the center (b).

4.2.2.1 Dual Hook Design

The dual hook configuration targeted slips approximately 2.54 cm from the cut edge and from the highest node at the top of the slip. Two parallel hooks cycled through the bin simultaneously, while slips at the bottom of the bin were grasped and removed. Hooks were designed and fabricated from 1.6 mm welding rod for easy modification (figure 4.4). Hooks fastened to the 35 ANSI chain through a horizontal tabbed master links. The hook's height and the length of the hook's base significantly affect sorting performance. Hook height determined the depth that hooks penetrated the bin. If the hook was too tall, large groups of slips would be removed. However, if the hook was too short, slips remained untouched inside the bin. Once slips were secured by the hooks, extracting slips from the bottom of the bin generated torque, exerting rotational force on the hooks. Therefore, the base of each hook was designed to contact the chain, where the contact force between the base of the hook and the chain kept the hook upright. Two distinct hook designs were evaluated. Hook-DH1 featured a gradual curve throughout the hook (figure 4.4a), while Hook-DH2 featured a straight vertical section with a 45^0 degree bend (figure 4.4b).



a b

Figure 4.4. Depiction of the Hook-DH1 (a) and Hook-DH2 (b). Note the difference in hook height (h) and hook shape and the length of the base (l) of each hook.

4.2.2.2 Single Hook Design

The second contact configuration, focused on securing each slip at the center. The non-uniform geometry of slips made securing the individual ends of each slip a difficult task. However, it was observed that as slips were extracted from the bin, the center of mass of each slip followed the same path out of the bin. Three hooks were designed at three widths. Each hook was manually inserted and extracted from the bin to determine the optimal range of motion (ROM) and hook width. Hooks widths included 2.54, 3.81 and 5.08 cm. Each hook design related to a specific sorting concept and ROM, Hook-SH1 and Hook-SH2, (figure 4.5) featured a round hook design, while, Hook-SH3 was triangular in shape (figure 4.6).

Hook-SH1 was developed through manually removing slips, with a curved fore-finger from a bundle of individual slips that was secured together. Hook-SH1 was a simple “J”-shape, the thickness remained consistent throughout before getting larger at the tip of the open end. Hook-SH2, similar to Hook-SH1 featured a round hook contour; however the hook featured a thinner tip and more material was left at the base of the hook. The additional material was left to potentially incorporate a closing mechanism. Hook-SH2 was designed through observation of a manufacturing mechanism that singulated steel round stock by grasping individual pieces.

Material at the back of the hook was angled to force slips out of the hook upon re-entry into the bin. Finally Hook-SH3 had a triangular shaped nose, was designed to act like a wedge creating separation between individual slips upon entry into the bin.

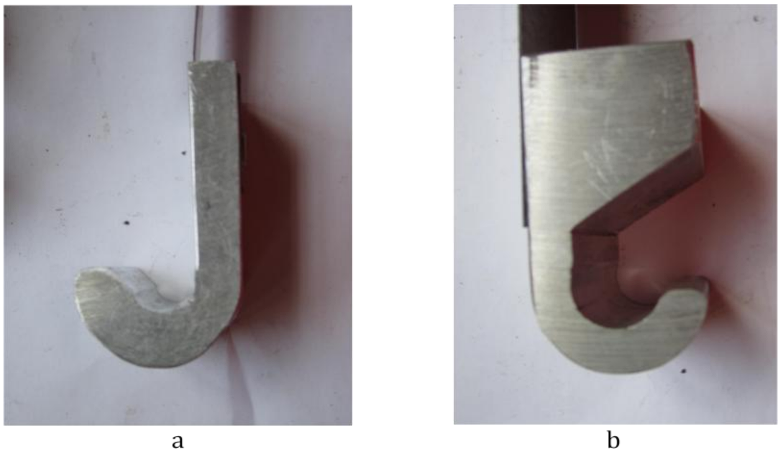


Figure 4.5. Images of Hook-SH1 (a) and Hook-SH2 (b) which were "J" shaped. A flexible linkage provided the handle for each hook, which aided in creating the required range of motion, while enabling manual testing.

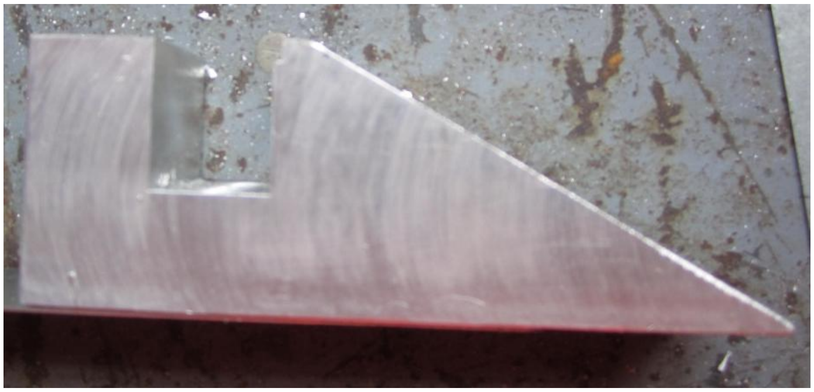


Figure 4.6. Hook-SH3 was triangular shaped, and acted as a wedge causing seperation between individual slips.

4.2.3 Range of Motion

The range of motion (ROM) of the hook mechanism played a significant role in the sorting of slips. Multiple ROM's were created through manual control of hooks and the ROM that sorted slips most efficiently was mechanized. Two distinct ranges of motion were developed with respect to hook configuration.

4.2.3.1 Dual Hook ROM

The dual hook configuration required a ROM that allowed two hooks to enter and exit the bin simultaneously. The ROM utilized two axle assemblies, each assembly featured a pair of Martin Sprockets 35BS18 ½, (35 ANSI chain with 18 teeth and 1.27 cm inner diameter), fixed to an axle. One assembly was mounted to the top and the other to the bottom of the holding bin's steel base. Two hooks fastened to each chain. The chains were spaced (Figure 4.7) 17.8 cm apart. A hand crank enabled manual control of the rate at which hooks cycled through the bin.

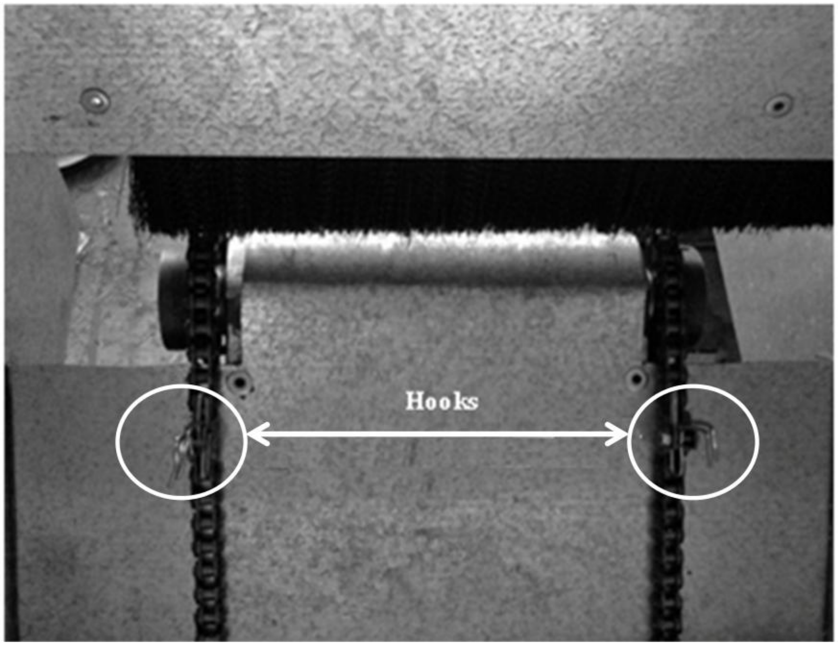


Figure 4.7. The dual hook Range of Motion (ROM), utilized 35 ANSI chain to cycle pairs of hooks through the bin simultaneously.

4.2.3.2 Single Hook ROM

The single hook configuration required a nonlinear ROM. A specific ROM was required for each hook design. Preliminary tests, performed by manually feeding each hook into the bin determined the desired ROM. Hook-1 utilized a ROM where it was inserted under the opening of the bin with the opening of the hook facing upward. After the hook was inserted past the opening, the hook was lifted upward, toward the bin and retracted. The intent was to hook and remove individual slips positioned at the bottom of the bin. Hooks 2 and 3 were inserted directly into the bottom of the bin at approximately 25° angle which was less than the angle (40.6°) of the back panel. Upon contact with the back panel, the hook was extracted. The hook followed the contour of the back panel as it was removed, securing slips between the hook and back panel which aided in slip separation. Manual testing indicated that Hook-SH2 and Hook-3 could effectively remove slips from the bin.

The ROM used to control Hook-2 and Hook-3 was mechanized through a cam design. The diameter of the cam, 8.9 cm, equated to the desired horizontal displacement of the hook. However, evaluations showed the slips were not completely removed from the bin. Therefore, the cam diameter was increased to 17.8 cm to pull slips free from the bin. A 16.5 cm arm connected the hook to the cam. A fulcrum was utilized to replicate the nonlinear ROM, (figure 4.8) which enabled the hook to enter the bin at an approximate 25^0 angle with respect to the ground. As the hook contacted the back panel, the arm crossed the x-axis of the cam which lifted the arm off the fulcrum. The hook was removed from the bin with the arm elevated from the fulcrum allowing the hook to remain in contact with the back panel.

The cam created the desired ROM, but testing revealed that the large diameter of the cam created excessive vertical displacement in the arm damaging the fulcrum. Thereby, the ROM was corrected by replacing the cam mechanism with a two gear assembly (figure 4.8 b) to further development and improved performance. The horizontal displacement of the hook was adjustable depending on the distance between the two gears, while the vertical displacement of the arm remained constant. The constant vertical displacement of the arm created a fixed pivot angle which meant the arm entered the bin at a constant angle, approximately 25^0.

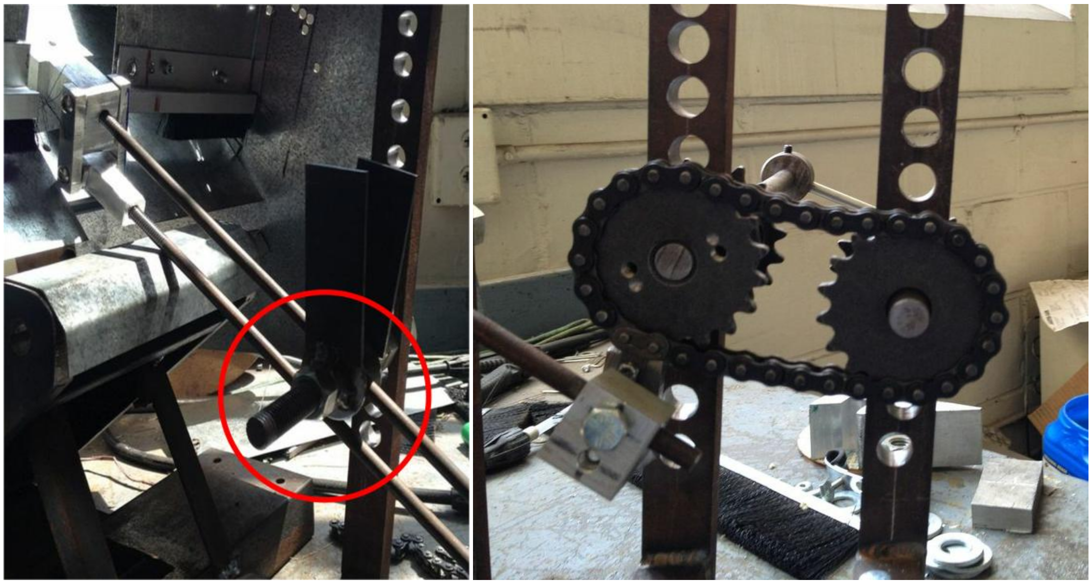

a b

Figure 4.8. Image of the gear and guide assembly which replaced the initial cam design. Image ‘a’ shows the fulcurm point, which produced the desired vertical displacement.Image ‘b’ illustrates the two gears that provided the desired horizontal displacement.

4.3 Method of Analysis

Prototype-1 was evaluated in a laboratory setting. Hook configurations and designs were evaluated through manually controlling the ROM. The dual hook configuration utilized two pairs of hooks that cycled through the bottom of the bin simultaneously. A hand crank controlled the rate hooks cycled through the bin. Each test evaluated the mechanism sorting 10 slips. All performance errors were noted and used in future design modifications. Interactions between each hook design and slips were also noted, specifically, the number of slips removed and how slips were secured by the hooks.

Three series of tests evolving around specific ROM evaluated the single hook configuration; 1) manual ROM, which evaluated hook design, width and the ROM, 2) the mechanized cam ROM, which compared and evaluated sorting performance of Hook-SH2 and SH3, and 3) the mechanize two gear ROM which evaluated Hook-SH4 at a faster sorting rate. Manual control of each hook was generated through a flexible arm fastened to each hook. Hook width and design was evaluated through manual testing which involved grasping and extracting a single slip from the opening at the bottom of the bin. The desired ROM for each hook was also determined through manual testing. The second series of tests qualitatively evaluated sorting performance of Hook-SH2 and Hook-SH3sorting 5-10 slips. The final series of tests featured Hook-SH4 and the ROM generated by the two gear assembly. The feed rate of slips was evaluated through all three series of testing.

4.4 Results and Discussion

4.4.1 Dual Hook Design

Preliminary testing identified key concepts that could be used to build an automated sorting mechanism. The objective was to identify which concepts would lead to a 70% sorting accuracy. Initial testing evaluated the dual slip contact concept which featured Hook-DH1 and DH2. The overall hook height and the length of each hooks' base played a critical role when sorting slips. The base of the hooks remained in contact with the chain while they cycled through the bin. Therefore, the base had to withstand the torque created by securing a slip. If the base was too short the hook rotated backwards releasing slips back into the bin. The required base length to keep hooks upright was 6.35 mm which was 1.5 times the vertical distance between the bolt hole in the masterlink to the center of the chain. Hook height determined the depth at which hooks penetrated the bin. The initial hook height did not produce desired results. Therefore, hook height was gradually increased by 6.35 mm until slips were consistently contacted. The desired hook height measured 3.7 cm.

A major drawback of the dual slip contact concept involved partially removed slips. The non-uniform nature of slips meant that slips rarely laid flat at the bottom of the bin. Slips wrapped themselves around one another creating tangles. As hooks cycled through the bin, hooks would contact several slips simultaneously. Once a slip was secured, the hooks would immediately extract them from the bin. It was common to see individual sides of slips to be extracted from the bin. However, the end that was not secured then rotated toward the middle of the bin creating tangles. As a result one end of the slip would hang freely from the bin while the other end remains inside impeding other slips from feeding to the bottom of the bin. A potential way to overcome this problem would involve physically grasping the end of each slip as it was secured by the hook. This would ensure removal and prevent the slip from sliding out of the hook.

Hook-DH1, the gradual curved hook (figure 4.5a) efficiently removed up to five slips from the bin. However, once more than five slips were loaded into the bin tests often ended prematurely. Hook-DH1 occasionally hooked small groups, at least 3 slips which often resulted in broken or partially removed slips. Hook-DH2 featured a 45^0 bend (figure 4.5 b). Multiple hook heights ranging from 3.49 to 4.76 cm were evaluated to determine hook height requirements before and after the bend. However, most hook lengths produced similar results to Hook-DH1. Tests often ended due to repetitive broken slips or tangles that the hooks could not separate. The variability of slip geometry and leaf geometry lead to an alternative slip contact concept.

4.4.2 Single Hook Design

Analysis of the dual hook configuration made it apparent that an alternative hook configuration was required. The geometric variability of slips introduced several variables that had to be generalized during sorting. It was observed that as slips exited the bin, the center of mass of each slip followed a similar path, thereby supporting a single hook concept. Initial manual testing evaluated three designs at three hook widths. The 2.54-cm wide hook broke slips as it extracted them from the bin. The shear stress exerted on the slips due to the small surface area bent slips past their elastic threshold breaking them prior to extraction. The mass and bulkiness of the 5.04 cm hook restricted made it difficult to manipulate inside the bin, which resulted in slips being pushed away from the opening. Ultimately, the 3.81cm wide hook removed slip most efficiently.

Three hook designs were manually tested and evaluated. Two physical characteristics of Hook-SH1 made it ineffective during testing. The round contour of the "J" shape produced a large surface area on the leading edge that contacted slips, pushing them away from the open hook and out of the ROM. The second characteristic that negatively affected performance was the shallow hook. Slips tended to slide out of the hook, remaining in the bin. Hook-SH1 was scrapped after manual tests. Hook-SH2 featured a deeper hook which improved the slip sorting rate. However, similar to Hook-SH1, the round contour of the outside edge pushed slips deep into the bin. Lastly, Hook-SH3 sorted slips most efficiently. Hook-SH3 required a more precise, longer ROM. However the wedge shaped nose created separation among groups of slips. Hook-SH2 and Hook-SH3 provided results that justified further evaluation with a mechanical ROM.

The second series of tests evaluated Hook-SH2 and Hook-SH3 along with the feed rate of slips with a mechanical ROM. The ROM utilized a cam and a fulcrum which created the desired non-linear range of motion which projected the hook upward into the bottom of the bin at approximately a 25^0 with respect to the top of the work station. Upon contact with the back panel, the arm crossed the x-axis of the cam, which elevated the arm of the hook off the fulcrum. As the hook was extracted the bin, it followed the contour of the back panel. Slips were gravity fed therefore the resultant forces created by the slope of the back panel determined the desired feed rate. Through the duration of testing the slope of the back panel was adjusted to determine a sufficient volume of slips accessible to the hook. The optimum slope of the back panel was determined to be approximately 40^0. This ROM allowed the hook to penetrate, separate and secure slips confining them between the hook and back panel to ensure that slips remained grasped.

