Improve Phase Report

PALM HARVESTER SENIOR DESIGN PROJECT

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The improve phase is the fourth report amongst five progress reports. As part of the Six Sigma Methodology, this project is broken up into phases, "Define, Measure, Analyze, Improve, Control" (DMAIC). The Palm Harvester team will provide a complete assembling update of the mechanism, as well as give an update on the remaining work.

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Abstract

The palm harvester senior design project is dedicated to create an effective, efficient, and economical solution to harvest palm fruits. For several years the methodologies used to harvest palm fruits have proven to be quite dangerous. This has caused a great need for more efficient methods to collect the palm fruit and maximize palm oil production. For the completion of this project, the team is following the six sigma methodology known as DMAIC (Define, Measure, Analyze, Improve, and Control). The improve phase consisted of the team identifying the root causes and assembling the improved design. Building of the telescoping pole and modification of the cart has been started. Mounting the pulleys and buffer striping to the telescoping segments has been completed and electrical system testing is currently underway. The building process is still in progress and is projected to be completed by the end of the control phase concluding with mechanism testing.

1. Introduction

The palm oil industry is advancing at an exponential rate, and the technology has to keep up with the growing demand. Current harvesting methods include: climbing up to forty feet and manually cutting down the fruits as well as using a sickle blade attached to an elongated pole. These fruits being cut down weigh upwards of fifty pounds, causing major safety concerns for the laborers [1]. In the last decade, it is estimated that a total of 45 million tons of palm oil has been extracted. The market is expected to grow more than 65% by 2020 [1]. Clearly these outdated methods need to change, and the development of the palm fruit harvester will help move the industry forward.

Dr. Okoli is the lead advisor for the team; the goal of this project is to build a safe, cost-effective, efficient mechanism to harvest these palm fruits that are in high demand. The previous year's team designed and built a palm harvesting mechanism to aid in the harvesting process of palm fruits. The goal of the current senior design team is to improve last year's model in order to sell it commercially to oil palm plantations.

Goals accomplished during the analyze phase comprised of stress and deflection diagrams that identified concentrated stress points on the telescoping pole and force calculations that categorized the appropriate motor for the needed improvements. Based on those procedures, the team was able to make the justified purchases. During the improve phase, the team was able to disassemble the old telescoping poles to make way for the new and improved poles. The new wheels were added to the cart, the pulleys were transferred from the old poles to the new, the poles were replaced, and the center of gravity was lowered. The next step of this project is to finish constructing the rest of mechanism.

2. Project Charter

2.1 Overview

Palm oil is used in everyday products such as soaps, washing powders, margarine, and cereal[2]. Palm oil is derived from the trees native to West Africa[2]. The current palm fruit harvesting method is performed in a dangerous manner where workers either climb the trees with sickle blades or they use an elongated pole with a sickle blade attached to the end in order to remove the fruit. Both of these methods are extremely dangerous because the palm fruit bunch could strike the workers on the ground and cause injury or the worker could injure themselves by climbing a tree with a blade in hand as seen in Figure 1(a) (left). Figure 1(b) (right) shows a plantation worker on the ground removing the palm fruit bunches from the tree [2&3].

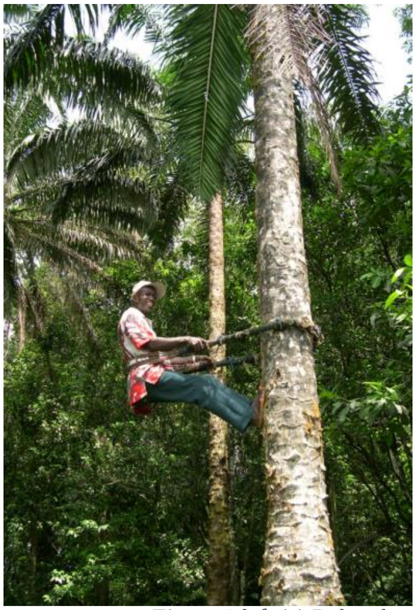

Figure 1 left (a) Palm plantation worker climbing a tree to remove the bunches of fruit right (b) Worker removing palm fruit bunches from oil palm tree [2 and 3]

The goal of this project is to create a mechanism that will both replace these dangerous methods and improve the previous senior design mechanism. The previous senior design mechanism consisted of an unstable telescoping pole mounted a non-maneuverable cart. To improve last year's mechanism, the stability of the pole must be maximized along with the mobility and portability so the worker can move from tree to tree with ease. For this mechanism to be implemented in oil palm plantations, it must be affordable, effective, and safer than current methods. Performing these improvements will minimize the risk of injury to the workers.

2.1.1 Background and History

Oil palm trees originated in the tropical region of West Africa [i]. Between the 14th and 17th century, these oil palm plants were taken to the Americas and then to the Far East. Indonesia, Malaysia, Thailand, Nigeria, and Colombia are the top five producing nations of palm oil today. Oil palms are grown as a plantation crop in countries with high rainfall exhibiting tropical climates within 10 degrees of the equator [i]. There are small-scale oil palm farms which cover up to 10 hectares, medium scale farms which cover 10 to 500 hectares, and large-scale farms which cover 500 hectares or more [i]. The oil palm trees can grow up to forty feet and grow palm fruits in bunches that could weigh up to 55 lbs [i].

2.1.2 Objectives and Expected Benefits

The team has decided that it would be most beneficial to improve the mobility of the mechanism, incorporate automation, change the material and shape of the telescoping poles, and modify the pulley system. The wheels of the existing mechanism will be replaced with more durable ones in order to suit the rough terrain of the plantation. A motor will be added to the cart, which will result in an automated telescoping pole. Figures 2(a) & 2(b) shows the previous (left) and new (right) ideas for the telescoping pole. The previous pole was made of circular PVC pipes that lacked ductility and rotated within each other, whereas the new design consists of square aluminum pipes that will not rotate within each other and increase ductility allowing for deformation to be visible before failure.

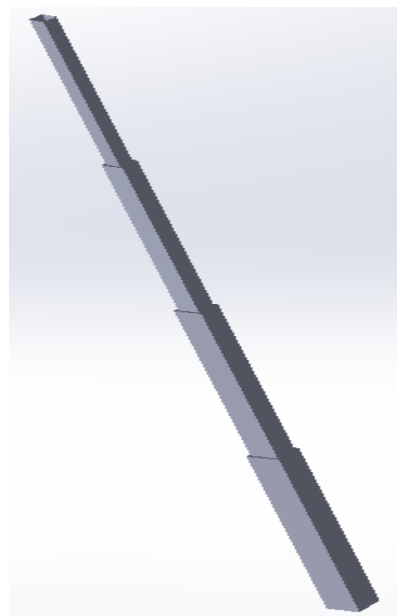

Figure 2 Comparison of old and new telescoping poles(old-left and new-right)

2.1.3 Business Case

Approximately 45 million tons of palm oil has been extracted in the past decade indicating a growing industry[2]. Indonesia and Malaysia are the main exporters of palm oil and by 2020 the palm oil market is projected to grow more than 65% [2].Palm oil plantations require an average of five workers per hectare whereas competing oil crops only require one worker for every 200 hectares[2]. Indonesia has 3.7 million people engaged in the palm oil industry while Malaysia has 590,000 people[2]. This shows that palm fruit impacts a large amount of people and with a way to safely and efficiently harvest the fruit the industry would benefit greatly.

The main reason behind this project is to create a safe and affordable way to harvest palm fruit. This project exists due to the fact that palm oil is profitable and high yielding. The versatility of the palm oil, its long shelf life, its low cost, and its nutritional benefits compared to other leading oils give it edge amongst the other oils.

Figure 3 shows the high consumption of palm oil. In 2011, India consumed 7 million tons of palm oil, 14% of all of the global palm oil consumption[2]. This shows that there is a very strong opportunity for palm oil in the market.