Hook-SH2 grabbed slips consistently through 2-3 cycles. However, once the bottom groups of slips were removed, the round contour of the hook prevented farther slips extraction. Tests were replicated with alternative hook entry angles. The hook entry angle was modified though adjusting the position of the fulcrum point, so the hook would enter the bin at a steeper angle. Varied hook entry angles and ranges of motion did not improve the sorting performance of Hook-SH2.

Hook-SH3, the triangular in design, sorted slips most efficiently with the mechanical ROM. The required hook entry angle was approximately to 23^0, this allowed the tip of the hook to lift and separate slips. Qualitative analysis indicated that contact between the hook and back panel prevented the hook opening from penetrating deep enough into groups of slips to extract them from the bin. Two modifications were introduced to improve the hook performance. Baffles were added inside the bin creating space between the back panel and slips enabling the hook to penetrate deeper into groups of slips. The baffles also aided with slip feed rate. The baffles created vibrational frequencies which motivates slips to cycle to the bottom of the bin when the hook entered the bin. The second modification, involved the hook. The nose of the hook was shortened 1.27 cm. The second set of tests showed an increase in the frequency of slips hooked. The frequency of hooked slips doubled creating another obstacle, the rate at which the hook cycled through the bin slips were pushed back into the bin. The hook was modified further with aluminum removed from the rear of the hook, behind the opening (figure 4.9).

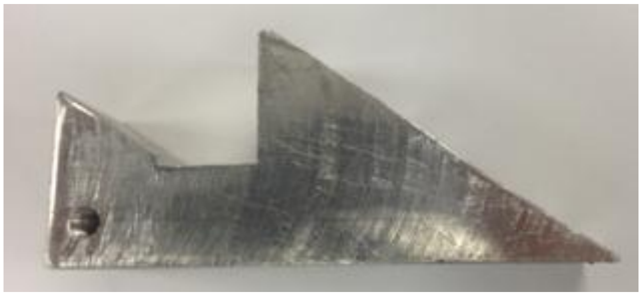


Figure 4.9. Hook-SH4 was created through modification of Hook-SH3, material was removed from nose and the opening.

The final tests performed with Prototype-1 evaluated Hook-SH4. Hook-SH4 consistently removed 5-10 slips from the bin, (the bin had a maximum capacity of 10-15 slips). The modifications improved the sorting efficiency and allowed slips to be released from the hook once removed from the bin. However, slips occasionally snagged the bin, remaining partially removed from the bin which caused slip feeding issues. It became apparent that the ROM did not extract the hook far enough from the bin. A sufficient distance would enable the hook to fully remove a slip, from both sides of the bin simultaneously. Therefore larger cam was fabricated. A cam diameter of 17.8 cm was used to extract slips completely from the bin while at the same time the large diameter created excessive vertical displacement in the arm. The excessive motion of the arm damaged the fulcrum point. Therefore, it was necessary to design an alternative ROM. The new ROM utilized two gears and a chain, as described in 4.2.3.2, to generated the desired horizontal displacement of the hook while maintain a constant vertical displacement. The new gear assembly improved the efficiency of the ROM.

4.5 Summary

The single hook configuration that utilized the two gear assembly ROM to drive the hook into and out the bin sorted slips most efficiently. Hook-SH4 consistently sorted 5-10 slips emptying the bin. Bin design played a critical role in the sorting of slips. The slopes at the bottom of the front and back panels, significantly affected the feed rate of slips. The optimum angles were evaluated to be 72.6° and 40.6° for front and back panels respectively which provided a consistent feed rate of slips. The feed rate was critical. The final series of test resulted in the conclusion that a larger scaled prototype was necessary to further evaluate hook and bin design.

Chapter 5 Prototype-2

5.1 Preface

This chapter outlines the development and evaluation of Prototype-2. The testing and qualitative analysis of Prototype-1 served as a baseline to provide initial design.. The bottom angles of the front and back panels, hook entry angle, range of motion (ROM), and Hook-SH4 were utilized to fabricate a larger scale prototype. Primary differences in Prototype-2 were the slip capacity of the holding bin and ROM was mechanized. Statistical analysis along with qualitative data provided evaluation of hook performance.

5.2 Mechanical Design

5.2.1 Holding Bin

Analysis of Prototype-1 was limited due to the scale at which it was built. Evaluation of the design made it apparent that the bottom angles of the front and back panels played a significant role in the feed rate of slips. The back panel for Prototype-2 was designed to feature an approximate 51° bottom angle, 10° steeper than Prototype-1. The bottom angle of the back panel was increased to improve the feed rate of slips and help supply a consistent feed rate to achieve a sorting rate equivalent to 70 plants per minute. The bottom angle of the front panel was also changed the angle was reduced from 72° to approximately 39°. The bottom angle of the front panel was decreased to increase the volume of slip storage in the bottom of the bin while providing clearance for the hook mechanism. The width front and back panels, 34.4 cm was maintained because it provided sufficient space for leaves and allowed slips to lay relatively flat when placed in the bin. The width of the side panels was increased, to 34.4 cm to increase the slip capacity of the bin. The bin was designed with a square cross-sectional area of 1,180 cm^2. The height of the bin was increased to 47.0 cm, to increase the capacity of the bin to approximately 100 slips (figure 5.1).

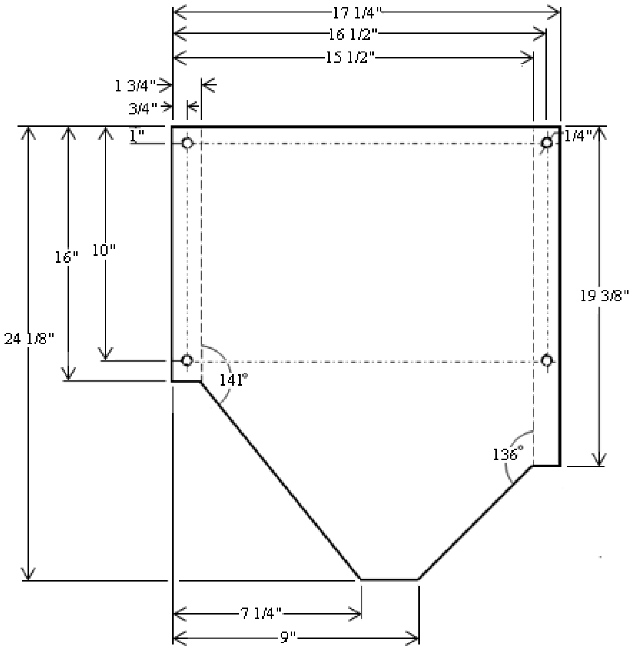


Figure 5.1. CAD illustration of the side panels of the holding bin with dimension (cm) of the holding bin.

The holding bin of Prototype-2 was designed to allow 20-30 slips to gather at the bottom of the bin. However, this large volume created tangles that impeded or prevented sorting and singulation. A baffle system was designed to fasten inside the bin to reduce slip capacity in the bottom of the bin, which would minimize tangles and aid in the feed rate of slips or seedlings to the bottom of the bin. The baffle system (figure 5.2) included three baffles. Two steel baffles were fixed to that back panel, while the third baffle fabricated from cardboard fastened to the front panel. Two rear baffle designs were evaluated to maximize the feed rate of slips or seedlings. The rear baffles utilized a channeled flange, which acted as a spring allowing the baffle to contact the front panel which maintained slips in the bin. Baffle-1 was designed to maintained a feed rate similar to the one produced by the back panel, (50^0). The baffle design varied compared to the back panel in that it featured a ridge to cause separation between individual slips within a large group. Baffle-2 (figure 5.3) featured a ripple design, which significantly restricted the feed rate of slips. This design was developed as a result of qualitative analysis of baffle-1. The geometry of slip leaves caused groups of slips to tangle. The front baffle was designed to gradually compress groups of slips to a single row. The geometry of the front baffle was played a critical role in the feed rate of slips. The front baffle was designed non-symmetrical to take into account for the volume of space that slip leaves consume. The baffle remained adjustable to account for slip variability. The angle at which the front baffle was mounted dictated the volume of slips that could feed to the bottom of the bin, increasing or decreasing the feed rate. Figure 5.3 illustrates the non-symmetric front panel.

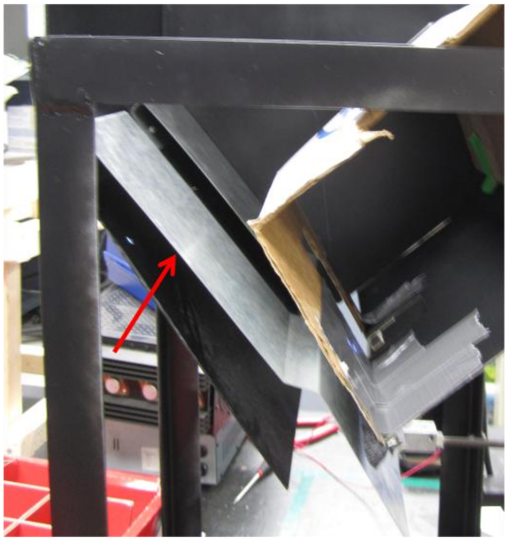


Figure 5.2. The baffle system, (Baffle-1), the arrow marks the rear baffle which is parallel to the back panel.

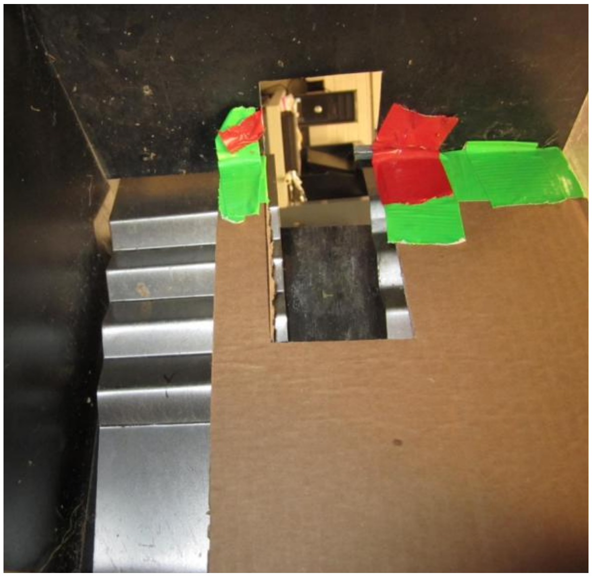


Figure 5.3. A view inside bin showing the front baffle. Note Baffle-2, the rippled baffle on the left, the ridges are visible due to the non-symmetric design of the front baffle which was required to due to volume slip leaves added.

The geometry of bin bottom of the bin played a critical role in the feed rate of slips or seedlings. A 5.08-cm wide by 7.62-cm tall rectangle section was removed from the bottom center of the front panel allowing the hook to enter the bin. The bin was designed so that the slip feed rate was adjustable through the angle of the front baffles mounted inside the bin. Two sets of nylon bristles mounted to the bottom of the front panel, on each side of the rectangular cut out section, to prevent slips from falling out of the bin.

A two piece base was fabricated to secure the bin upright and mount the drive motor, which controlled the rate of which the hook was inserted and extracted from the bin. One piece of the base had the dimensions 35.56 cm x 35.56 cm with a height of 55.88 cm. Steel tabs were welded onto the bin, which acted like stops when the bin was inserted firmly into the base. The second piece of the base fastened to the front of the holding bin's base. This piece was adjustable vertically 10.16 cm. The motor and two L-brackets mounted directly to the base. The fulcrum mounted to the L-bracket closest, 12.07 cm to the bin. A second bracket and the motor mounted to a reinforced platform welded to the horizontal section of the base. This platform provided horizontal adjustability for the gear and motor assembly (figure 5.4).

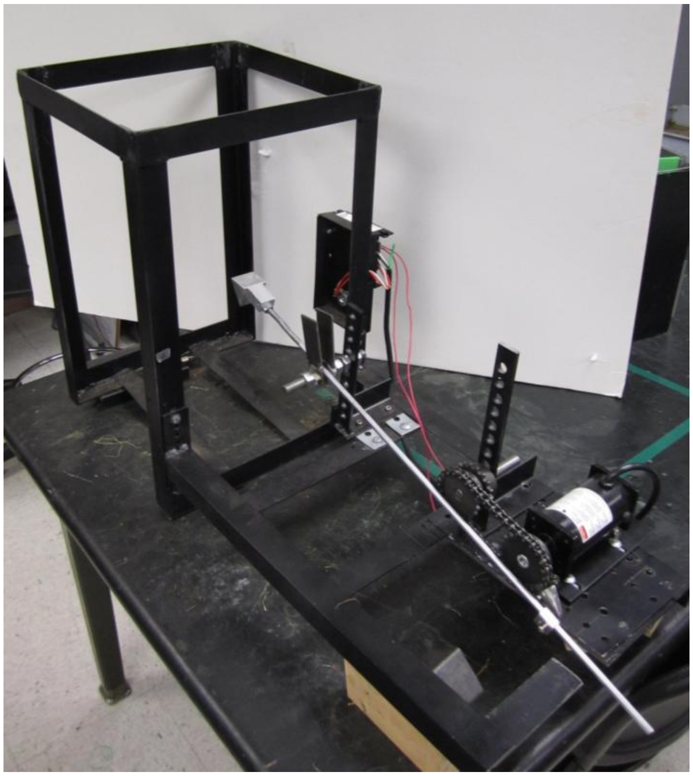


Figure 5.4. The assembled base minus the holding bin. Note the order of which the two gear motor assembly and fulcrum are mounted to base.

5.2.2 Range of Motion

The range of motion (ROM) was mechanized (figure 5.4) using a Dayton 3EX20D DC motor rated 1/9 hp, 24 Vdc. A Dart Controls 65E10 variable rate controller with a speed pot allowed the operator to control the rate of the motor through limiting the current that flowed to the motor. This setup was capable of 70-100 cycles per minute. The rate varied significantly depending on the torque requirements to extract slips from the bin. However, this set up provided sufficient analysis to evaluate to design concepts. Figures 5.10 shows how the motor attached to the gear assembly.

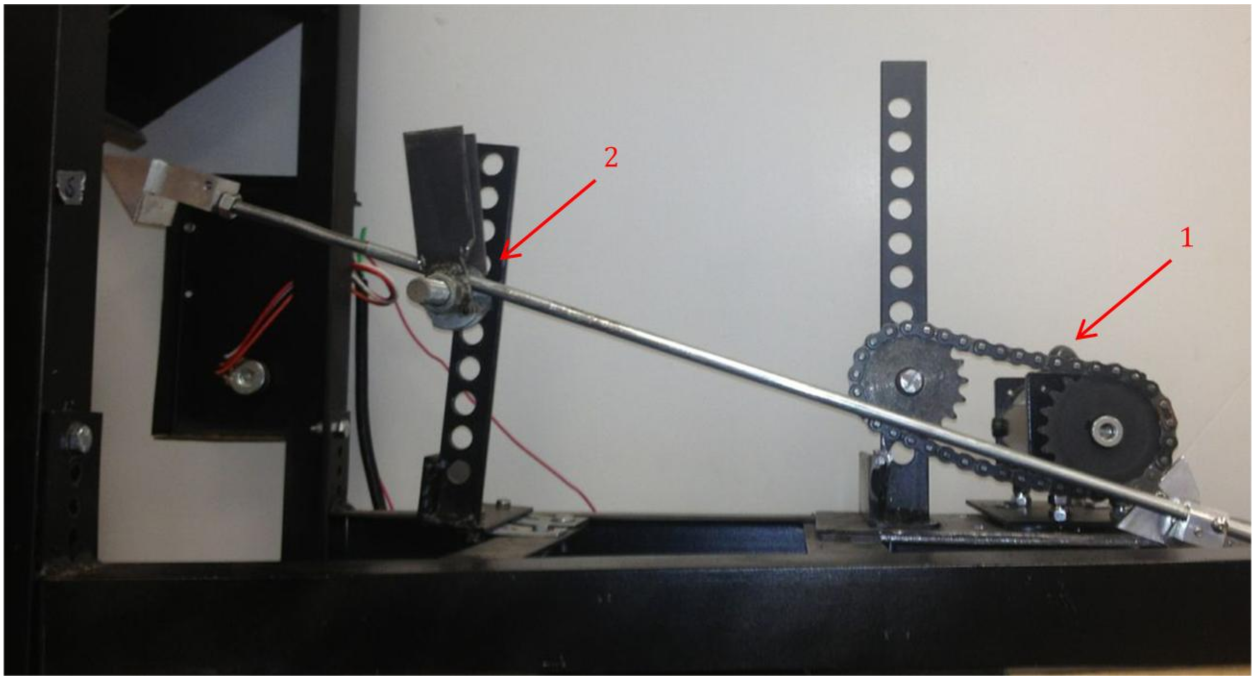


Figure 5.5. The Dayton DC motor (1) powered the chain assembly clockwise, which utilized a fulcrum (2) providing the hook an upward trajectory when entering the bin.

5.2.3 Revised Hook Designs

Hook-SH4 sorted slips with the highest efficiently during evaluation of Prototype-1. The mechanized ROM increased the hook cycle rate to a minimum of 70 cycles per minute. The increased performance introduced significant problems. Upon removal from the bin, slips were forced back into the bin until they were released from the hook. The shape of the Hook-SH4's opening did not allow slips to be released from the hook at a sufficient rate. Material behind the hook opening was modified to create Hook-SH5 (figure 5.6).

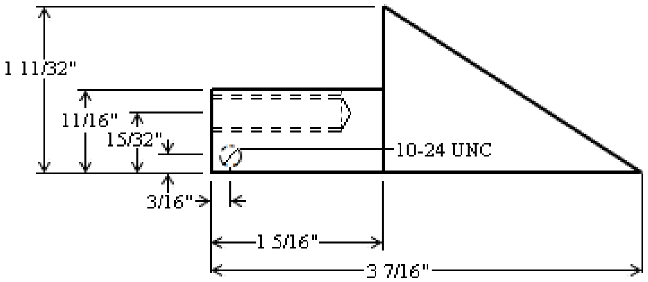


Figure 5.6. Hook-SH5 was designed through modification of Hook-SH4, in which material was removed from the nose and opening (dimensions are represented in English units).

Hook-SH5 allowed slips to be released immediately upon removal from the bin. Slips were released instantly from the hook, as the hook cycled toward the bin. However, slips occasionally remained caught between the front panel and rear baffle. Partially removed slips ultimately impeded the sorting of slips more than forcing a slip back into the bin. Therefore, a mechanism was designed to physically grasp slips through the duration of the removal process, which lead to the design of Hook-SH6 (figure 5.7).

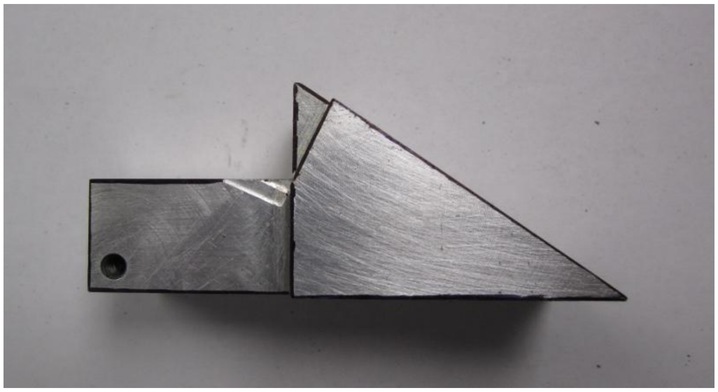


Figure 5.7. Side view of Hook-SH6, material was removed from each side of the hook, behind the triangular shaped nose to allow the closing mechanism to mount flush to the sides.

5.2.4 Closing Mechanism

Preliminary testing of Hook-SH5 indicated that slips, specifically the leaves snagged the bin, and would slide out of the hook prior to removal. Slip flexibility allowed the hook to be fully extracted from the bin while one or both ends of the slip remained pinched between the rear baffle and the front panel. Upon completion of two series of open hook tests, a group of 20-25 slips were bounded together, approximately 2.54 cm from the top and bottom of the slip. Slips were manually removed from the group first with Hook-SH5 and secondly by hand, fore-finger and thumb. Physically grasping provided removal from the bundle whereas, slips would slide out of the open hook. A mechanism was designed to physically grasp the slips. The final grasping mechanism utilized a four link system, controlled by a servo motor is presented in figures 5.8 and 5.9.

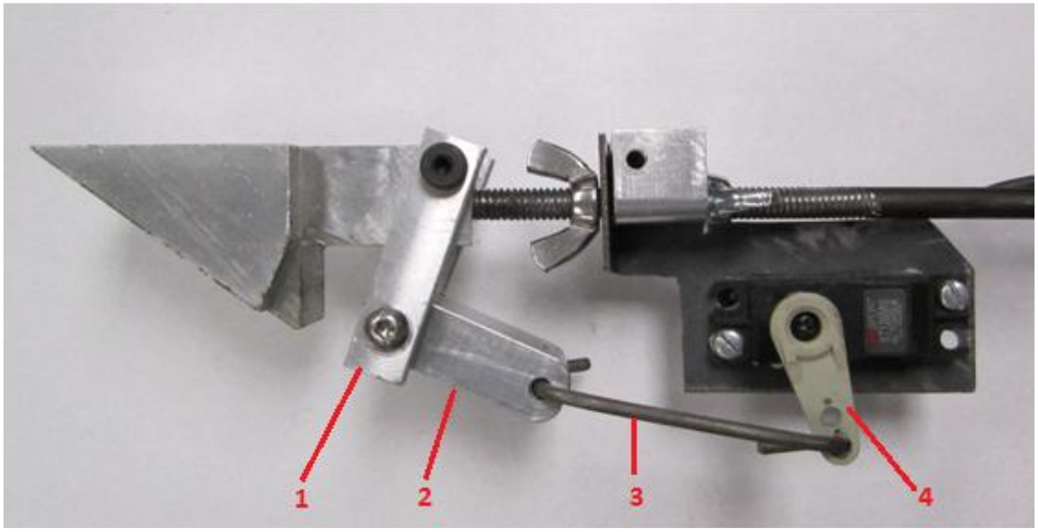


Figure 5.8. Side view of the assembled grasping mechanism which consisted of four links; (1) the closing arm created a pivot point, (2) connecting link connected the closing arms to link (3), and (4) the servo.

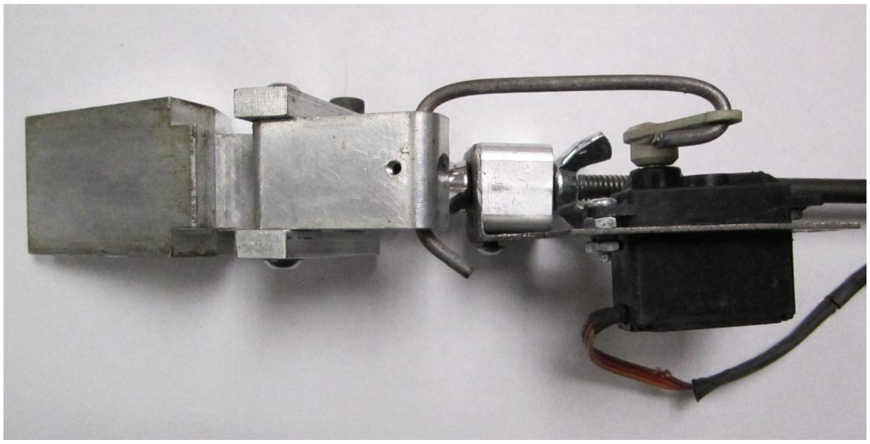


Figure 5.9. Top view of the assembled grasping mechanism. Note the threads on the arm extend past the servo motor, making the location of the servo adjustable with respect to the hook.

A JRSPORT ST126MG hi-torque servo motor opened and closed the grasping mechanism. The motor attached to the arm through an L-shaped bracket bolted to a slider (figure 5.9). The slider allowed the position of the servo motor adjustable, which made it compatible with alternative hook designs. The plastic arm of the servo motor, (link-4, figure 5.8) attached to the closing mechanism through a generic 4.76 mm diameter welding rod (link-3 figure 5.8). A welding rod was utilized because it was light weight, rigid and easy to fabricate. The welding rod was fabricated to connect the master link (link 2) to the servo motor. The closing mechanism included two arms (link 1) to connect the hook to the master link. The arms attached to the hook through two shoulder bolts. The shoulder enabled the arms to rotate freely. The arms fastened securely to the master link to create a locked joint. The locked joint maintained a constant ROM each time the servo motor cycled. The hook was modified, milled 6.36 mm on each side to maintain a 3.81 cm width when closed. Figure 5.9 illustrates where the arms (link-1) overlap the hook.

National Instruments LabView 2010 and NI-6210 data acquisition modules were used to program the servo motor. Two LabView programs (Appendix B) were developed to utilize the voltage drop across a Hall Effect sensor to trigger the servo motor. Program-1, a sub-VI cycled the servo motor. The servo motor required a 50 Hz signal. Position of the servo motor was controlled through the duty cycle. Three consecutive flat sequence structures were utilized to open and close the grasping mechanism. The first and third sequences structures closed and opened the mechanism by setting the duty cycle at 14% and 4%. Time delays were used to synchronize the grasping mechanism to the ROM. The grasping mechanism to enter the bin opened and exited closed. Time delays were dependant on the speed of the servo motor. Sequence-1and 2 enabled the hook to close for 200 milliseconds and remained closed for an additional 100 milliseconds, respectively. Sequence-3 opened the mechanism for 300 milliseconds. Time delays were determined through video analysis and depended on the rate at which the hook entered and exited the bin. The minimum rate at which the motor could continuously remove slips from the bin was used to set time delays to ensure that the servo opened and closed completely. The speed of the servo motor limited the rate at which the hook could cycle through the holding bin. The 600 millisecond servo cycle limited the hook to a maximum rate of 600 milliseconds per cycle, or 100 cycles per minute.

Program-2 identified the voltage drop of the Hall Effect sensor. The sensor detected when the arm crossed a specified location relative to the ROM. Voltage was charted, and voltage drops were counted to identify how many times the hook cycled through the bin during a test. The program utilized a series of case structures which read the voltage output of the sensor, comparing the voltage to the previous. The sensitivity of the sensor significantly affected the accuracy of the closing mechanism. The minimum rate at which the motor could continuously remove slips from the bin was approximately 70 cycles per minute. The diameter of the Hall Effect sensor was 1.746 cm. It takes the arm 0.033 seconds to pass the case of the sensor. In order for the sensor to identify when the arm passed, a steel bracket was fabricated and an arm attached, figure 5.10, to increase the exposure time to the sensor.

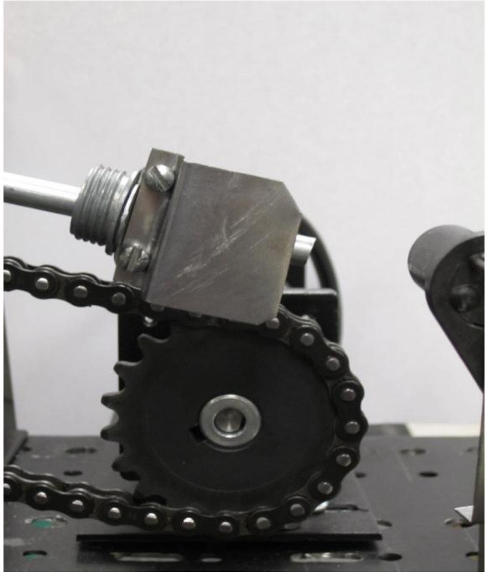


Figure 5.10. A steel tab increased the sureface of the arm permitting the Hall Effect sensor to recognize the arm.

5.3 Method of Analysis

Prototype 2 focused on quantitative tests and evaluations with a primary focus on how slips and seedlings exited the bin, specifically the number of slips or seedlings. Prototype 2 significantly differed than prototype-1 in that the ROM was motorized. The base for Prototype-2 enabled laboratory evaluation. Data (Appendix E) was documented in Microsoft Excel and categorized by seedlings or slip, the quantity removed from the bin, hook design and baffle shape. The number of slips or seedlings removed was recorded as: singles, doubles, groups or misses. The rate at which the hook cycled into and out of the bin required video analysis for qualitative and quantitative analysis. A high speed video analysis was attained using a through the Sony Content Management software and Sony NEX-FS700 super slow motion NXCAM camcorder.

The first three series of tests evaluated the sorting of sweet potato slips. Preliminary testing qualitatively analyzed the length of the arm, the height of the motor bracket with respect to the bin, the horizontal locations of the fulcrum point, baffle requirements and the gear and motor assembly with respect to the bin. Frame by frame video analysis provided statistical data of sorting tendencies. The first series of tests included 40 total tests which evaluated rear baffle design. The second series of tests evaluated hook entry angle. The final series of test analyzed the performance of the grasping mechanism. Hook design was evaluated through each stage of testing.

Pine seedlings were analyzed due to the limited availability of sweet potato slips. Similar to slip sorting, three trials were evaluated. Preliminary tests which utilized the final experimental setup used to sort sweet potato slips (the grasping mechanism). The second series of tests evaluated the open hook, Hook-SH5. Lastly, the third series of tests evaluated a modified hook (Hook-SH7). Due to increased friction generated by pine needles, the sorting mechanism was positioned at an incline to increase the feed rate of seedlings. Similar to slip analysis, all tests were recorded and analyzed frame by frame.

An analysis of variance (ANOVA) was conducted using Microsoft Excel to determine possible statistical differences between treatment means for each test. Parameters evaluated include: 1) sorting accuracy (frequency slips or seedlings were extracted from the bin); and 2) singulation (percentage at which single slips or seedlings were sorted from the bin when slips were extracted). Means were statistically compared using a 90% confidence interval ($\alpha = 0.1$). Initial analysis compared sorting rates of each treatment, if the interaction was not significant, then further analysis of singulation rate was performed.

5.4 Results and Discussion

5.4.1 Sweet Potato Slips

Preliminary tests involved initial adjustments and modifications. Significant adjustments were made to hook entry angle and the length of the arm which connected the hook to the chain assembly. The hook entry angle played a critical role in sorting slips and seedlings. The hook entry angle was dependent on the mounting location of the motor bracket which fastened to the base of the holding bin with 10.2 cm of vertical adjustability. Qualitative data showed sorting rate improved; more slips were removed from the bin when the bracket was mounted at the lowest possible position. The motor was mounted 56.8 cm from the bin. Hook penetration depth was primarily controlled by the length of the arm, which connected the hook to the gear assembly. The distance between the two gears controlled the horizontal displacement of the hook which was 9.84 cm. The trajectory of the hook was controlled through the height of the fulcrum point.

Preliminary tests were initially performed with only rear baffles mounted in the holding bin. The large empty volume of the bin allowed groups of slips to gather at the bottom and become tangled. Slips were often broken due to the force required to pull tangled slips from the bin. The additional torque requirements created by tangles also tore and severed leaves from slips. Installation of the front baffle significantly reduced the volume slips at the bottom of the bin. The front baffle compressed groups of slips together which caused separation within groups of slips controlling slip feed rate. The controlled feed rate increased sorting efficiency. Qualitative analysis of the front baffle lead to a non-symmetric design which took into account for the volume produced from the leaves attached to slips. The baffle was modified by removing material on the leaf side of the bin.

The Sony NXCAM recorded every test after installation of the front baffle. The initial series of tests utilized Hook-SH5 with Baffle-1. Two tendencies developed through testing; slips either cycled through the bin in small groups or a large group would sit on the ridge of the rear baffle which prevented slips from falling to the bottom of the bin. As testing progressed, the feed rate of slips was restored due vibrational frequencies generated in the rear baffles by the hook contacting the back panel. Quantitatively slips were sorted 42.6% percent of the time the hook entered into the bin, with a singulation rate of 27.0%. The sorting rate varied significantly due to the variability of slips. Slips settled into unique positions each time the bin was loaded. Baffle-2, the rippled rear baffle were designed to create separation between individual slips. The rippled baffle slightly improved the sorting efficiency from 42.6% to 46.5%. However, Baffle-2 significantly improved slip singulation. The mean slip singulation increased from 27.0% to 66.7%. Future testing will utilize the rippled baffle. Mean data with the standard deviation of each baffle is presented in figure 5.11. Rippled baffles significantly increased the singulation rate of slips (p-value = .096). The second series of tests were used to analyze and optimized sorting efficiency.

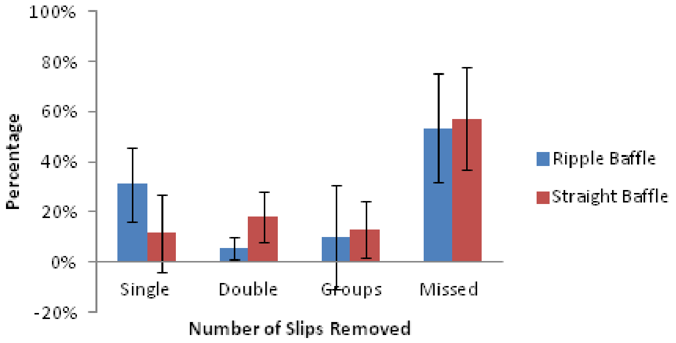


Figure 5.11. Mean baffle results with standard deviation bars, rippled baffle compared to straight baffles.

Hook entry angle, α was the focus of the second series of tests. Five tests at five different hook entry angles were evaluated to determine the optimum hook entry angle, the angle with the highest sorting accuracy. The guide, the fulcrum point mounted to an “L”- bracket which fastened to the motor bracket through two flexible steel tabs. Bending the steel tabs up or down significantly changed the hook entry angle and thereby, significantly changing the ROM. When the top of the “L”-bracket rotated away from the bin, hook entry angle increased. Figure 5.12 illustrates how the hook entry angle, α affects the trajectory of the hook.

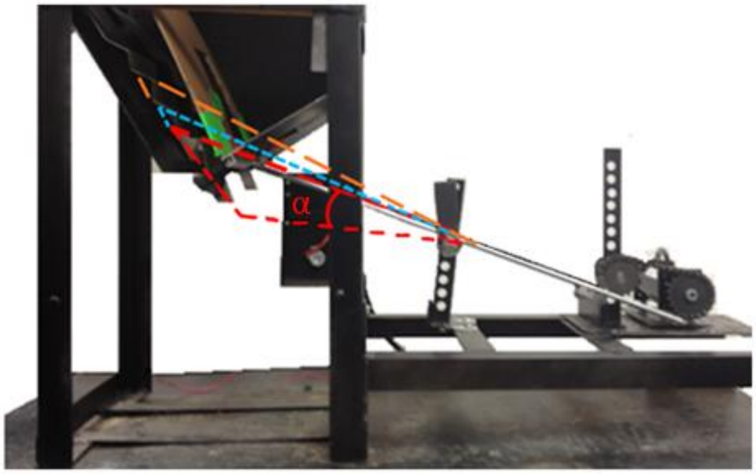


Figure 5.12. The trajectory of the hook into the bin was dependent on the hook entry angle, α (each line represents an alternative hook entry angle).

The hook entry angle was adjusted approximately 2^0 through the duration of these 20 tests. The final hook entry angle evaluated was approximately 23°, which resulted in the hook entering the bin between the front baffle and front panel. The initial hook entry angle, α_1 was 21.1^0 projected the hook low into the bin which required slips to feed into a narrow part of the bin. Slips were removed from the bin 32.0% of the time with singulation occurring 62.5% of the time slips were removed from the bin. The fourth hook entry angle, 22.3^0 produced the best results. The sorting accuracy for α_4 was 55.1% compared to the 32% sorting accuracy produced with α_1. The results for all hook entry angles are shown in figure 5.13. However, slip singulation decreased from 62.5% to 57.2%. A single factor ANOVA test was used to statistically compare the sorting rates. The 22.3^0 hook entry angle significantly increased (p-value = .016) the sorting accuracy that occurred compared to the 21.1^0 hook entry angle in a 90% confidence interval.