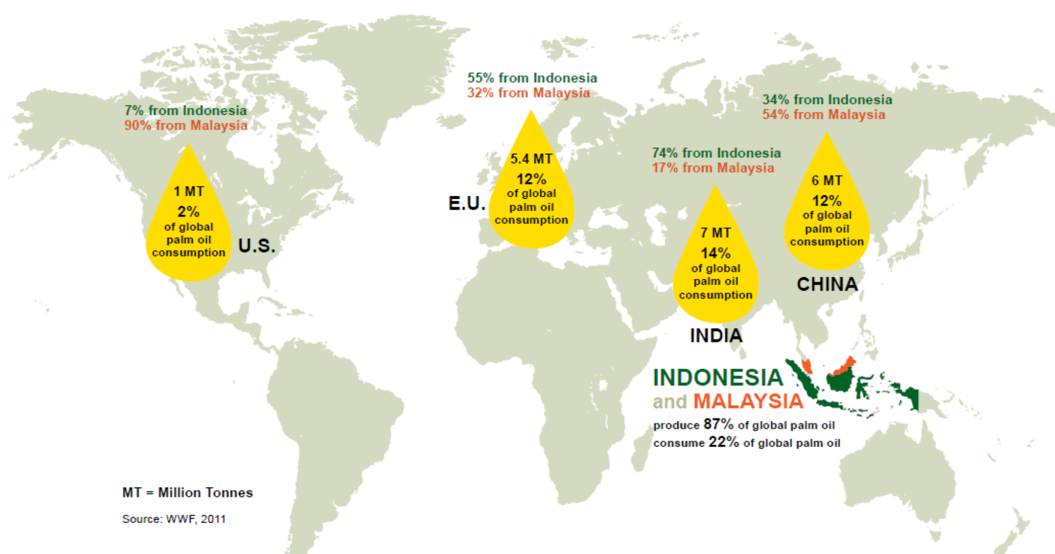

Figure 3: Trade flows of palm oil between the main production regions for palm oil (Malaysia and Indonesia) and the world's main palm oil consumer markets [2]

A Threat & Opportunity Matrix was conducted to further explain the short term and long term threats and opportunities associated with this project as seen in Table 1.

Table 1 Threat and Opportunity Matrix

	Threats	Opportunity
Short Term	• More injuries using the normal method • May not be faster than climbing the tree	• Less workers will be injured • Opportunity for sponsor to patent design
Long Term	• Other designs could be competition • Design may need to be modified based on market demands	• Abundance of palm oil due to automation of process • Device will become a necessity for palm plantations

The short term threats are injuries due to the current method and that there is a risk that the new method may not be faster than the current manual pulley method. On the other hand, the short term opportunities include fewer injuries to plantation workers, commercial manufacturing of the mechanism, and a potential patent design. A long term threat affecting this project is a device that wraps around the tree and climbs up it to retrieve the fruits, this could be considered competition due to the fact that it is smaller and more efficient than our mechanism. Depending on long term market needs, the mechanism may need to be modified to meet the customer's needs. Long term opportunities include this device becoming a necessary item for every palm plantation and an abundance of palm oil due to automating the process and eliminating fatigue in the worker.

2.1.4 Team Members/ Major Stakeholders

Dr. Okoli is the key stakeholder and sponsor for this project. He is the chair of the Industrial and Manufacturing Engineering Department. Dr. Frank is one of the advisors but also serves as the instructor of the Electrical and Computer Engineering senior design class. Dr. Shih and Dr. Gupta are the instructors of the Mechanical Engineering senior design class. Dr. Edrington serves as the Electrical Engineering advisor while Dr. Chuy serves as the Mechanical Engineering advisor. Dr. Edrington and Dr. Chuy have guided the team in the process of selecting a motor and installing the electrical system, while Dr. Shih and Dr. Gupta have served as a guide to the redesign of the telescoping poles. Margaret Scheiner and Emily Hammel serve as the Industrial and Manufacturing

Engineering teaching assistants who help the project run smoother by answering all the team's questions.

Given that Talya Levin would like to focus on materials research post-graduate and has had additional coursework in material science based classes, she has been tasked to the material selection process. Thomas Baker is the mechanical lead and is in charge of designing the new pulley system. Thomas takes a hands on approach to his work and finds improvements in the current system easily making him the ideal candidate for this position. Christopher Chiros has had an internship at Caterpillar working within an engineering team in charge of providing technical documentation to move forward with engineering projects. Given his credentials, Chris is the industrial lead and technical writer. Shaneatha Gates is the electrical lead and in charge of automation; given her coursework within the Electrical Engineering department she has the knowledge and resources to accomplish this task. Amber Smith is the financial advisor and web designer; having been an application developer for JP Morgan and the National Science Foundation she has the expertise to design a functional website. Maurice Derius is the parliamentarian and Six Sigma leader; having a Green Belt in Six Sigma gives Maurice the credentials to ensure our project is aligned within the requirements of Six Sigma and overall DMAIC process.

2.2 Approach

2.2.1 Scope

Improvements to the previous mechanism include: replacing the polyvinyl chloride (PVC) telescoping pole with aluminum, incorporating an efficient easy-to-use and non-tangling pulley system, adding automation to the telescoping pole so that it may ascend and descend to and from the bunches of fruit, replacing the wheels with all-terrain, never flat tires.

2.2.2 Assumptions and Constraints

A variety of factors play a key role in the design of the oil palm fruit harvester. From the personal standpoint of the senior design team, the assumptions and constraints are limited to Florida's environment instead of Malaysia's. Being that the College of Engineering has no physical palm trees, the parameters of the average height, weight of fruit bunches, and other key factors were found in dated statistical data as shown in Table

2 [2]. The team also assumes that the weather conditions and working conditions are accurate based upon averages found online [2]. It is assumed that the workers operate on an 8 hour work day and only one to two workers are needed to operate the mechanism. During the harvesting process the mechanism operate on horizontal ground in order to maintain proper stability.

The main constraints are the weight of the aluminum poles and the size of the overall mechanism. The weight of the aluminum poles are considered a constraint because of the difficulty of maneuvering the poles during the maintenance process. The size of the overall mechanism is crucial, as it needs to be stored on site and have the ability to move between trees.

Table 2: The key dimensions of a typical palm [2]

Characteristics	Values
Palm Fruit Weight	40 – 55 lbs
Number of Fruits per Bunch	Up to 200 fruits
Growing Temperatures	77 – 82° F
Plantation Planting Density	143 Palms per Hectare
Begins to Produce	3 – 4 years
Growth Height	40 ft
Diameter	0.75 – 2.5 ft
Amount of Sunlight	4-5 hours/day
Amount of Rainfall	Year-round

2.2.3 Deliverables

Upon the conclusion of this project, the sponsor will be presented with the following:

- Functioning palm harvester
- Instruction manual

2.2.4 Milestones

During each phase of the Palm Harvester project, several milestones must be completed to stay on track and to complete successfully the goal of improving the palm harvester mechanism. These milestones are:

Define Phase:

- Visit Prototype: Assemble and gather data from previous year's harvester
- Gather Requirements: Speak with sponsor on expectations and goals
- HPMI Safety Meeting: Certify team members to access the HPMI building
- Finalize New Design: Determine the most feasible design that best suits expectations and product improvements

Measure Phase:

- Build Scaled Prototype: Assemble a functioning prototype for sponsor.
- Incorporate Automation: Determine the most efficient product for automation of mechanism

Analyze Phase:

- Order Parts and Materials: Submit all product & material orders to Industrial & Manufacturing Engineering Office
- Plan Labor Assembly: Prepare plan of action to assemble actual palm harvester

Improve Phase:

- Assemble Actual Mechanism: Physically assemble the final palm harvester mechanism

Control Phase:

- Finalize Building: Finish building the remainder of the mechanism
- Test Mechanism: Operate & observe final mechanism
- Final Product: Fabricate to achieve overall manufactured look

3. Defining Customer and Technical Requirements

In order to address the customer requirements, a House of Quality (HOQ), shown in Figure 4, was created .

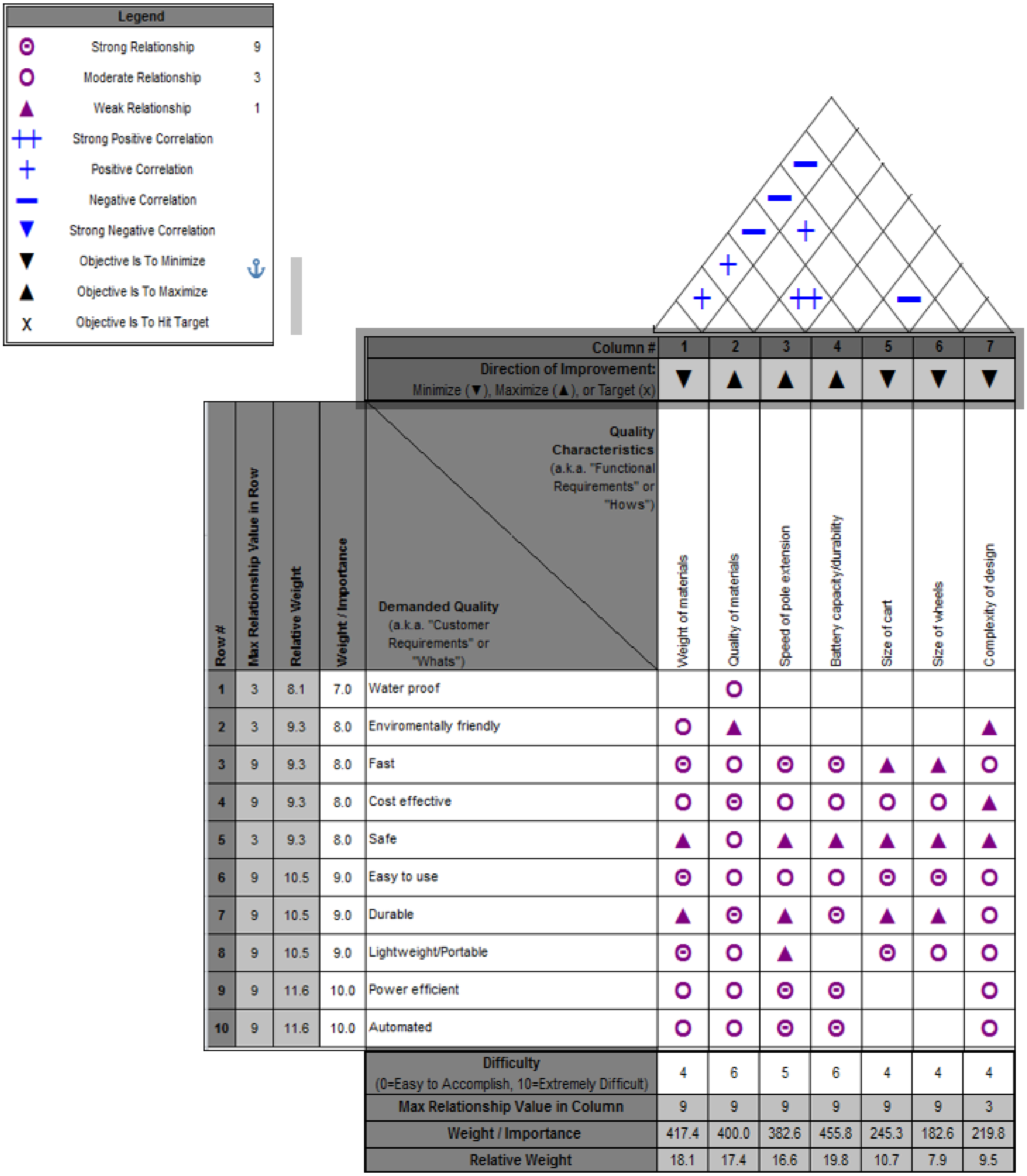

Figure 4 House of Quality

The HOQ is divided into two main categories: The "Whats" and the "Hows". The "Whats" section lists the customer requirements or what the customer wants from the product. The

“Hows” depicts the functional requirements; these requirements are the processes that will be used to meet the customer requirements. The most important customer requirements are listed in the following Table 3. After brainstorming with the team, a scale was created in order rank the customer requirements, using a scale from 1 to 10 with 10 being the most important and 1 the least important.

Table 3 Customer requirements and importance

Customer Requirements	**Weight/Importance**
Automated	10.0
Power efficient	10.0
Light-weight/ Portable	9.0
Durable	9.0
Easy to use	9.0
Safe	8.0
Cost effective	8.0
Fast	8.0
Environmentally friendly	8.0
Water proof	7.0

Automation and power efficiency are ranked the highest since the customer wants the final product to be both automated and power efficient. Waterproof is the lowest ranked customer requirement as is it not crucial in the operation of the mechanism.

The team brainstormed several quality characteristics: weight of materials, quality of materials, speed of pole extension, battery capacity/durability, size of cart, size of wheels, and complexity of design. The weight of materials is very important for the implementation of the new design. Using heavy materials will require greater force and power to push the cart and could cause musculoskeletal disorders to user. In other words, it will not be ergonomically safe to select heavy materials as it will cause injuries to the user. The type of the material needed for this design needs to accommodate climate changes as the final product will be used in humid and hot climates. The size of the cart is another important factor in this design because it will be implemented in oil palm plantations where there is an average of 143 palm trees per hectare [2]. The cart should be compact because it will be difficult to transport and store. The wheel size needs to be at optimal size for stability and movement of the cart. When the initial push force is applied, the contact between the tires and the muddy/rocky soil will experience a frictional force. The final product is going to be designed for owners of oil palm plantations in Malaysia, therefore it must be easy to use and have low maintenance cost as this is not a wealthy country. The speed of the pole extension of the final mechanism needs to be quicker when compared to the current harvesting methods. Furthermore, the goal of this team is to come up with a product that will be more efficient than a human climbing an oil palm tree.

The weight/importance, located at the bottom of the House of Quality matrix, determines the most critical customer requirements. The relative weights on the left of the HOQ were obtained by dividing each customer's rating index by the total of all the indices, which totaled 86. For example, waterproof has a customer rating index of 7.0, dividing 7.0 by 86 will give 8.1%. This calculation is performed for each of the other relative weights. The weights/importance at the bottom of the HOQ were calculated by adding all the products resulting from multiplying the relative weight by the index number assigned to the relationship between the functional requirements and the customer requirements. For example, there is a moderate relationship between environmentally friendly and the weight of the materials. A moderate relationship has an index value of 3 and environmentally friendly has a relative weight of 9.3, so multiplying 3 and 9.3 will give a portion of the technical weight. This calculation is performed for each relationship in the matrix and the products for a specific column are added together. Battery capacity/durability has the highest weight, and is therefore very important to take that into account when designing the final product. Example formulas and calculations used in the HOQ are provided in Appendix A.

The roof of the HOQ identifies the correlations that exist between each functional requirement. For example, there is a positive correlation between the weight of the materials and the speed of the pole extension, because the lighter the pole, the easier it will be able to extend. The box below the roof indicates the objective of functional requirements, it can either minimize, maximize, or hit the target. The HOQ helped to pinpoint the improvements that need to be made. Rather than having a broad focus, the HOQ allowed the criteria to be narrowed down to the most important factors. The most important quality characteristics were the weight of the material, the quality of the material used and the speed of pole extension. These quality characteristics need to be considered in the design and manufacturing of the final product.

4. Measuring the Baseline Performance

In the Measure Phase, the team tested the recommended improvements against the previous year's device. This test proved that the key areas of improvement were essential to having a more effective, efficient mechanism that will be one step closer to improving working conditions on oil palm plantations. The measurements taken included the time of assembly and disassembly and the stress experienced by the telescoping pole.

When the project began, the team agreed that an improvement to the assembly and disassembly of the cart was necessary. The excessive time consumed putting the palm harvester together is something that is just not viable out on the job site. To show improvement between the old design and the new, the time of assembly was recorded and broken down in a series of steps. The steps are outlined in Figure 5 and the times are recorded in Table 4. It was concluded that automation will drastically cut this assembly time, as well as make the process smoother and safer.