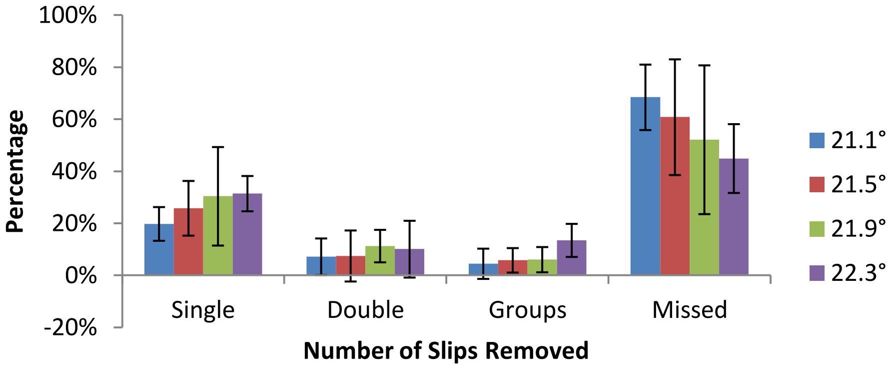


Figure 5.13. Mean results evaluating hook entry angles utilizing the open Hook-SH6 with Baffle-2, each trial included five tests.

Slips were considered "missed" if they were not completely removed from the bin. Two main reasons were "missed" included either slips that became snagged on the front panel or slips did not cycle through the bin. Snagged slips were a result of slips caching the front panel and getting pulled out of the hook. A grasping mechanism was designed to physically secure slips insuring complete removal from the bin. The biggest limitation of the grasping mechanism involved synchronization of the servo motor to the ROM. The internal timer of the NI-6210, the data acquisition module limited the rate at which the servo motor could be triggered. The program was designed to operate at 600 ms or approximately 100 cycles per minute.

Results presented in figure 5.14 compare the performance of the grasping mechanism to open Hook-SH5. Commercially grown bedded slips were utilized in this test, (all prior testing was performed with slips grown in Auburn University's greenhouse). The commercially grown slips were smaller in diameter and more elastic compared to those grown in the greenhouse slips.

The open hook tests showed a 30.6% slip sorting rate with 54.6% singulation. The closing mechanism increased the sorting rate to 62.0% and 43.7% singulation rate. The closing mechanism significantly improved the sorting accuracy; a single factor ANOVA test produced a p-value of 0.0053, by dramatically reducing the number of slips that were snagged the bin upon exiting.

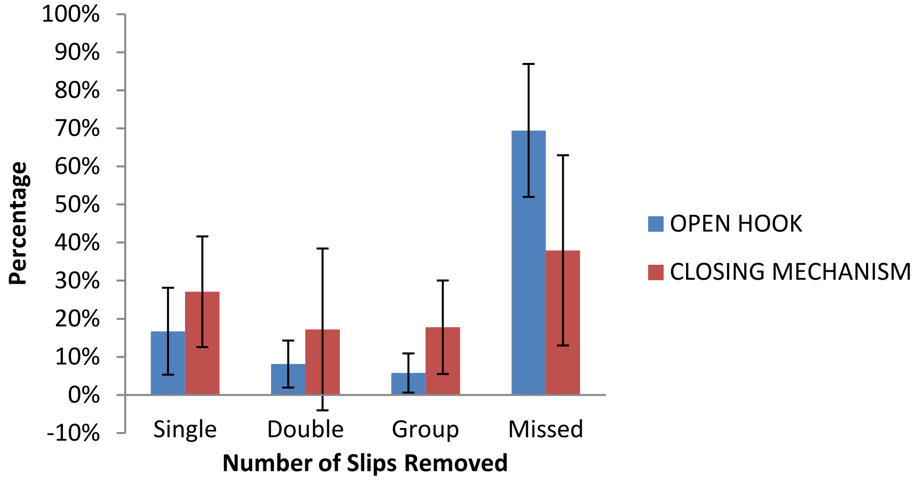


Figure 5.14. Mean open hook data compared to the mechanical closing hook results.

5.4.2 Pine Seedlings

Pine seedling lengths varied between 30.5 to 40.6 cm. Seedlings were trimmed to 30-31.75 cm, using two methods. The first method trimmed the pine needles at the top while the second method trimmed the roots of the seedling. Seedlings were grouped, so all trimmed seedlings were randomized. Preliminary tests with pine seedlings utilized Prototype-2 with Hook-SH6, Baffle-2 and the grasping mechanism, which was the final experimental set up used to evaluate slip sorting. Tests showed that pine seedlings interacted significantly different to the hook mechanism and the holding bin compared to sweet potato slips. Seedlings were heavier and more rigid compare to slips. The rigidity of seedlings increased the force required to pull seedlings from the bin. The increased force exceeded the motor’s torque requirements which resulted in failed tests. Testing was continued either by manually assisting the ROM or by increasing and decreasing the rate of the motor with respect to the ROM, (the angular velocity was increased upon the hook's exit from the bin). The stiffness and rigidity of the pine seedlings made the grasping mechanism ineffective.

Tests that utilized the grasping mechanism ended prematurely due to the physical characteristics of the seedling. Seedlings were thicker and more rigid compared to slips. Seedling thickness and rigidity made the seedling too large for the grasping mechanism. The increased torque requirements also caused tests to end prematurely. The fluctuating rate of the motor caused by varying torque requirements caused the grasping mechanism to become unsynchronized with the ROM and ultimately ineffective. The most common timing error involved the grasping mechanism remaining closed as it cycled through the bin. Figure 5.15, showed the results of the grasping mechanism. The closing mechanism yielded a 24.0% sorting rate. Seedlings were singulated just 46.3% of the time. Removal failed tests increased the sorting rate to 29.3% with a singulation occurring 71.3%.

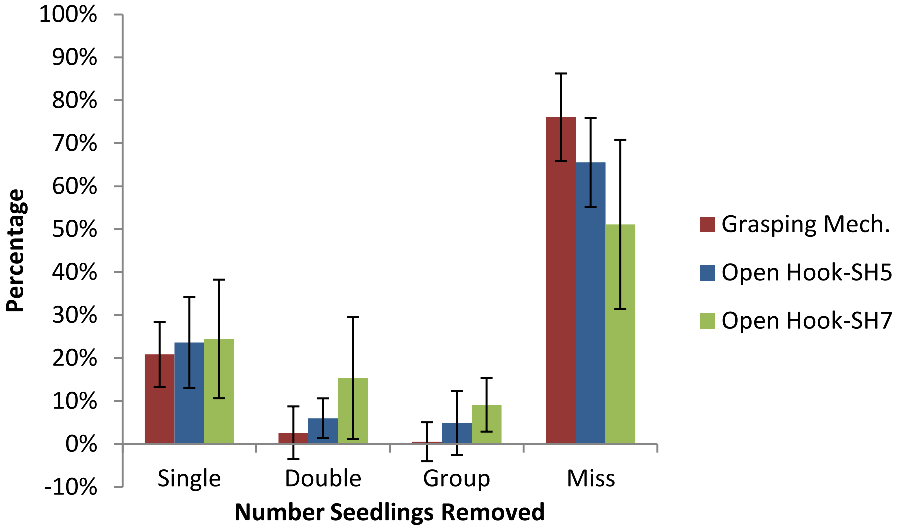


Figure 5.15. The mean results and standard deviation from all three pine seedling trials: closing mechanism, Hook-SH6 and Hook-SH7.

The feed rate of seedlings was much slower compare to sweet potato slips. Since the increased diameter of seedlings impeded the feed rate through the bin. Feed rate was improved through adjusting the distance between the front and rear baffle and changing the angle at which the bin sits. The bin was tilted inside the base, 7.84^0, while the 0.8 cm spacer was placed under rear section of the base, raising the bin 1.25^0. The bin was titled forward a total 9.09^0. The feed rate improved significantly when the angle of the bin changed. Preliminary tests showed that seedlings fed consistently through the baffle system. However, a few large seedlings still restricted flow. The second series of tests evaluated the improved feed rate with the open hook configuration.

Rigidity of seedlings created a force between the hook and front panel that kept seedlings wedged in the open hook through the removal process. The open hook eliminated the error produced by the grasping mechanism and reduced the overall mass of the along with the torque requirements exerted on the motor. Lower torque requirements allowed the hook to run continuously without manual assistants. The mean sorting rate of open hook tests was 34.6%, with a singulation rate of 68.2%. Doubles and groups of seedlings were sorted 6.0% and 4.9%. Compared to the closing mechanism the misses were reduced from 70.7% to 65.6% (figure 5.15). Statistical analysis showed that in a 95% confidence interval the open hook did not significantly decrease the number of misses.

Analysis showed that error remained high due to contact between the hook and back panel. An elastic collision created when the hook contacted the back panel resulting in the hook ricocheting over seedlings. Two solutions were developed to limit this contact force. The first solutions involved the rate of the DC motor. Reduced angular velocity of the motor reduced the contact force, which resulted in more hooked seedlings. However, the slower velocity required the motor to be manually assisted. The slower pace also violated a design constraint. The singulation rate dropped below 62 plants per minute, that of the commercially available semi-automatic transplanters. The second method to reduce the contact force involved shortening the length of the hook, which allowed the hook to penetrate deeper into groups of slips prior to contacting the back panel, which decreased the contact force with the back panel. The hook was shortened 2.54 cm (figure 5.16).

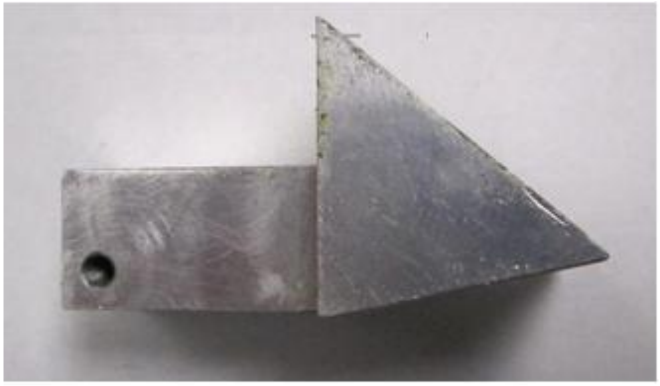


Figure 5.16. Hook-SH7 was a revised design of from Hook-SH6. It was shortened 2.54 cm to allow deeper penetration into the bin.

The final series of 20 tests evaluated Hook-SH7". The first five tests determined the hook entry angle, arm length and seedling feed rate. The arm was lengthened 0.6 cm. The tests were divided into four groups of five tests and the mean sorting rate was compared (figure 5.17). The means were compared to evaluate seedling variation. Seedlings were placed into the bin by the handful for each test and no adjustments were made through the duration of all tests. Therefore, the physical variability of slips was the only variable between each group of five tests. Seedlings averaged a 49.0% sorting rate with 51.0% singulation. Hook-SH7 reduced the number of misses by14.0% over Hook-SH5. The sorting rate significantly increased from 32.2% to 51.6%.

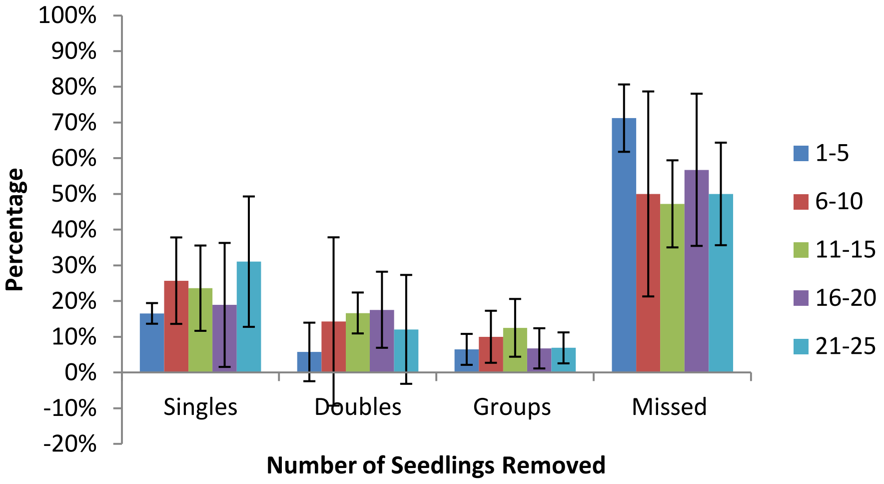


Figure 5.17. Evaluation of Hook-SH7 was evaluated by grouping and comparing every five tests. The first five tests were used to set up up Prototype-2 with the shorter hook, the prototype remained unchanged for test 6-25.

5.5 Summary

Prototype-2 was designed and a fabricated based off the sorting concepts developed through evaluation of Prototype-1. All components including the Dayton DC motor and other electrical components were compatible with the electrical output system of most modern tractors. The Hall-Effect sensor and the servo motor are durable enough to withstand the harsh elements related to an outdoor work environment. The motor fulfilled the performance design constraint, powering the sorting mechanism at a rate between 70-100 cycles per minute which is comparable to the performance of a commercially available semi-automatic transplanter, approximately 62 plants per minute per row.

The efficiency of the sorting mechanism improved through analysis and subsequent modifications. Evaluation of the interactions between slips, the hook and the bin improved sorting performance. Results indicated that the rippled baffles created separation between individual slips in groups, thereby improving the slip and seedling singulation. Video analysis highlighted physical limitations of slips and seedlings. Slip flexibility limited the performance of the open hook requiring the design of a grasping mechanism. The designed grasping mechanism significantly improved slip sorting efficiency, by physically grasping slips. The sorting rated increased from 31.5% to 62.0%. Sorting Pine seedlings was significantly different compared sweet potato slips. The larger diameter made seedlings more rigid and heavier. The thickness and rigidity of individual seedlings made the grasping mechanism ineffective. Further, results showed that the rigidity of individual seedlings created sufficient force between the hook and bin to ensure seedling removal with an open hook. Hook-SH5 was shortened 2.54 cm creating Hook-SH7, which allowed the hook to penetrate deeper into groups of seedlings significantly improving the sorting rate. The best sorting rate achieved was 49.0% with a seedling singulation rate of 51.0%. Statistically Hook-SH7 sorted seedling significantly better than the closing mechanism in a 90% confidence interval with a p-value of 0.062.

Chapter 6 Conclusions

6.1 Conclusion

The conclusions to this research are as follows:

1. An automated sorting mechanism was designed and fabricated to mechanically sort and singulate sweet potato slips and pine seedlings. Slips and seedling were stored in a holding bin (20-30 slip/seedling capacity). The bottom of the front and back panels tapered together at 51° and 46°, respectively to funnel slips or seedlings to the bottom of the bin. A baffle system inside the bin significantly improved the singulation rate of slips and seedlings. The rippled rear baffle (Baffle-2) significantly increased (p-value = 0.096) the singulation rate from 27.0%, using the straight rear baffle (Baffle-1) to 66.7%. A single contact point sorted slips and seedlings more efficiently compared to the dual contact approach. Slip flexibility made securing the middle of individual slips ideal. The 3.81-cm wide, triangular nosed hook (Hook-SH3) consistently removed slips from the bin. The hook entry angle also significantly affected sorting accuracy, the optimum hook entry angle was 22.3° (p-value = 0.016), which lifted, separated and aided in feeding slips or seedlings to the bottom of the bin. One major drawback was the flexible nature of slips which allowed slips to slide out of the hook upon extraction from the bin. A grasping mechanism was designed to physically secure and remove slips from the bin which significantly improved (p-value = 0.0053) sorting accuracy. The highest sorting accuracy for slips was 61.0% with 43. 7% slips singulation compared to 30.6% with an open hook (Hook-SH5). Physically, sweet potato slips varied significantly compared to

pine seedlings. The more rigid and larger diameter seedlings made the grasping mechanism ineffective. The grasping mechanism sorted seedlings on just 29.3% of hook cycles. The thick and abrasive nature of pine needles increased friction between seedlings and the bin, impeding seedling feed rate. Feed rate was restored by tilting the holding bin forward 9.1°. Hook-SH7, a shortened version of SH5 extracted seedlings with the highest accuracy of 49.0% with 51.0% singulation.

2. Physical characteristics of sweet potato slips and pine seedlings significantly affected sorting and singulation rates. An important physical characteristic that affected sorting and singulation was slip flexibility and seedling rigidity. The flexibility of slips allowed them to slide out of the open hook mechanism during the extraction process. The lack of slip elasticity caused minimum reactant forces upon extraction which facilitated partial removal of slips. The grasping mechanism was designed to physically secure slips in the hook, which significantly improved sorting performance and ensured complete removal from the bin. The rigidness of pine seedlings made them elastic. The elasticity of seedlings generated significant force through the duration of the removal process keeping seedlings inside the open hook. Slips and seedlings also varied significantly in geometry individually and comparatively. The leaves that protruded from slips were large and flexible which caused tangles. Tangles were reduced using the baffle system, which compressed slips together and limited the volume of slips that funneled to the bottom of the bin. Thick pine needles were abrasive which increased friction between seedlings and the bin reducing the feed rate. Seedling mass also affected the gravity fed holding bin. Repetitive testing removed the preservative gel and sand from seedlings, reducing the mass on average by 2.4 g per seedling.

6.2 Future Research

Prototype-2 did not produce the desired 70% sorting accuracy to justify complete design of a fully automated planter. However, the designed sorting mechanism developed fundamental sorting concepts through qualitative and quantitative analysis. It was learned that a gravity fed holding bin generalize slip or seedling variability during storage and to target the middle of the slips during extraction. Future research should include three categories: field testing, mechanical design and slip or seedling production.

Field testing should evaluate how much force can be exerted onto slips or seedlings before the physical damage affects the plants survival rate and yield. This study would determine a threshold force applied by physically grasping slips or seedlings. Field studies should also evaluate how physical damage, broken slips, damaged leaves and missing leaves would affect the survival rate and the yield.