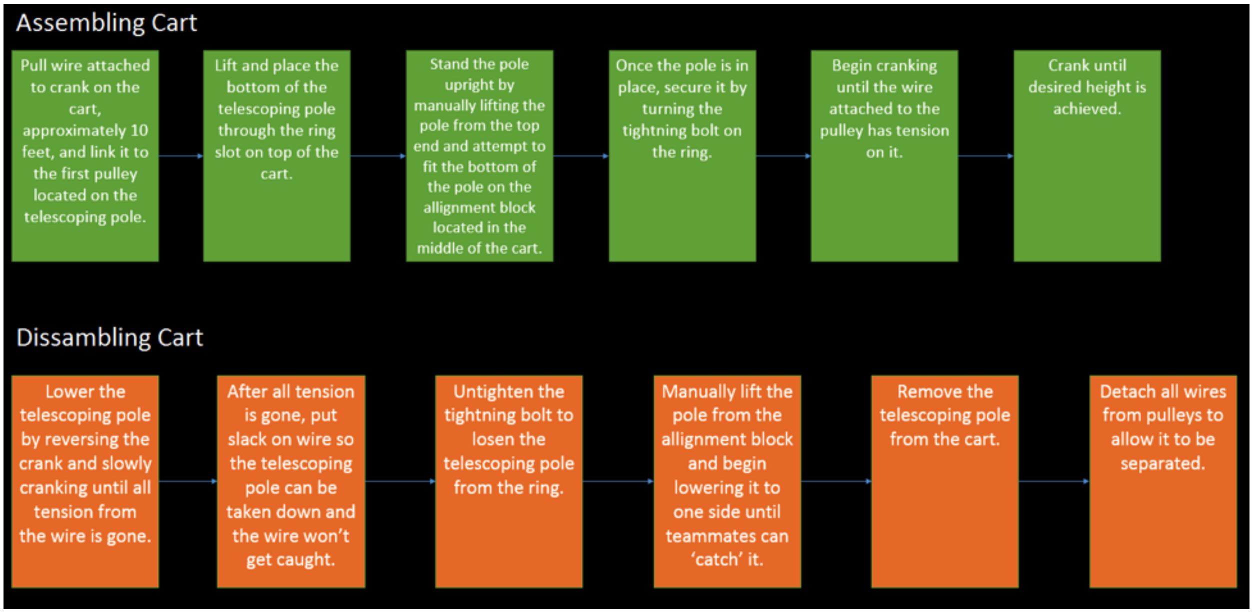

Figure 5 Steps to assemble and disassemble cart

Table 4 Assembling and disassembling times

Steps	Assembling Time (min)	Disassembling Time (min)	Assembly Time Interval (s)	Disassembly Time Interval (s)
1	0:00-0:39	0:00-0:40	39	40
2	0:39-1:15	0:40-1:12	36	32
3	1:15-2:15	1:12-1:22	60	70
4	2:15-2:25	1:22-1:50	20	28
5	2:25-3:10	1:50-2:05	45	15
6	3:10-3:50	2:05-2:20	40	15

The telescoping pole will be changed from having circular cross-sections to square-cross sections. Having a square cross-section will not allow the poles to rotate within each other. During the Measure Phase, it was decided that the pulley system would be located within the poles but this idea changed in the Analyze Phase. The material of the pole is being changed from PVC/steel to Aluminum 6063. A stress analysis for each telescoping pole was performed using Creo Parametric, resulting in a Von Mises Stress diagram for each. In order to do an equivalent comparison, the same forces were applied to the two poles. These forces along with a legend are shown in the schematic in Figure 6 . The PVC pole had stress values that ranged from 3.2×10^{-4}

MPa to 113.76 MPa while the aluminum cross section's stress ranged from 4.8×10^{-4} MPa to 28.45 MPa, therefore making the aluminum cross sections a better option.

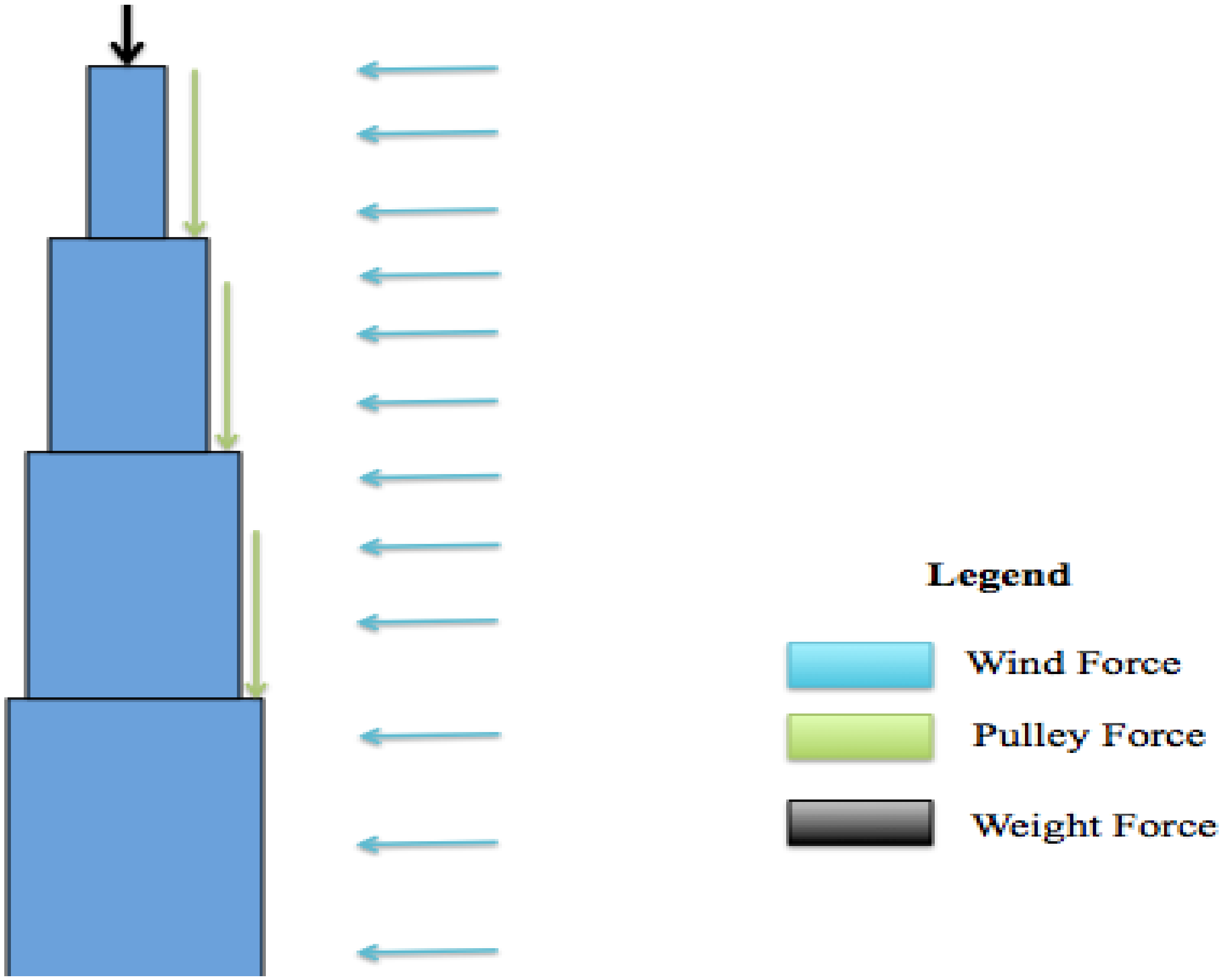

Figure 6 Forces acting on the telescoping pole

Overall, the Measure Phase was successful in allowing the team to determine the necessary adjustments that need to be made to the palm harvester. It was determined that the wheels will be upgraded to increase mobility. This will allow the mechanism to effectively traverse the oil palm plantation's rough terrain. The telescoping pole will be moved to the lower section of the cart in order to lower the center of gravity of the cart and improve the telescoping process. The team will add a motor to make the process completely automated, to decrease the setup time. Square cross-sectioned Aluminum 6063 will be used in replacement of the circular cross section PVC and steel in order to increase the ductility of the telescoping pole.

5. Identifying the Root Causes

5.1 Telescoping Poles

As previously stated, the telescoping poles have been changed from circular Polyvinyl Chloride (PVC) poles to square aluminum poles (Aluminum 6063) in order to attain ductility. Using a ductile material allows the user to physically see the material fail. For example, if the aluminum poles reach the end of their life, they will begin to neck, which will cause a visible deterioration. This allows the user to see that failure is occurring and take safety precautions. Materials such as PVC do not possess this quality and will break without any warning because of its brittle nature. After analysis the team decided to order four 3.05 m (10 ft) tall poles with cross sectional dimensions of 0.15 m x 0.15 m, 0.13 m x 0.13 m, 0.10 m x 0.10 m, 0.08 m x 0.08 m (6”x6”, 5”x5”, 4”x4”, and 3”x3”) which in total weighed 58.5 kg (129 pounds). These cross-sectional dimensions were chosen because they were similar in size to the one’s previously used. Before ordering the poles, a final analysis was completed to make sure the poles were exactly what was needed in respect to the motor, stress on the cart, weight, and budget. The key factor in this analysis was weight. This final analysis showed that if the weight of the poles could be reduced then the stress due to the poles on the cart would decrease as well. First the equation for stress (Equation 1) was analyzed, where σ is the amount of stress, F is the amount of force applied, and A is the area perpendicular to the force.

$$\sigma = \frac{F}{A} \qquad \text{Equation 1}$$

It can be seen from this equation that by applying less force, in this case due to the weight, the amount of stress applied to that area will decrease. Another aspect considered, was the amount of torque required to power the motor, shown in Equation 2, where τ is the torque, F is the force applied, and d is the perpendicular distance the force is applied from the axis of rotation.

$$\tau = F \times d \qquad \text{Equation 2}$$

By reducing the amount of force, required to power the motor to lift the top three telescoping poles and the cutting mechanism, the amount of torque needed would also decrease. Reducing the weight of the poles causes less stress on the cart, especially on the bottom shelf where the poles will be resting, and requires less torque from the motor. Another benefit of reducing the weight of the poles, was a decrease in cost of material. In order to decrease the weight of the poles, less material is needed, thus the cross sectional area of the poles needed to be reduced. By reducing each cross-sectional (square) pole dimension by 0.03 m (1"x1"), the total weight of the four poles would go from 58.5 kg (129 pounds) to 48.1 kg (106 pounds), which is a 10.4 kg (23 pound) decrease, and similar to the weight of the previous PVC and steel poles. Since the poles didn't come in fractional sizes, the team decided that reducing the square shape by 0.03 m (1"x1") was enough because if the shape was reduced by more, then the inside of the smallest pole would be too small to fit the pulley cable and wiring (camera and cutting mechanism). The decrease in weight and dimension of the poles, allowed more money in the budget and more importantly enhanced the portability of the mechanism.

5.2 Wheels

The previous year's palm fruit harvester utilized 0.25 m (10") pneumatic swivel castor wheels, shown in Figure 7.

Figure 7 Picture of previous year's wheels

These particular wheels are said to be self-inflating, however the current condition of the wheels are flat making the palm harvester very difficult to maneuver on asphalt let alone on the soft soil found at an oil palm plantation. There was a major need to replace these wheels with wheels that can also withstand the weight but not deflate at any time. A zoomed in view of the condition of the current wheels is shown in Figure 8 .

Figure 8 Zoomed in view of the condition of last year's wheels

The wheels that were chosen are 0.26 m (10.25") "never flat wheels", capable of a 158.8 kg (350 pounds) load for each wheel, easily supporting the weight of the entire mechanism. To avoid replacing the entire swivel castor assembly on the current cart, a wheel that had the same axle diameter of 0.02 m (5/8"), was chosen, for easy replacement. Although the diameter of the new wheels is a quarter of an inch larger than the previous ones, there is still enough space between the axle and the top bracket of the cart leg, to accommodate this. The wheels chosen are made of solid polyurethane, allowing the cart to be easily maneuvered without having to worry about tire inflation. The new tires, shown in Figure 9, have arrived [4].

Figure 9 New wheels that arrived

5.3 Pulley System

The pulley system has undergone a series of improvements throughout the course of this project. The initial idea was an internal pulley system, where all of the pulleys and cabling were attached to the inside faces of the telescoping pole segments. A schematic of the internal pulley system can be found in Figure 10 (a). The main reasons for building an internal pulley system was to minimize the risk of tangling and to protect the pulley system from weather conditions. There was one key factor that was not thought of during the initial design phase and that was maintenance. Imagine a laborer in the middle of an oil palm plantation, unable to harvest because of a pulley failure or cable mishap. The laborer would not be able to fix the issue if it were located on the inside of the telescoping pole without bringing it back to the main facilities for repair. This would be costly for the plantation as well as unproductive. With an external pulley system, the malfunction would be clearly visible and possibly able to be repaired while on the job site. Overall, it was decided that an external pulley system would be used in the future design.

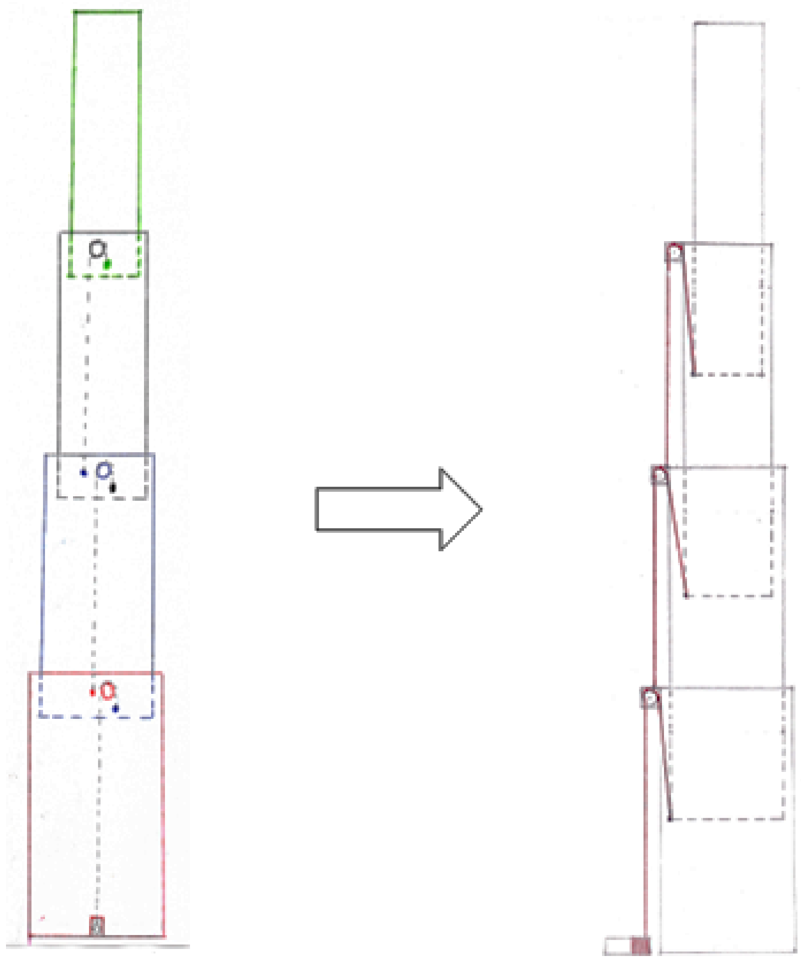

Figure 10 (a) Internal pulley system (b) External pulley system

The schematic in Figure 10 (b), on the right, is the design for the external pulley system. Each cable segment is attached to three telescoping pole segments. The lower most pulley system begins at the motor and travels upwards, parallel to the first pole, and wraps around a pulley mounted at the top of the pole. From the pulley, the cable travels in between the first and second pole segments and finally attaches to the bottom of the second segment. This entire process is repeated for the other two pulley systems with the exception that the beginning of the pulley segments attach to the prior telescoping pole segments instead of the motorized winch. As the motorized winch pulls the steel cabling, it lifts all of the telescoping segments simultaneously, reducing the amount of lift time and the amount of battery power used.