Future research should further develop Prototype-2. The holding bin should be re-designed reduce the unusable space produced by mounting the baffles. This re-design would increase bin capacity and potentially improve slip and seedling feed rate. Baffles should mount flush inside the bin eliminating all possibility of slips getting snagged inside the bin. The feed rate of slips or seedlings could be improved through incorporation of solenoids between the rear baffle and the back panel. The impulse and vibration generated by the solenoid could create a consistent feed rate. Future research should optimize the range of motion of the hook mechanism. The required rate at which the hook cycled through the bin negatively affected the sorting rate. Faster sorting rates increased the contact force between the back panel and hook which caused the hook to ricochet over slips. However, at slower sorting rates the contact force became marginal created inconsistent feed rates. The range of motion could be optimized through replacing the DC motor and gear assembly with a hydraulic cylinder mounted to a stepper motor. The hydraulic cylinder would eliminate unwanted lateral displacement created by the fulcrum point. The stepper motor would allow the hook to penetrate the bin consistently at the any desired angle. The suggested ROM would require a control system synchronize the stepper motor and hydraulic cylinder. The ROM would be accurate and more efficient.

Slip and seedling singulation is limited due to the geometric variability. Future research should evaluate slip production. Physical characteristics (size, mass, flexibility, etc.) vary significantly among individual slips and seedlings. Horticulturalist should study a method to systematically grow a straighter, more rigid slip with fewer nodes. A uniform slip would increase sorting. Both conventional and automated planting could be improved if slips were straighter, stiffer and more durable. The automated planting of sweet potatoes, depends greatly on the slips. Researchers need to look at how slips vary among different varieties of sweet potatoes to determine the potential benefit of a new transplanter. Ultimately, a study should determine if optimizing a conventional transplanter would be more practical than design of an automated transplanter.

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Appendix A Electrical Components

A.1 Dayton DC Motor

Figure A.1. A Dayton DC motor, (3XE20D) mounted to Prototype-2, mechanizing the range of motion of the hook mechanism.

Model number:	3XE20D
HP:	1/20-1/9
Voltage:	12-24
Amps:	5.1
RPM:	1750-4000
Torque:	1.81 in-Lb/0.20 Nm
Service Factor:	1.0/10
Max. Ambient Temp.:	40°C
Form Factor Max.:	1.05
Insulation Class:	B

A.2 Dart Controls 65E10 DC Motor Controller

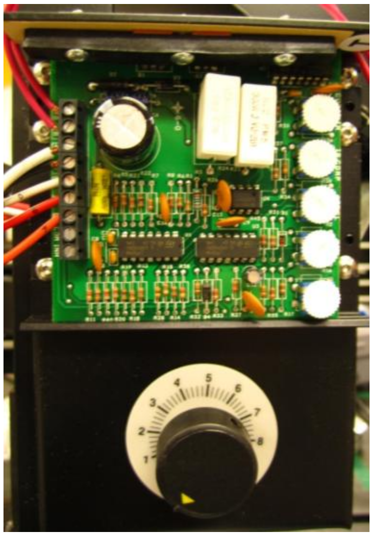


Figure A.2. The Dart Controls controller mounted with speed pot.

Load Current (continuous):	10 Amps
Speed adjustment:	5K Ω potentiometer or 0 to +10VDC input signal
Speed Range:	30:1
Overload:	200% for 10 seconds; 150% for one minute
Current Limit:	Adjustable 100% to 200% of full motor load, up to 200% of control current rating
Acceleration:	Adjustable – to 10 seconds
Deceleration:	Non-adjustable – 0.5 seconds
Maximum Speed:	Adjustable – 50 to 100% of base speed
Minimum Speed:	Adjustable – 0 to 30% of max speed
Connections:	Euro-style terminal block (14 Ga. To 28 Ga.)
Speed Regulation:	1% base speed via adjustable I.R. Compensation trimpot
Operating Temperature:	-10°C to +45^{0}C
Package Configuration:	Black anodized aluminum extrusion
Internal Operating: Frequency:	Approximately 18K Hertz

A.3 Tektronix PWS2326 DC Power Supply

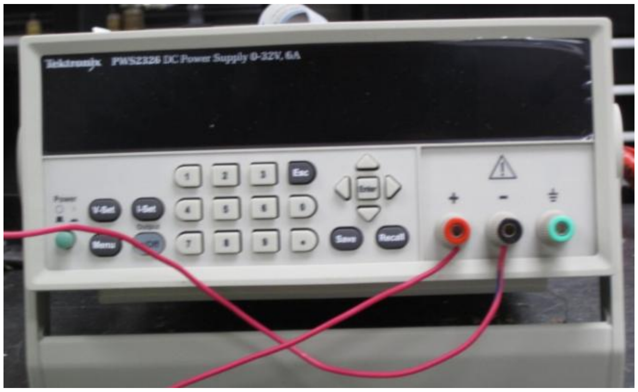


Figure A.3. Tektronix 0 to 32 VDC regulated power supply.

Model number	PWS2326
DC Output Rating	
Voltage	0 to 32 V
Current	0 to 6 A
Load Regulation	
Voltage	≤0.04% +6mV
Current	≤0.1% +2mA typical
Line Regulation	
Voltage	≤0.1% +5mV
Current	≤0.1% +2mA typical
Ripple and Noise (20Hz to 7 MHz)	
Voltage	$\leq 1mV_{rms}$/ $3mV_{23}$
Current	$\leq 5mA_{rms}$
Settling Resolution	
Voltage	10 mV
Current	10 mA
Settling Accuracy	
Voltage	≤0.05% + 10mA
Current	≤0.2% + 10 mA
Readback Resolution	
Voltage	< 20 V: 10 mV ≥ 20 V : 100 mV
Current	10 mA
Readback Accuracy	
Voltage	<20 V: ≤0.05% +15 mV ≥20 V: ≤0.05% +120 mV
Current	≤0.1% +15 mA

A.4 JR Sport ST126MG Servo Motor

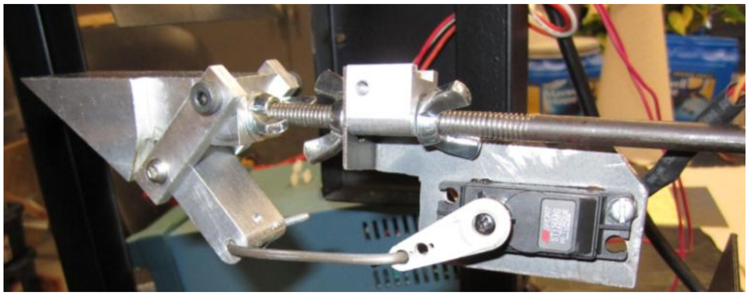


Figure A.4. Hook assembly controlled by a JR Sport ST126MG servo motor.

Model Number:	JSP20071
Description:	MG126 High-Torque
Rating at 4.8V:	126 oz - .21 seconds
Rating at 6.0V:	142 oz - .17 seconds
Dimensions:	1.52” x 1.32” x .73”
Weight:	1.60 oz (43.6 g)

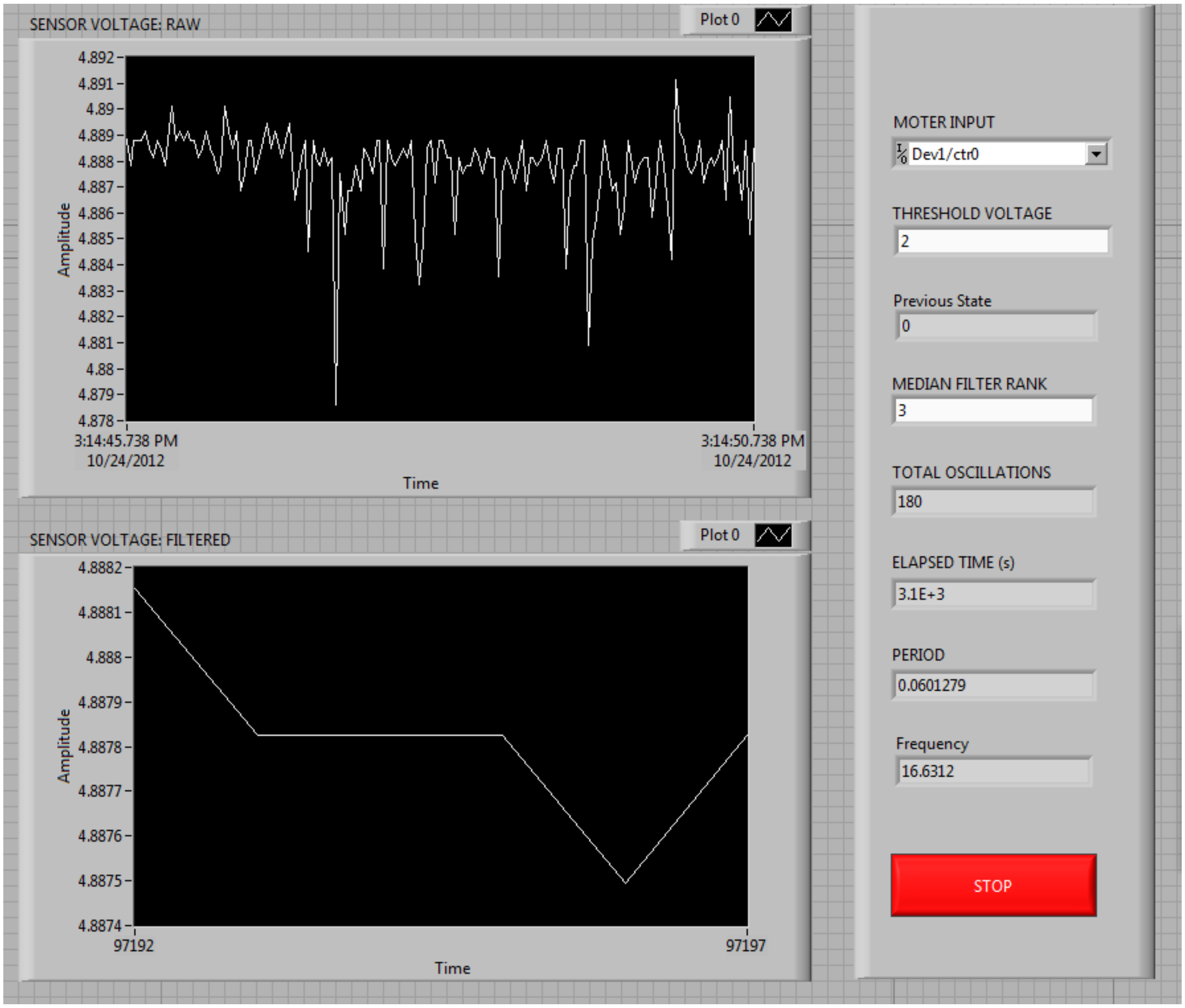
A.5 Honeywell 1GT101DC Hall Effect Sensor

Figure A.5. Hall Effect sensor triggered the servo motor each time the arm, connecting the hook to the gear assembly, crossed a specific location in the range of motion.

Manufacturer:	Honeywell
Model Number:	1GT101DC
Supply Voltage:	24 V
Mounting Type:	Screw
Max. Operating Temperature:	150 C
Min. Operating Temperature:	-40 C
Max. Output Current:	40 mA

Appendix B National Instruments Labview Programming

B.1 Front Panel



MOTER INPUT: Dev1/ctr0

THRESHOLD VOLTAGE: 2

Previous State: 0

MEDIAN FILTER RANK: 3

TOTAL OSCILLATIONS: 180

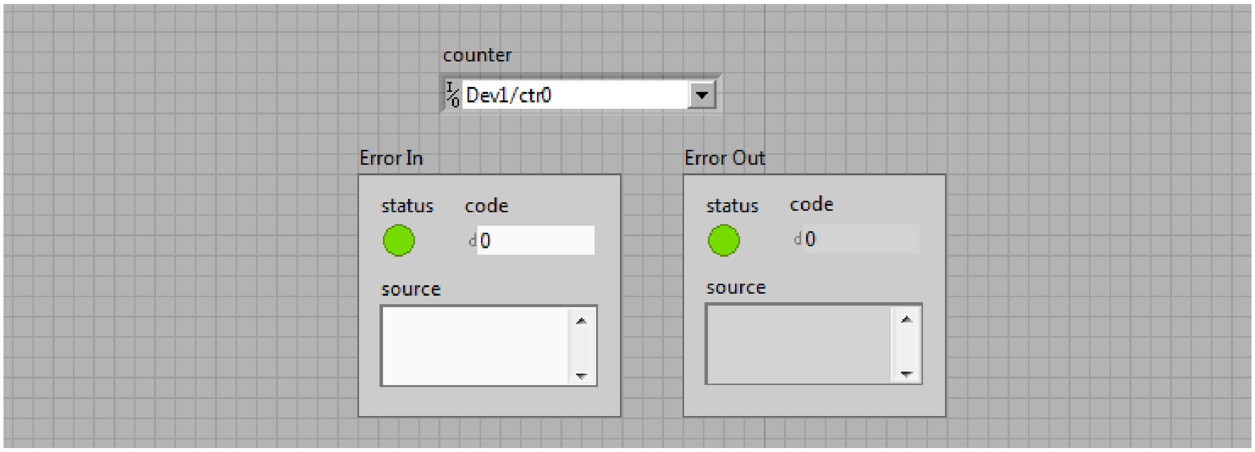
ELAPSED TIME (s): 3.1E+3

PERIOD: 0.0601279

Frequency: 16.6312

Figure B.1. The main control panel, shows the filtered and unfiltered voltage emitted by the hall effect sensor; the front panel also show the count, nunber of voltage drops, hook oscillations the time ellapsed and the calcuated period and freguency.

B.1.2 Servo Motor Sub-VI front panel



counter

Dev1/ctr0

Error In

status

code 0

source

Error Out

status

code 0

source

Figure B.2. The servo motor front panel presents errors as they occurred and required selection of the DAQ (data acquistition module) channel connected to the servo motor.

B.2 Labview Block Diagrams

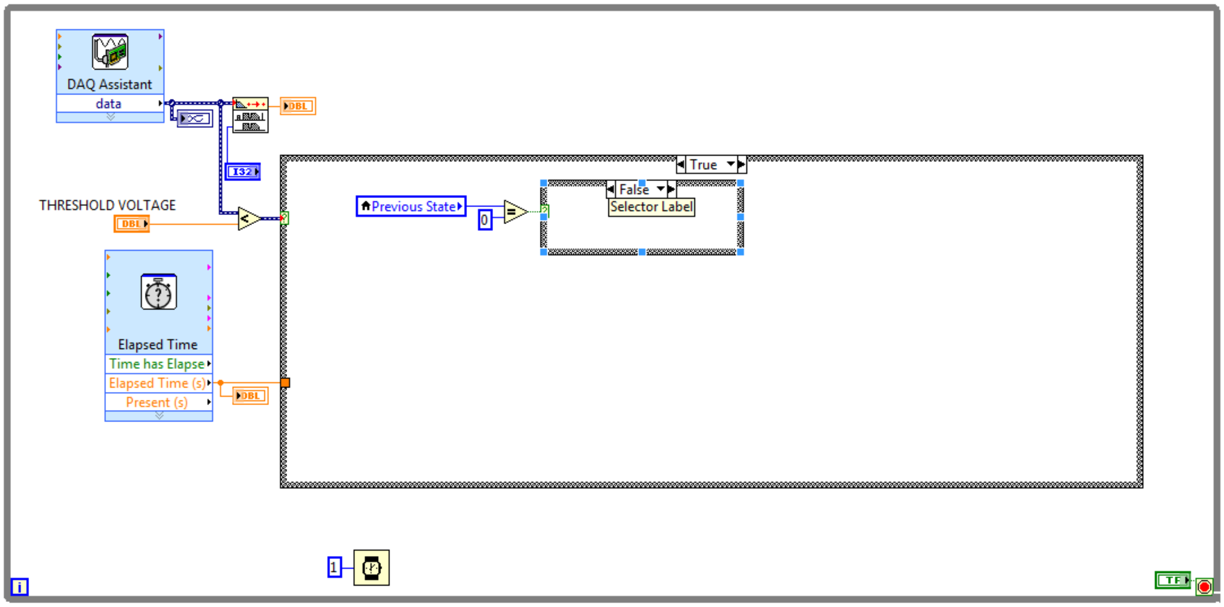


Figure B.3. Block diagram with true-false case structure.

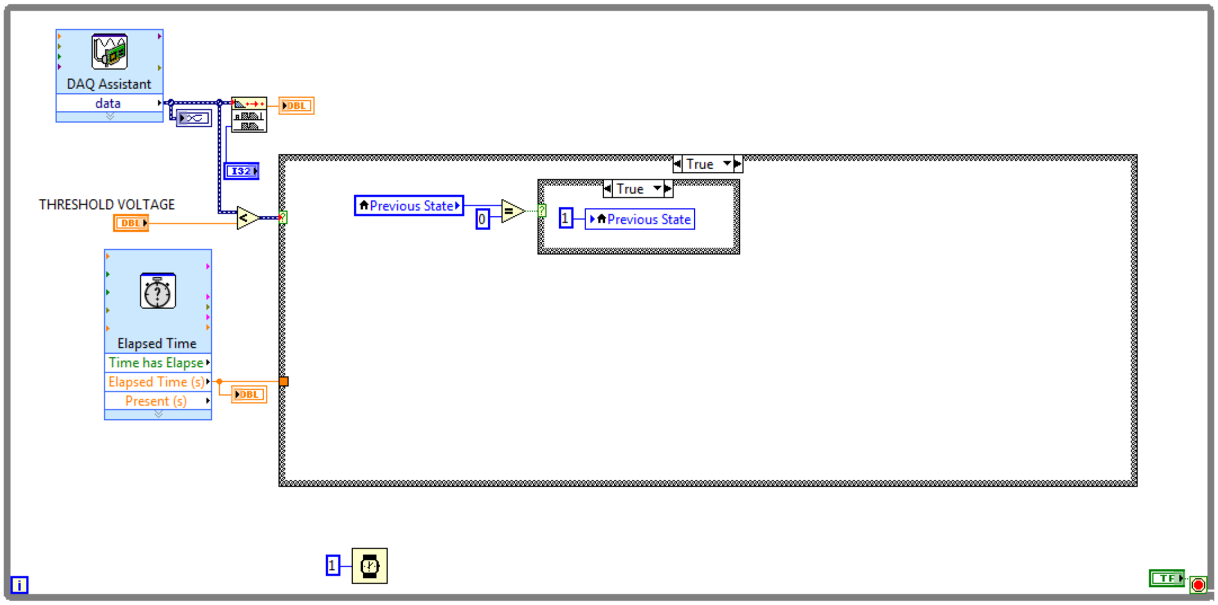


Figure B.4. Block diagram with true-true case structure.