Note that the depicted pulley layout is for visual representation only as there are a few modifications that will be made during the fabrication process. It can be seen from the figure that the cabling in between telescoping pole segments are at a significant angle, which would cause a moment or torque to be place on the telescoping pole. This will not be an issue for the actual telescoping pole because the empty space between the pole segments range from a quarter-inch to three-eighths-inch. This amount of space for the cable to travel in the horizontal direction will not equate to a significant torque, as can be seen from Equation 2. Another deviation from the external pulley schematic is that all of the pulleys will not be on the same side of the square cross-sectioned aluminum tubing. In order to distribute the forces placed on the pole segments evenly, each individual pulley will be mounted on its own separate face of the telescoping pole. Less friction will be encountered between the buffer striping and the faces of the telescoping pole segments because all of the tension forces in the cabling will not be on the same side. Having the pulleys mounted to different sides of the poles will also allow for the pole to be compressed down further. If all of the pulleys were mounted on the same side then the pole would only be able to compress as far as when the pulleys are stacked on top of each other. When the pulleys are on separate sides, the pole will compress until each individual pulley comes into contact with the prior telescoping pole segment, making for a lower initial height of the telescoping pole.

5.4 Alignment Block

The previous palm harvester team made use of an alignment block mounted to the top shelf of the cart in order to aid in the stability and alignment of the telescoping pole. The circular cross-sectioned telescoping pole would fit into the pivot ring and the alignment block would become inserted into the bottom of the outermost telescoping pole segment as seen in Figure 11.

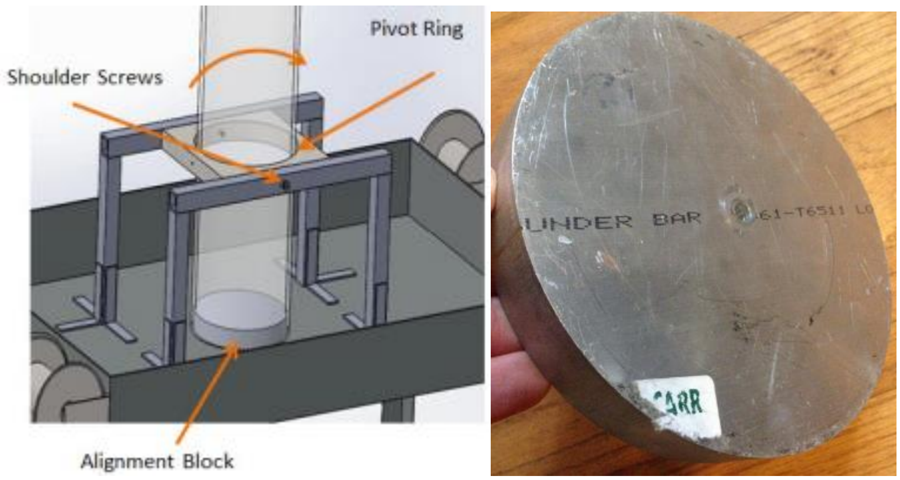

Figure 11 Alignment block mechanism [5]

Without the use of this alignment block, the bottom of the telescoping pole is not locked into place, allowing the bottom to pivot about its axis of rotation. This situation would be extremely dangerous for the operators of this device. Since the telescoping pole is being moved down to the lower shelf of the cart, the pivot point would be the top shelf.

The original idea for locking the telescoping pole in place was to mount an alignment sleeve that fit over the outside of the first telescoping pole segment to the bottom shelf of the cart. Due to time and budget constraints, this idea was not used, yet a simpler plan was constructed in its place. By reusing the old alignment block, cuts can be made in order to fit the current telescoping pole segment. The alignment block will be mounted to the bottom shelf and perform in the same manner as it was originally intended.

5.5 Assembly

In order to attain the most accurate stress analysis, a model of the entire assembly (cart and pole) was created, as shown in Figure 12.

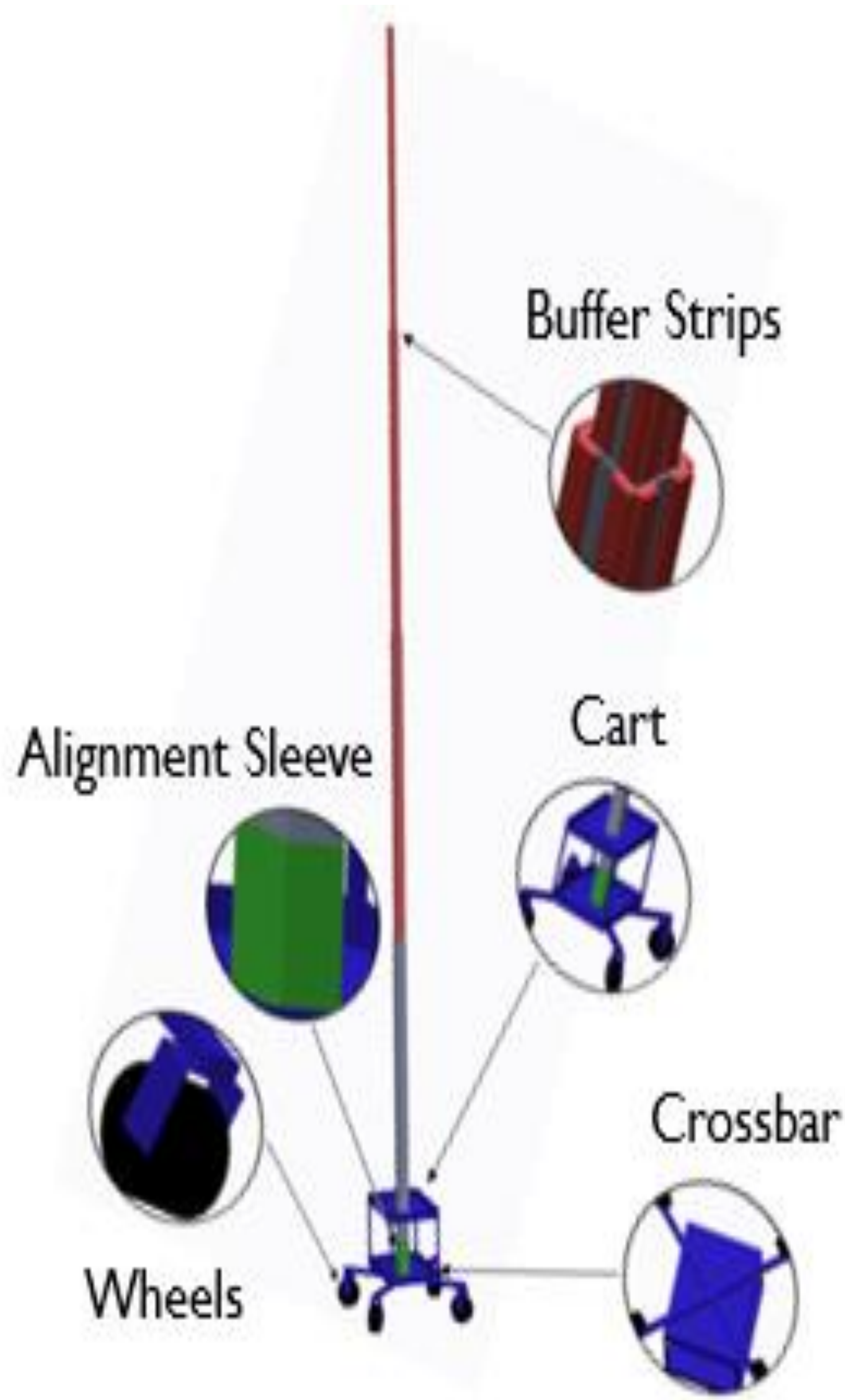

Figure 12 Assembly of mechanism

Figure 12 is made up of many important parts, which are labeled with a zoomed view for a better understanding. The steel cross-bar created by the previous year's team, shown below the bottom level of the cart, serves a very important purpose. The purpose is to provide more support for the weights being applied to the cart, in order to prevent the cart from buckling. The cart would manage without the cross-bar but would not have as long of life because eventually the stress would cause plastic (permanent) deformation. Another part is the buffer strips, which were originally attached to the outside (each side) of each of the top three poles, but have been moved to the inside face of each segment in order to be hidden during the telescoping process. These Teflon buffer strips allow the poles to smoothly (minimal friction) extend out of each pole and also eliminate the unwanted gap between each pole. The alignment sleeve is another part of the mechanism, keeping the pole in place on the bottom shelf. As mentioned before, instead of the alignment sleeve, an alignment block will be used for the same purpose. The last crucial component is the wheels, which were replaced with polyurethane no flat wheels in order to prevent the wheels from deflating.

5.5.1 Stress Analysis

Once the assembly was completed, it was time to put it to the test and see whether it could withstand all the wind and load forces. Figure 13 shows the Von Mises stress diagram in MPa of the entire assembly, consisting of the forces shown on the poles in Figure 6 as well as the force the poles exert on the cart. The calculations for the forces applied to the cart are shown in Appendix B.

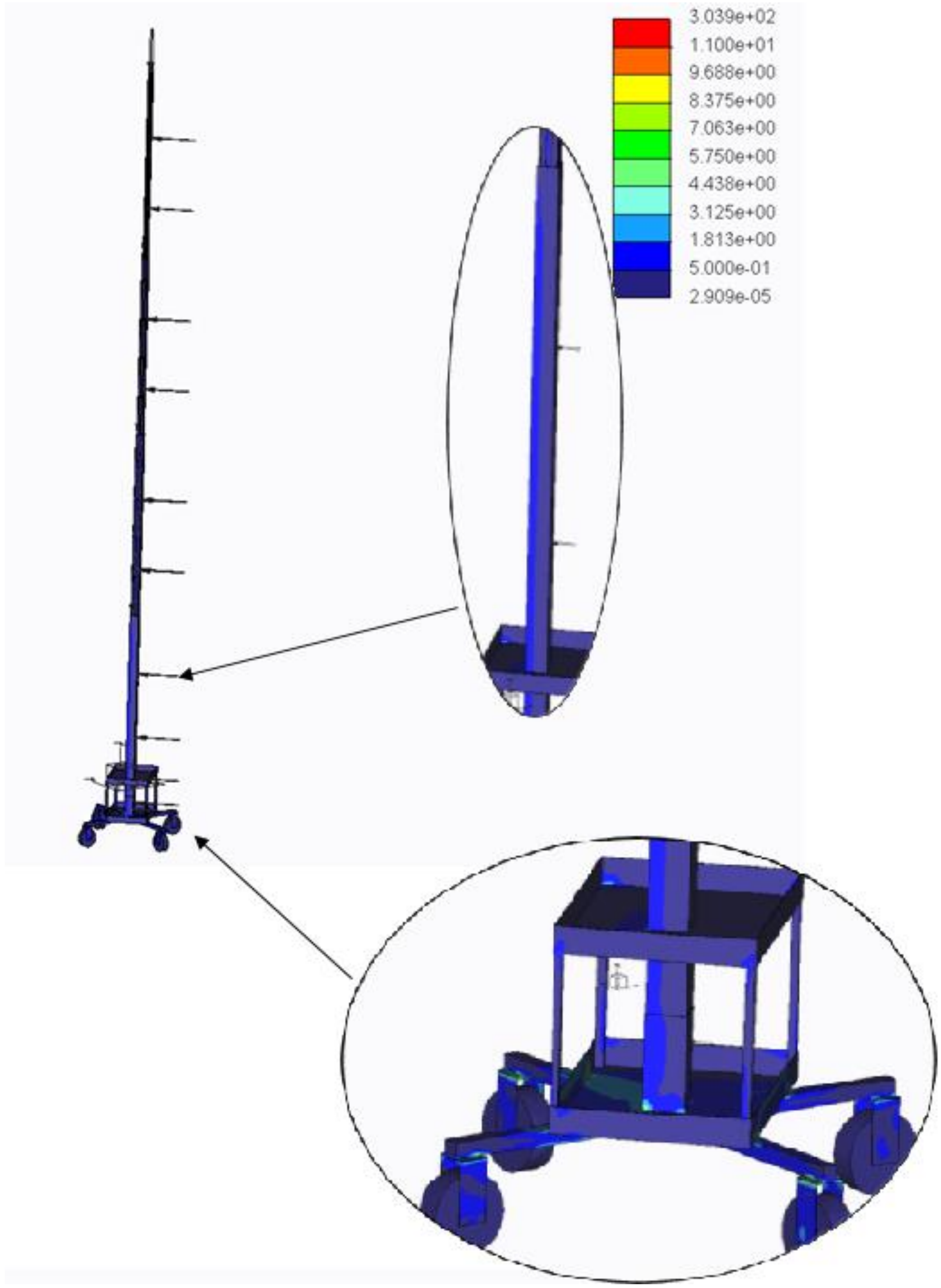

Figure 13 Stress analysis of assembled mechanism

Figure 13 shows that the maximum stress distribution occurs on the bottom shelf of the cart where the crossbar is supported, the telescoping pole rests, and the motor and its components rest. Starting from the bottom of the assembly, the brackets that hold the wheels feel the weight of the crossbar, which is why there is some blue distribution, indicating minimal stress. The connection between the crossbar and the wheels brackets shows a wider variety of stress distribution with green being intermediate stress and red being maximum stress. This maximum stress the cross-bar feels from the cart is due to the weight placed on the end of each bar. As the bars reach the corners of the bottom shelf, a stress is shown due to the weight the cross-bars feel from the cart. Due to the fact that the cart and cross-bar are in compression, because of the weight of the poles and the ground applying an equal but opposite force on the wheels, the bottom shelf of the cart shows a stress distribution that mimics the shape of the cross-bar. This stress distribution can be considered moderate. Another aspect of the stress diagram that is crucial to understand is the telescoping pole. One thing that should be noted is that due to the wind forces, the telescoping pole experiences a minimal amount of stress on the side of the pole that is perpendicular to the force. Lastly, the buffer strips on each of the top three poles cause a minor stress on the poles because they are being pushed onto the poles by the previous poles for a tight fit. Overall the most crucial stress locations are at the connection point of the wheel brackets and the cross bar. The maximum stress felt here is between 9 and 11 MPa which is approximately twice the amount of water pressure coming out of a spray nozzle at a regular car wash [6]. Although this does not cause major concern, this part of the cart will still need to be monitored regularly, as a safety precaution.

5.5.2 Deflection Analysis

The deflection analysis was the last analysis done on the assembly, which is shown in Figure 14.

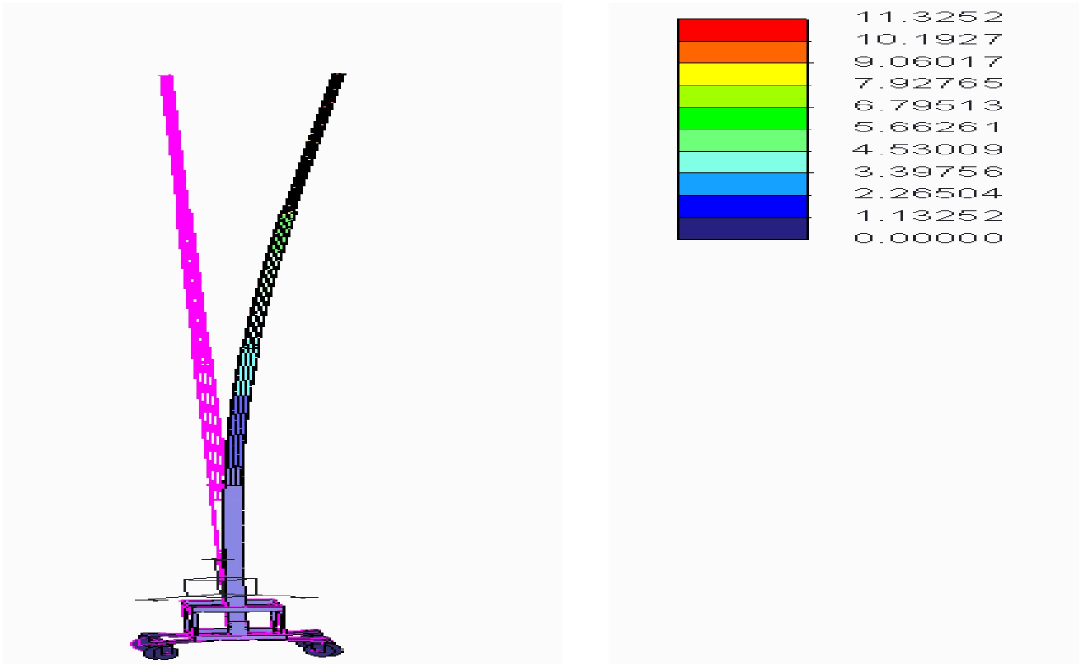

Figure 14 Deflection analysis of assembled mechanism

In Figure 14, measured in millimeters, the maximum deflection of 11.3 mm is shown at the top of the telescoping pole. This maximum deflection occurs due to the lack of stability at the top of the mechanism. More specifically, since there is nothing holding the top of the pole in the upright position, it becomes somewhat flimsy. Since the value of the maximum deflection is about twice the size of an ant, it does not pose any concern, as it is minute compared to the overall height of the poles [7].