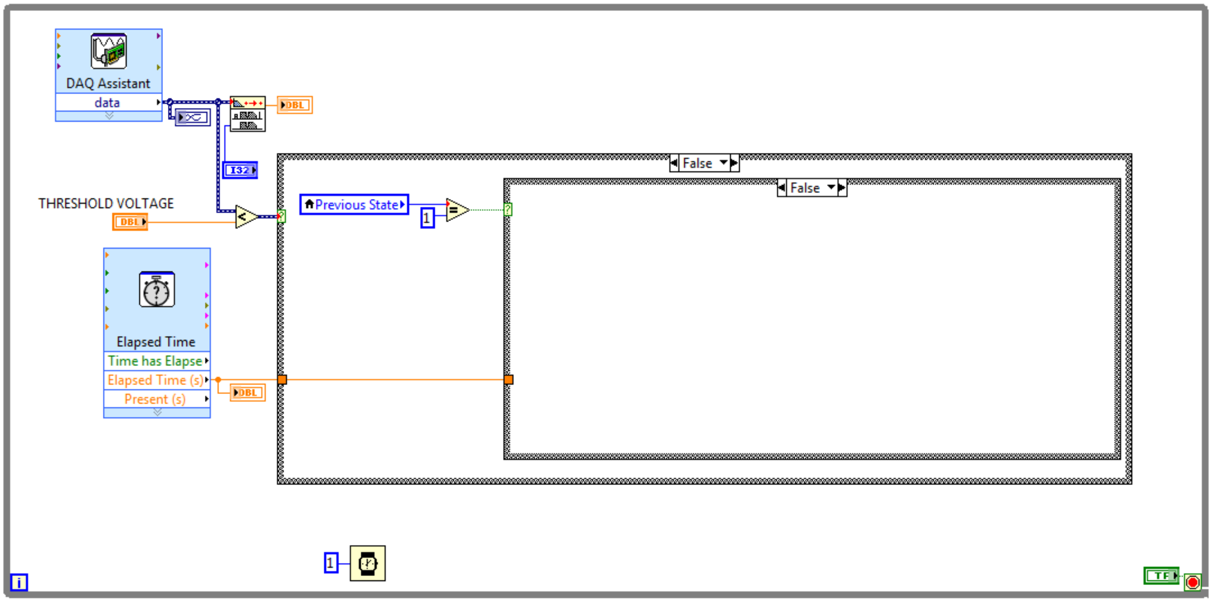


Figure B.5. Block diagram with false-false case structure.

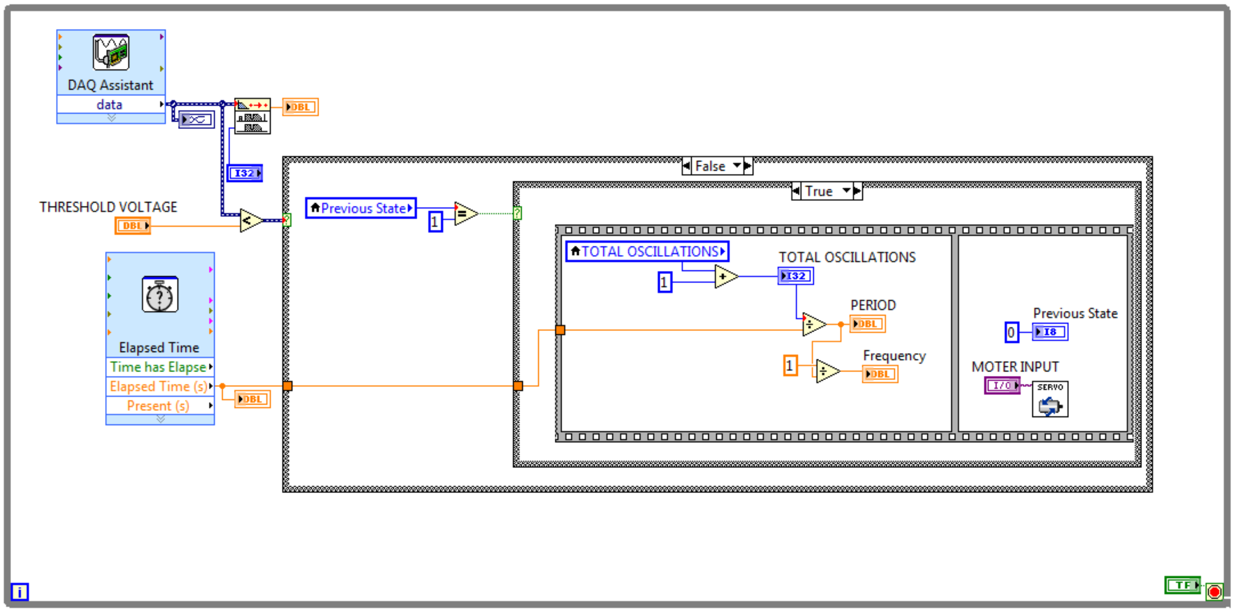


Figure B.6. Block diagram with false-true case structure.

B.2.1 Servo Motor Sub-VI Block Diagram

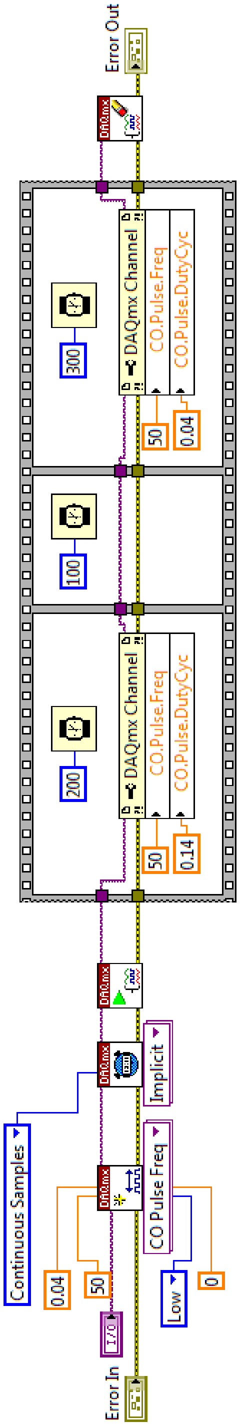


Figure B.7. Servo motor block diagram.

Appendix C Prototype-2 CAD Models

Dimensions in CAD illustrations are fractional English units. The units were requested from Precision Prototypes. The radii shown in Hook-1 and Hook-2 were replaced by straight lines due to tooling limitations.

C.1 Bin Design

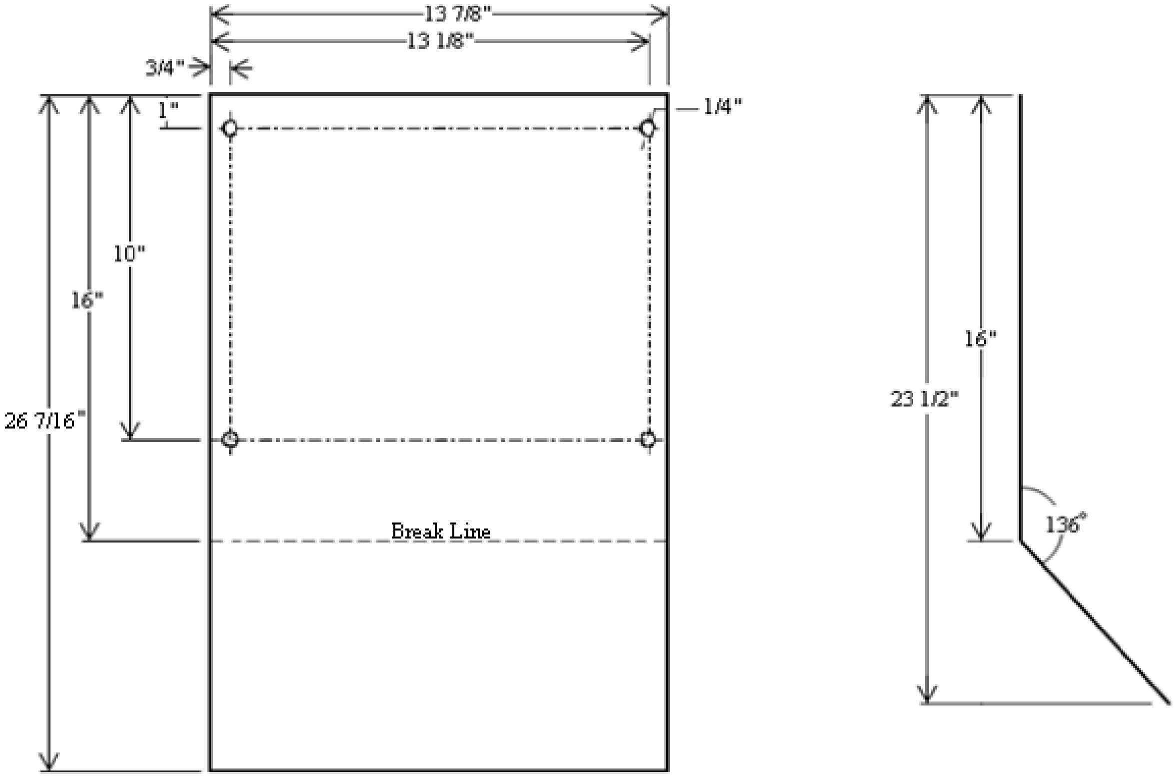


Figure C.1. Back panel representation, dimension are in cm.

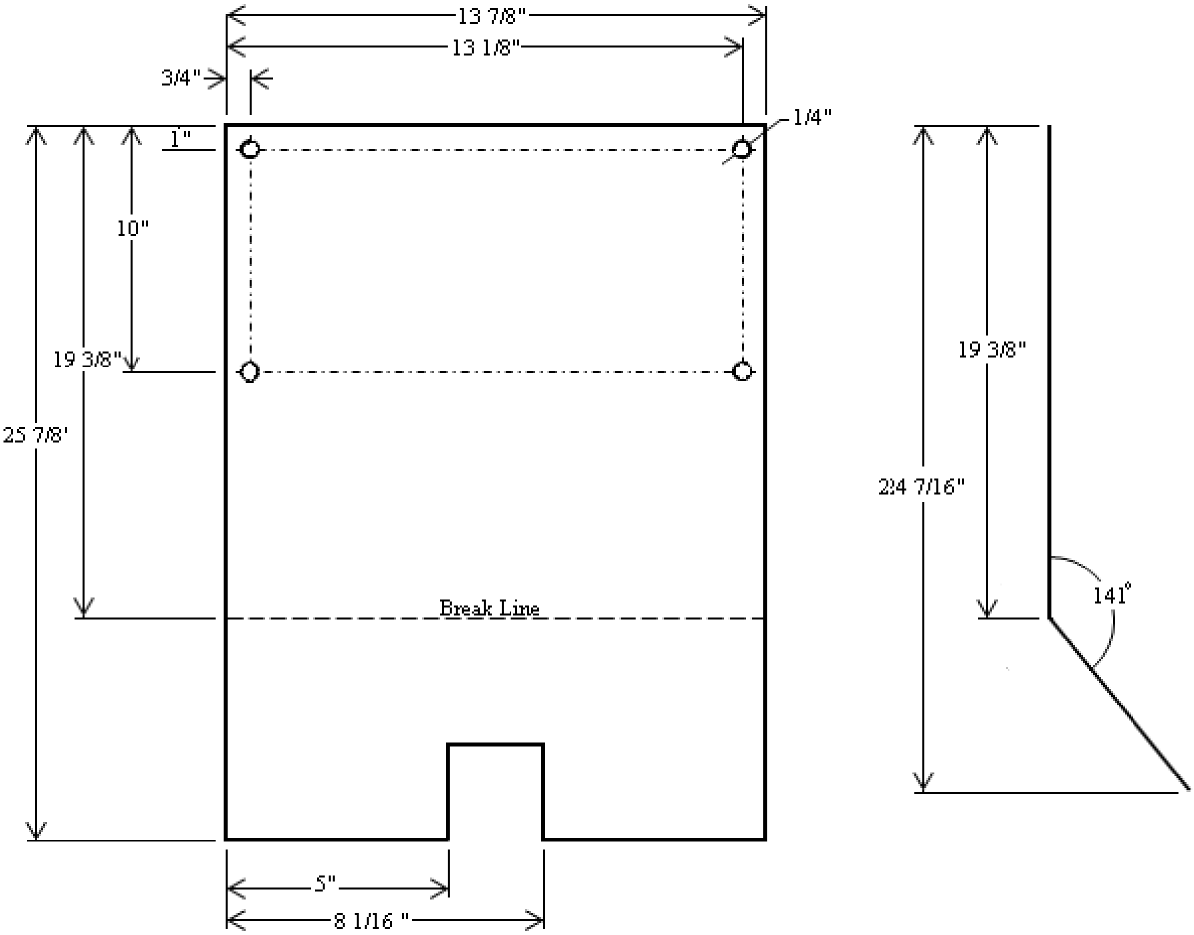


Figure C.2. Flat view and the lateral profile of the front panel.

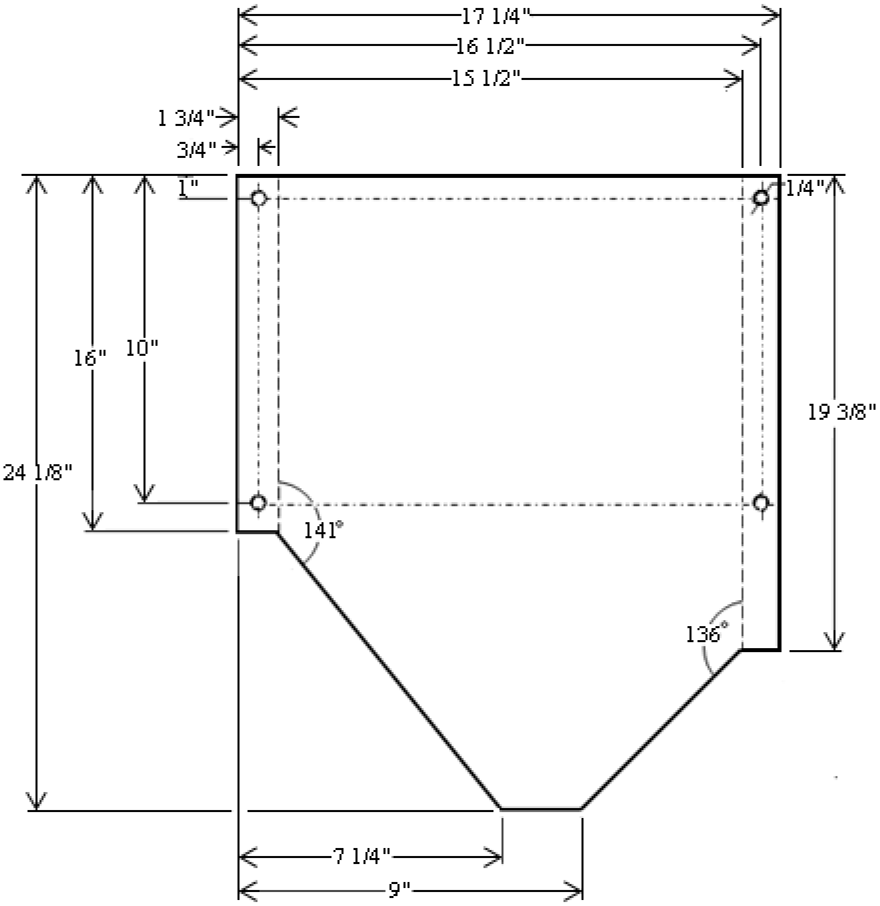


Figure C.3. Flat representation of the holding bin's side panelsm dimensions in inches.

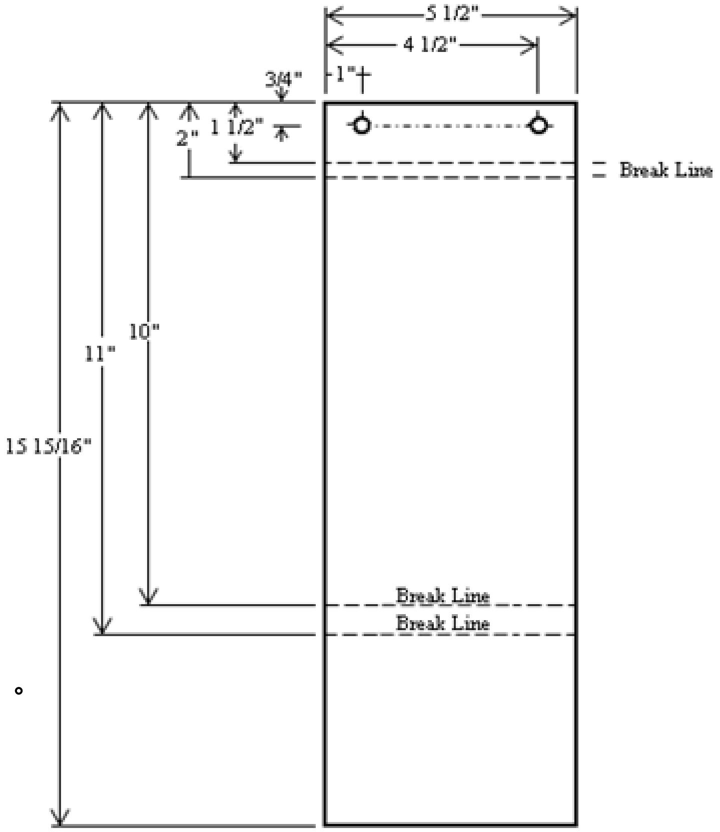


Figure C.4. Flat view and side profile of Baffle-1, dimensions in inches.

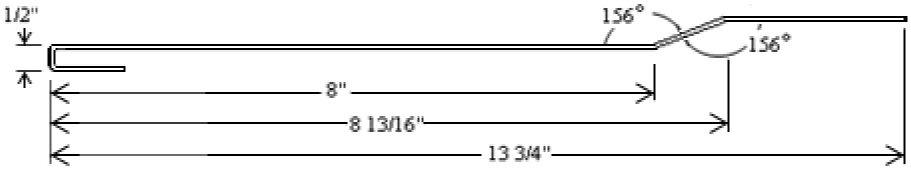


Figure C.5. Flat view and side profile of Baffle-1, dimensions in inches.

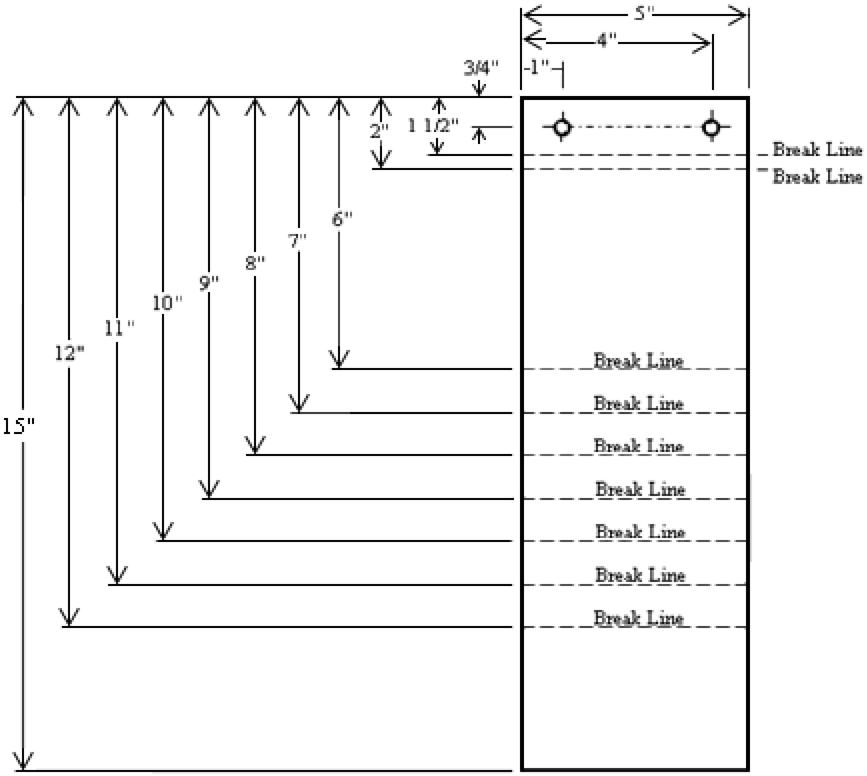


Figure C.6. Flat representation of the rippled baffle, dimensions in centimeters.

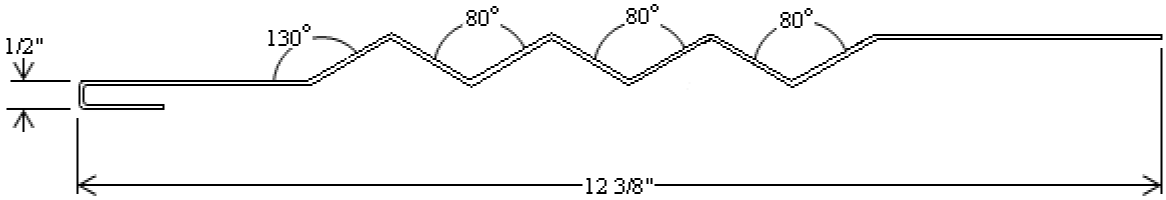


Figure C.7. Side view of bent baffle.

C.2 Prototype-2 Base

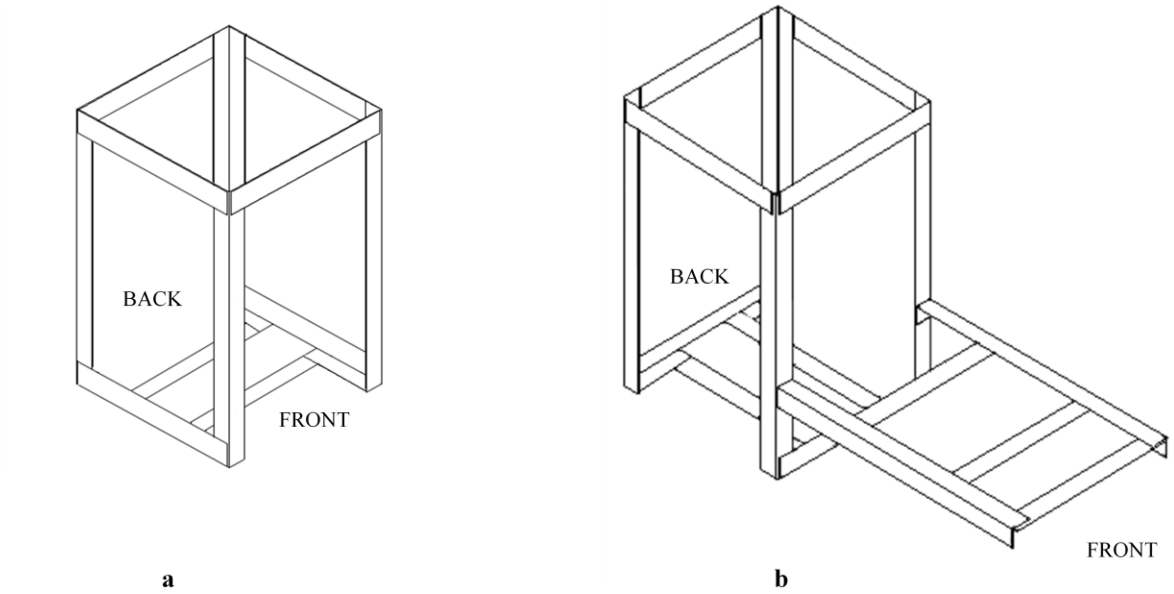


Figure C.8. The holding bin base fabricated from 3.81 cm steel flat stock and angle stock. The base (a) stood 55.9 cm tall and had a square cross sectional area, 33.6 cm x 33.6 cm, the assemled assembled base (b) included a horizontal bracket for the motor and gear assembly.

C.3 Hook Design

C.3.1 Hook-SH5

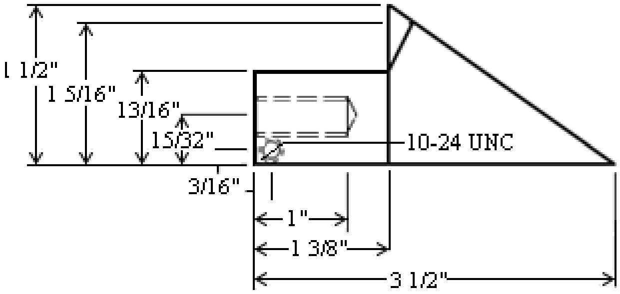


Figure C.9. Side view Hook-SH5 (dimensions in inches).

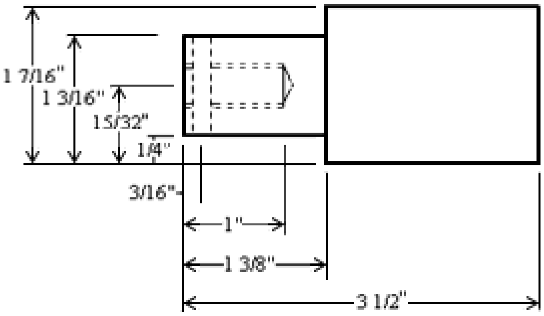


Figure C.10. Bottom view of Hook-SH5 (dimensions in inches).

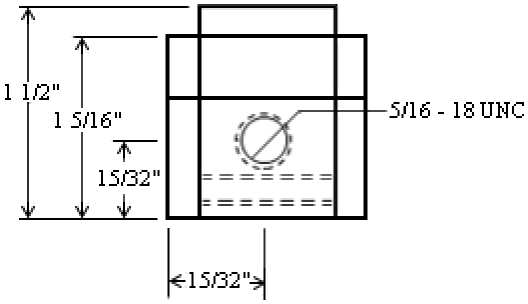


Figure C.11. Back view Hook-SH5 (dimensions in inches).

C.3.2 Hook-SH6

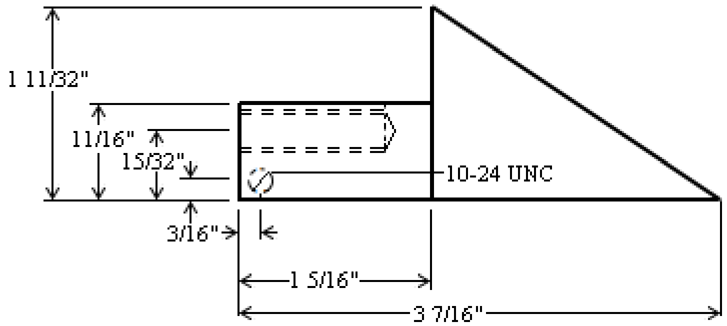


Figure C.12. Side view Hook-SH6 (dimensions in inches).

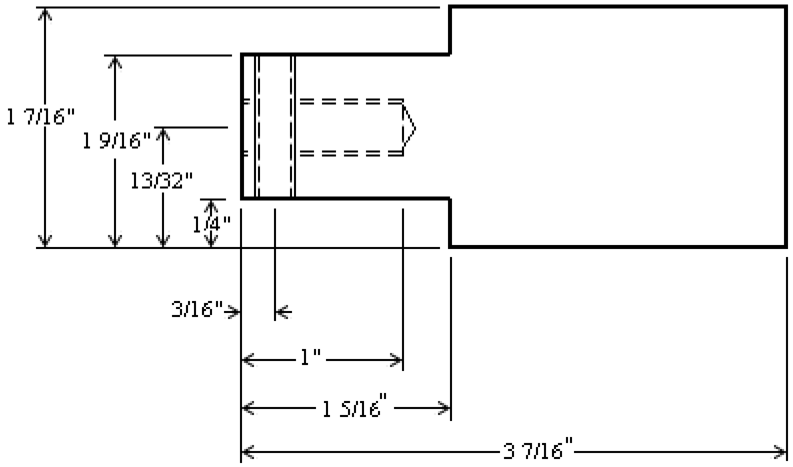


Figure C.13. Bottom view of Hook-SH6 (dimensions in inches).

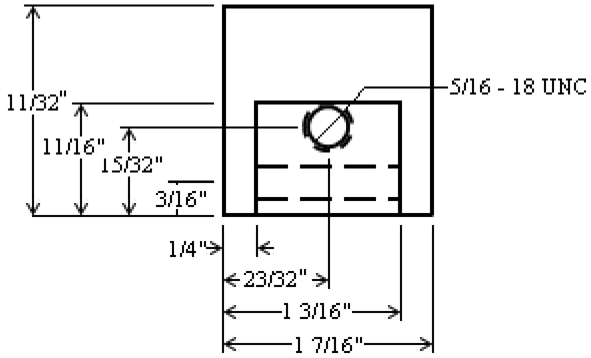


Figure C.14. Back view Hook-SH6 (dimensions in inches).

C.4 Closing Mechanism

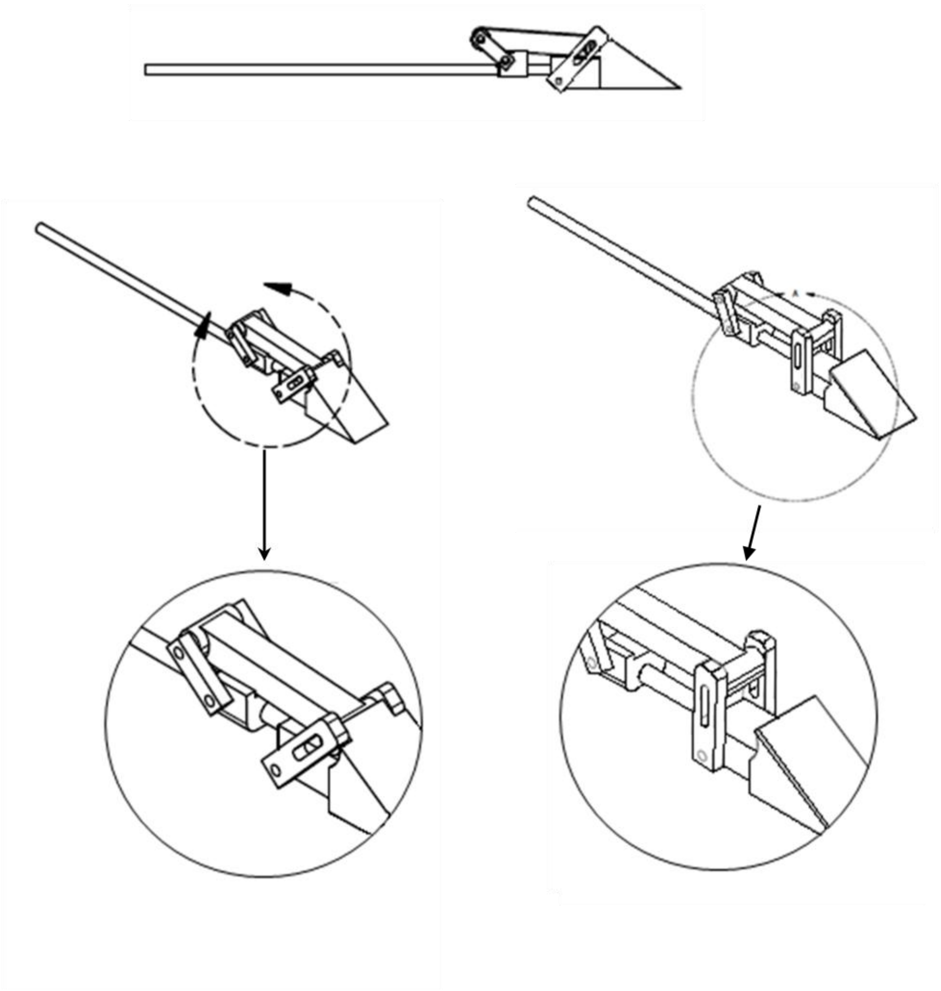


Figure C.15. The intial closing mechanism concept utilized a sliding four link assembly.

Appendix D 2010 Old Rotation Sweet Potato Orientation Field Study

D.1 Field Planter

The Old Rotation field study was planted with a prototype disc planter (figure D.1). The planter utilized two pairs of discs to open and close the furrow around sweet potato slips. The planter mounted to a tractor through a 3-point hitch allowing the operator to control planter height (figure D.2). Figure D.3 shows how slips were manually transplanted between the front and rear discs of the planter.

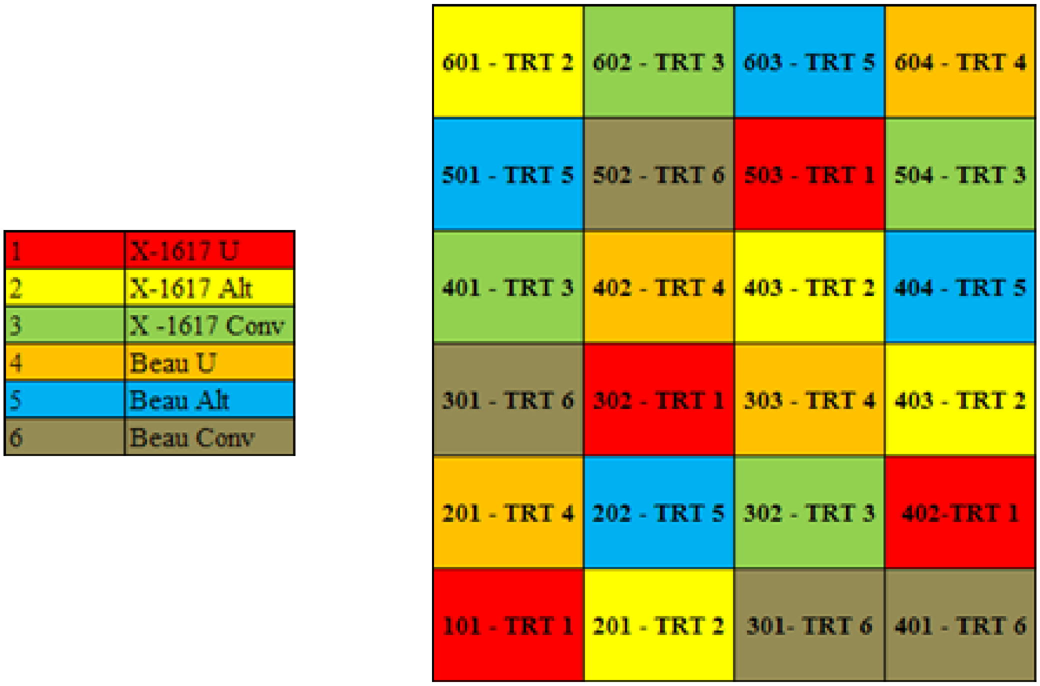
Figure D.1. Side view of the designed disc mechanism used to open and close the furrow around the slip.

Figure D.2. Rear view of the proposed disc mechanism.

Figure D.3. Slips being manually transplanted between the discs of the prototype planter.

D.2 Old Rotation Sweet Potato Orientation Results

Tyler Monday's Old Rotation field study evaluated how slip orientation affected sweet potato survival rate and yield. The plot plan figure D.4, utilized two varieties of sweet potatoes, Beauregard and X-167 and three transplant treatments. Treatment 1 featured conventional transplanting, slips were transplanted 3-4 inches deep into bedded soil. Treatment 2 (New) evaluated slips transplanted 3-4 inches deep in non-bedded soil. Treatments 1 and 2 were transplanted manually as previously described with the prototype planter. Lastly, treatment 3 involved slips bent into a “U”-shape and transplanted 3-4 inches deep into bedded soil. The survival rate of treatment 3, slips transplanted in a “U” shape was significantly lower than treatments 1 and 2 (table D.1).



1	X-1617 U
2	X-1617 Alt
3	X -1617 Conv
4	Beau U
5	Beau Alt
6	Beau Conv

601 - TRT 2	602 - TRT 3	603 - TRT 5	604 - TRT 4
501 - TRT 5	502 - TRT 6	503 - TRT 1	504 - TRT 3
401 - TRT 3	402 - TRT 4	403 - TRT 2	404 - TRT 5
301 - TRT 6	302 - TRT 1	303 - TRT 4	403 - TRT 2
201 - TRT 4	202 - TRT 5	302 - TRT 3	402-TRT 1
101 - TRT 1	201 - TRT 2	301- TRT 6	401 - TRT 6

Figure D.4. Plot plan from Tyler Monday’s 2010 sweet potato slip orientation study.

Table D.1. Field data from the 2010 Old Rotation study showed that the survival rate for treatment 3, slips transplanted in a "U" shape was significantly lower than treatments 1 and 2.

Plot	TRT	Survival	Survival (%)	Yield (lbs)	Calculated Yield (lbs/A)
101	X-1617 U	8	32	67	38914
302	X-1617 U	10	40	50.3	29214
503	X-1617 U	5	20	66	38333
204	X-1617 U	13	52	67.2	39030
Mean		**9.0**	**36.0**	**62.6**	**36372.6**
STDEV		**3.4**	**13.5**	**8.2**	**4782.0**
601	X-1617 New	18	72	65.2	37868
102	X-1617 New	14	56	80	46464
403	X-1617 New	16	64	74.9	43502
304	X-1617 New	17	68	91.6	53201
Mean		**16.3**	**65.0**	**77.9**	**45258.8**
STDEV		**1.7**	**6.8**	**11.0**	**6383.4**
401	X-1617 Conv	21	84	92.8	53898
602	X-1617 Conv	22	88	87.6	50878
203	X-1617 Conv	19	76	71.4	41469
504	X-1617 Conv	15	60	73.2	42515
Mean		**19.3**	**77.0**	**81.3**	**47190.0**
STDEV		**3.1**	**12.4**	**10.6**	**6142.5**
301	Beau Conv	21	84	84.7	49194
502	Beau Conv	20	80	62.5	36300
103	Beau Conv	23	92	88.1	51168
104	Beau Conv	23	92	78.7	45709
Mean		**21.8**	**87.0**	**78.5**	**45592.8**
STDEV		**1.5**	**6.0**	**11.4**	**6593.6**
501	Beau New	23	92	90.9	52795
202	Beau New	21	84	76	44141
603	Beau New	18	72	77.5	45012
404	Beau New	18	72	47.45	27559
Mean		**20.0**	**80.0**	**73.0**	**42376.6**
STDEV		**2.4**	**9.8**	**18.3**	**10616.9**
201	Beau U	13	52	61	35429
402	Beau U	12	48	37.3	21664
303	Beau U	9	36	59.2	34383
604	Beau U	19	76	82.9	48148
Mean		**13.3**	**53.0**	**60.1**	**34906.1**
STDEV		**4.2**	**16.8**	**18.6**	**10820.7**

Appendix E Prototype 2 Data

E.1 Sweet Potato Slip Data

Table E.1. Sweet potato slip, baffle comparison data (straight refers to Baffle-1, ripple is Baffle-2).

Baffle	Single	Double	Groups	Missed	Total Pulls	Percent Singles	Percent Doubles	Percent Groups	Percent Missed
Straight	3	2	1	11	17	17.6%	11.8%	5.9%	64.7%
Straight	3	1	2	2	8	37.5%	12.5%	25.0%	25.0%
Straight	0	2	3	5	10	0.0%	20.0%	30.0%	50.0%
Straight	1	4	1	5	11	9.1%	36.4%	9.1%	45.5%
Straight	0	2	1	12	15	0.0%	13.3%	6.7%	80.0%
Mean	1.4	2.6	1.6	7.0	12.2	11.5%	18.0%	13.1%	57.4%
STDEV	1.5	1.1	0.9	4.3	3.7	16%	10%	11%	21%
Ripple	3	1	2	13	19	15.8%	5.3%	10.5%	68.4%
Ripple	6	1	0	6	13	46.2%	7.7%	0.0%	46.2%
Ripple	9	2	0	9	20	45.0%	10.0%	0.0%	45.0%
Ripple	2	0	2	9	13	15.4%	0.0%	15.4%	69.2%
Ripple	2	0	3	1	6	33.3%	0.0%	50.0%	16.7%
Mean	4.4	0.8	1.4	7.6	14.2	31.1%	5.6%	9.9%	53.5%
STDEV	3.1	0.8	1.3	4.5	5.6	15%	5%	21%	22%

Table E.2. Hook entry angle data.

Angle	Single	Double	Groups	Missed	Total	Percent Singles	Percent Doubles	Percent Groups	Percent Missed
21.1°	3	3	2	8	16	18.8%	18.8%	12.5%	50.0%
21.1°	1	0	1	6	8	12.5%	0.0%	12.5%	75.0%
21.1°	6	2	1	26	35	17.1%	5.7%	2.9%	74.3%
21.1°	4	1	0	20	25	16.0%	4.0%	0.0%	80.0%
21.1°	8	2	1	16	27	29.6%	7.4%	3.7%	59.3%
21.5°	5	4	2	5	16	31.3%	25.0%	12.5%	31.3%
21.5°	3	0	0	27	30	10.0%	0.0%	0.0%	90.0%
21.5°	11	1	2	23	37	29.7%	2.7%	5.4%	62.2%
21.5°	4	2	1	9	16	25.0%	12.5%	6.3%	56.3%
21.5°	8	2	2	9	21	38.1%	9.5%	9.5%	42.9%
21.9°	5	2	2	8	17	29.4%	11.8%	11.8%	47.1%
21.9°	10	3	1	9	23	43.5%	13.0%	4.4%	39.1%
21.9°	5	2	2	8	17	29.4%	11.8%	11.8%	47.1%
21.9°	10	3	1	9	23	43.5%	13.0%	4.4%	39.1%
21.9°	8	2	1	27	38	21.1%	5.3%	2.6%	71.4%
22.3°	7	2	2	13	24	29.2%	8.3%	8.3%	54.2%
22.3°	5	4	1	3	13	38.5%	30.8%	7.7%	23.1%
22.3°	4	1	3	10	18	22.2%	5.6%	16.7%	55.6%
22.3°	4	1	3	5	13	30.8%	7.7%	23.1%	38.5%
22.3°	8	1	3	9	21	38.1%	4.8%	14.3%	42.9%
MEAN	5.2	1.7	1.4	12.1	20.3	25.6%	8.1%	6.9%	59.4%
STD	3.1	1.2	1.0	8.2	9.9				

Table E.3. Summary of hook entry angle mean data.

Test	Single	Double	Groups	Missed	Totals	Percent Singles	Percent Doubles	Percent Groups	Percent Missed
21.1°	22	8	5	76	111				
Mean	4.4	1.6	1.0	15.2	22.2	19.8%	7.2%	4.5%	68.5%
STDEV	2.7	1.2	0.7	8.3	10.4				
21.5°	31	9	7	73	120				
Mean	6.2	1.8	1.4	14.6	24.0	25.8%	7.5%	5.8%	60.8%
STDEV	3.3	1.5	0.9	9.7	9.3				
21.9°	38	12	7	61	118				
Mean	7.6	2.4	1.4	12.2	23.6	32.2%	10.2%	5.9%	51.7%
STDEV	2.5	0.6	0.6	8.3	8.6				
22.3°	28	9	12	40	89				
Mean	5.6	1.8	2.4	8.0	17.8	31.5%	10.1%	13.5%	44.9%
STDEV	1.8	1.3	0.9	4.0	4.9				

Table E.4. Sweet potato slips Grasping mechanism vs. open Hook-SH5 data.

Hook Type	Single	Double	Group	Missed	Total	Percent Singles	Percent Doubles	Percent Groups	Percent Missed
Open	3	1	1	27	32	9.4%	3.1%	3.1%	84.4%
Open	0	0	0	16	16	0.0%	0.0%	0.0%	100.0%
Open	5	2	2	33	42	11.9%	4.8%	4.8%	78.6%
Open	6	2	2	27	37	16.2%	5.4%	5.4%	73.0%
Open	0	2	0	21	23	0.0%	8.7%	0.0%	91.3%
Open	2	4	0	18	24	8.3%	16.7%	0.0%	75.0%
Open	2	2	1	6	11	18.2%	18.2%	9.1%	54.5%
Open	6	0	1	13	20	30.0%	0.0%	5.0%	65.0%
Open	4	1	2	5	12	33.0%	8.3%	16.7%	41.7%
Open	3	1	1	8	13	23.1%	7.7%	7.7%	61.5%
Total	28	12	9	110	159				
MEAN	4.0	1.8	1.1	16.4	22.8	16.7%	8.1%	5.7%	69.4%
STDEV	2.2	1.2	0.8	9.6	10.9	11.4%	6.2%	5.1%	17.5%
Closing	1	0	3	4	8	12.5%	0.0%	37.5%	50.0%
Closing	2	4	0	0	6	33.3%	66.7%	0.0%	0.0%
Closing	8	1	0	12	21	38.1%	4.8%	0.0%	57.1%
Closing	2	1	1	2	6	33.3%	16.7%	16.7%	33.3%
Closing	2	1	1	0	4	50.0%	25.0%	25.0%	0.0%
Closing	1	0	2	5	8	12.5%	0.0%	25.0%	62.5%
Closing	3	2	1	2	8	37.5%	25.0%	12.5%	25.0%
Closing	1	2	3	6	12	8.3%	16.7%	25.0%	50.0%
Closing	2	0	2	7	11	18.2%	0.0%	18.2%	63.6%
Total	33	24	51	122	84				
MEAN	2.4	1.2	1.4	4.2	9.3	27.1%	17.2%	17.8%	38.0%
STDEV	2.2	1.3	1.1	3.8	5.0	14.5%	21.2%	12.3%	25.0%

E.2 Pine Seedling Data

Table E.6. Hook-SH6 with the grasping mechanism was used to obtain preliminary data.

Video	Single	Double	Group	Misses	Total	Percent Singles	Percent Doubles	Percent Groups	Percent Missed
165513	3	0	0	13	16	18.8%	0.0%	0.0%	81.3%
165339	5	0	0	16	21	23.8%	0.0%	0.0%	76.2%
165206	1	0	1	7	9	11.1%	0.0%	11.1%	77.8%
165107	2	0	0	15	17	11.8%	0.0%	0.0%	88.2%
163410	4	1	0	14	19	21.1%	5.3%	0.0%	73.7%
162813	8	1	0	19	28	28.6%	3.6%	0.0%	67.9%
162155	6	1	0	18	25	24.0%	4.0%	0.0%	72.0%
*161957	1	0	0	10	11	9.1%	0.0%	0.0%	90.9%
160344	4	2	0	6	12	33.3%	16.7%	0.0%	50.0%
155849	5	0	0	20	25	20.0%	0.0%	0.0%	80.0%
*155741	1	0	0	8	9	11.1%	0.0%	0.0%	88.9%
Total	28	5	1	80	114	20.8%	4.4%	0.9%	70.2%

* Incomplete tests excluded from the mean as they did not accurately represent the prototype.

Table E.7. Hook-SH5 seedling sorting, incomplete tests are marked in red.

Video	Single	Double	Group	Misses	Total	Percent Singles	Percent Doubles	Percent Groups	Percent Missed
161559	5	0	0	9	14	35.7%	0.0%	0.0%	64.3%
160808	2	0	1	2	5	40.0%	0.0%	20.0%	40.0%
160754	1	0	1	5	7	14.3%	0.0%	14%	71%
153024	3	0	1	12	16	18.8%	0.0%	6%	75%
152047	3	0	0	7	10	30.0%	0.0%	0.0%	70%
151346	1	1	1	6	9	11.1%	11.1%	11.1%	66.7%
*151336	0	1	1	17	19	0.0%	5.3%	5.3%	89.5%
151144	3	1	0	7	11	27.3%	9.1%	0.0%	63.6%
145222	5	0	0	6	11	45.5%	0.0%	0.0%	54.5%
144433	2	0	1	3	6	33.3%	0.0%	16.7%	50.0%
144231	3	1	0	12	16	18.8%	6.3%	0.0%	75.0%
144013	3	1	0	8	12	25.0%	8.3%	0.0%	66.7%
142754	2	1	1	8	12	16.7%	8.3%	8.3%	66.7%
142324	2	1	0	8	11	18.2%	9.1%	0.0%	72.7%
*142307	2	0	0	8	10	20.0%	0.0%	0.0%	80.0%
*141732	2	0	0	16	18	11.1%	0.0%	0.0%	88.9%
*141601	3	0	0	15	18	16.7%	0.0%	0.0%	83.3%
143209	3	3	0	15	21	14.3%	14.3%	0.0%	71.4%
143004	3	1	1	6	11	27.3%	9.1%	9.1%	54.5%
141120	2	1	1	8	12	16.7%	8.3%	8.3%	66.7%
140856	3	2	0	3	8	37.5%	25.0%	0.0%	37.5%
140613	1	1	1	3	6	16.7%	16.7%	16.7%	50.0%
140050	5	0	1	11	17	29.4%	0.0%	5.9%	64.7%
135434	4	0	1	8	13	30.8%	0.0%	7.7%	61.5%
141624	7	2	2	28	39	14.9%	5.1%	5.1%	71.8%
Total	63	16	13	175	267				
Mean	2.8	0.7	0.6	7.8	11.8	23.6%	6.0%	4.9%	65.5%
STDEV	1.4	0.8	0.5	4.0	4.4				

* Incomplete tests excluded from the mean as they did not accurately represent the prototype.

Table E.8. Hook-SH7 seedling sorting data.

Video	Singles	Doubles	Groups	Missed	Total	Percent Singles	Percent Doubles	Percent Groups	Percent Missed
143135	8	3	2	46	59	13.6%	5.1%	3.4%	78.0%
142924	3	0	1	11	15	20.0%	0.0%	6.7%	73.3%
142721	5	2	2	21	30	16.7%	6.7%	6.7%	70.0%
142151	4	0	3	13	20	20.0%	0.0%	15.0%	65.0%
142042	3	3	1	8	15	20.0%	20.0%	6.7%	53.3%
141909	5	2	2	6	15	33.3%	13.3%	13.3%	40.0%
141711	3	1	2	17	23	13.0%	4.3%	8.7%	73.9%
141529	1	3	1	0	5	20.0%	60.0%	20.0%	0.0%
141214	5	1	2	10	18	27.8%	5.6%	11.1%	55.6%
141051	4	3	0	2	9	44.4%	33.3%	0.0%	22.2%
140905	3	1	2	3	9	33.3%	11.1%	22.2%	33.3%
124715	1	2	3	7	13	7.7%	15.4%	23.1%	53.8%
124539	3	3	1	6	13	23.1%	23.1%	7.7%	46.2%
124333	5	3	2	14	24	20.8%	12.5%	8.3%	58.3%
124136	5	3	1	4	13	38.5%	23.1%	7.7%	30.8%
123953	1	4	1	9	15	6.7%	26.7%	6.7%	60.0%
123320	1	2	2	8	13	7.7%	15.4%	15.4%	61.5%
123123	7	1	1	7	16	43.8%	6.3%	6.3%	43.8%
120700	5	1	1	17	24	20.8%	4.2%	4.2%	70.8%
120502	0	5	0	1	6	0.0%	0.0%	0.0%	16.7%
120324	4	0	1	8	13	30.8%	0.0%	7.7%	61.5%
120030	4	3	0	5	12	33.3%	25.0%	0.0%	41.7%
115906	1	3	1	4	9	11.1%	33.3%	11.1%	44.4%
115359	6	0	1	3	10	60.0%	0.0%	10.0%	30.0%
115107	3	1	1	9	14	21.4%	7.1%	7.1%	64.3%
Total	90	50	34	239	413				
Mean	3.6	2.0	1.4	9.6	16.5	21.8%	12.1%	8.2%	57.9%
STDEV	2.0	1.4	0.8	9.2	10.6				

Table E.9. Hook-SH7 five test means, test 1-5 were used to determine the length of the arm.

Videos	Singles	Doubles	Groups	Missed	Total	Percent Singles	Percent Doubles	Percent Groups	Percent Missed
1-5	23	8	9	99	139	16.6%	5.8 %	6.5%	71.2%
6-10	18	10	7	35	70	25.7%	14.3%	10.0%	50.0%
11-15	17	12	9	34	72	23.6%	16.7%	12.5%	47.2%
16-20	14	13	5	42	74	18.9%	17.6%	6.8%	56.8%
21-25	18	7	4	29	58	31.0%	12.1%	6.9%	50.0%

Table E.10. Seedling sorting comparison of all three hook treatments, grasping mechanism, Hook-SH 5 and Hook-SH7.

Test	Percent Singles	Percent Doubles	Percent Groups	Percent Missed
Grasping Mech.	20.8%	2.6%	0.5%	76.0%
Open Hook-SH5	23.6%	6.0%	4.9%	65.5%
Open Hook-SH7	24.5%	15.3%	9.1%	51.1%