5.6 Motor

To reduce the man power and time to harvest the palm fruit, the team has chosen to automate the telescoping mechanism. This will also make the mechanism more marketable than having to manually crank the telescoping pole 40 feet. The mechanical engineers on the team collaborated to calculate the force and torque that the motor would need to supply to the poles. These calculations allow the electrical engineer to choose a motor based on the torque and power ratings. The calculations for force and torque can be seen in Appendix C.

After reviewing these calculations with a technical advisor, a motor was selected. The team decided to go with a winch and motor set by Trakker that has 1 horsepower (HP) [8]. This specific set seen in, **Figure** is capable of pulling up to 907.2 kg (2000 pounds) and will have no problem lifting the telescoping poles. Some commercial benefits to this motor are that it is within the allotted motor budget. This choice includes a handheld switch allowing the user to control the motor from a distance. A technical benefit of this motor is the pole rise time of 3 minutes; this addresses the goal of the machines competitiveness with present harvesting techniques. Other technical benefits are circuit breaker protection and low power consumption. These are all aids that will minimize production cost, increase safety and efficiency. A picture of the Trakker motor is seen in Figure 15.

Figure 15 Electric winch[7]

5.7 Budget

The budget displayed in Table 5 shows a total of $1078.10 was spent on necessary components such as wheels, aluminum square poles, a power source, vinyl tubing and motorized winch. This being said, there is still a large amount of money left in the budget leaving the project in good standing. The remainder of the budget will not be used and can be put towards future modifications.

Table 5: Money spent on this project as of 2/3/15.

Item	**Vendor**	**Price**
Trakker 1 HP Universal Winch	Lowes	$104.26
Never Flat Wheel	Discount Steel	$236.80
Aluminum Square Tube	Grainger	$640.26
Power Source	O'Reilly	$94.99
Vinyl Tubing	Lowes	$1.79
Total		$1078.10

6. Power

6.1 Generator

The palm fruit harvester team, three years ago, purchased a generator to aid in the production of electrical power used in various components of the project. The generator purchased was the SPT TG-1000, capable of generating a maximum of 1000W as seen in Figure 16. This generator is capable of lasting six hours on a full tank (1.2 gallons). The electrical components of the current palm harvester include: electric saw, camera/monitor, car battery, and motorized winch. Since the car battery is used to power the motorized winch, the other components need to obtain power from some other source, in which the generator would be a perfect fit.

Figure 16 Previous year's generator

The generator would not start on initial trial runs therefore maintenance was needed. Fuel/oil mixture was replaced and the generator started up with the choke fully engaged. When the choke was let off, the generator would sputter to a halt. In order to fix this issue, the air filter and carburetor were cleaned. Upon attempting to start the generator back up, the manual start cable snapped, rendering the generator completely useless.

With the generator out of commission, the other components of the palm fruit harvester will need some other means of power. The cutting mechanism will be powered by its own battery pack supplied by the manufacturer and the camera/monitor will be powered by a 12 volt battery from last year's project. The car battery will be solely responsible for powering the motorized winch which drives the telescoping pole up and down.

6.2 Camera

The electrical components are essential to our project. These modules consist of: the camera, monitor, motor, and battery. As for the camera/monitor, they are being reused from last years' design. To assemble and power the camera/monitor there are wires and an eight volt battery to accompany it. Some preliminary testing, as seen in Figure 17, was completed and it was concluded that the wires were damaged. This prompted the electrical engineer to rewire the connection through wire threading and masking with electrical tape. The remaining task was to connect the red (positive) and black (ground) wires to the proper components to accomplish power to the camera and monitor. To receive video input the engineer simply connected the V1 (video-1) cables together, similar to the connections of a DVD player.

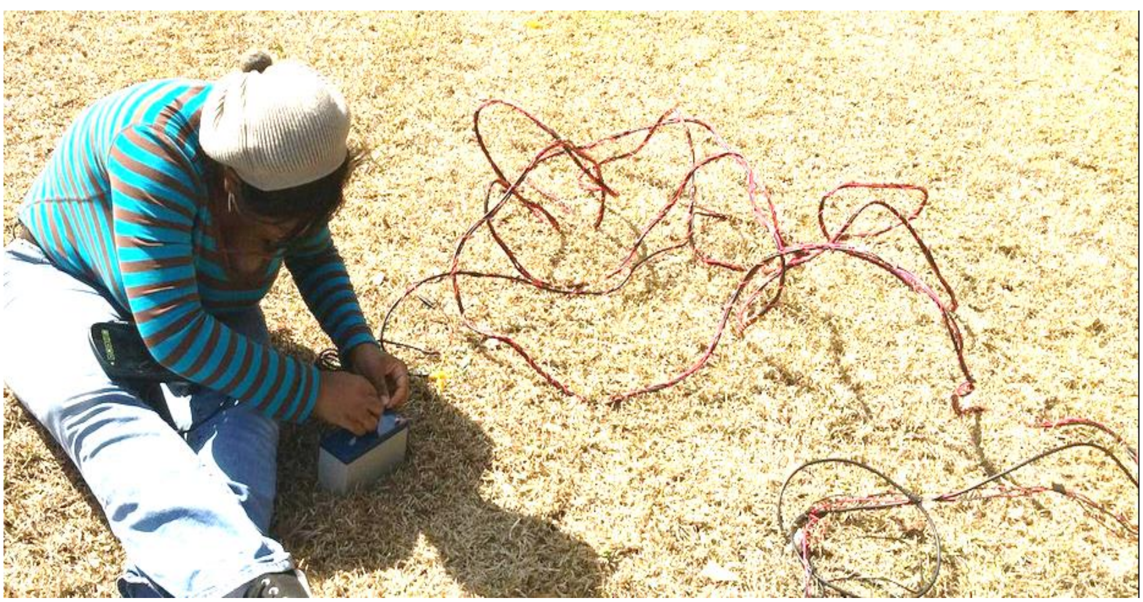

Figure 17 Preliminary testing of the electrical components

6.3 Motor and Battery

The remaining electrical components are the battery and motor. As of Friday February 27, 2015 the office notified our team that the components have just been ordered. We can begin testing and making proper adjustments once these parts arrive.

7. Mechanical Systems

7.1 Wheels

The Never Flat Wheels made of polyurethane arrived on February 3rd, 2015. The old, Pneumatic Swivel Caster wheels were replaced with the new wheels, which made the cart easier and safer to maneuver. Figure 18 shows the old wheels compared to the new ones.

Figure 18 Comparison of the old (left) and new (right) wheels

After installing the new wheels, the cart was easier to push, as the wheels were no longer deflated and cracked. The cart was pushed throughout HPMI on concrete, then on asphalt on the roadway, and on the grass/dirt in front of HPMI. This is shown in Figure 19 below.

Figure 19 Cart being pushed on different terrain

When turning the cart, the old wheels would get stuck and the operator would need to kick the wheels in order for them to realign, whereas with the new wheels this is not an issue. So far the wheels have met the team's expectations of moving in a smooth manner.

7.2 Telescoping Poles

7.2.1 Pulley System

The pulley system being implemented into the current design is very similar to last year's pulley design therefore all of the pulleys and bolts have been reused in order to save the team time and money. To start off, the entire telescoping pole mechanism from last year was disassembled in order to conserve all of the pulleys, corner bracing, and nuts/bolts. Once this process was completed, the mounting of the pulleys could begin on the new square cross-sectioned aluminum.

Holes were drilled out of the aluminum in order to mount the corner brackets that hold the pulleys in place as seen in Figure 20. This process was completed on the three inner segments of the telescoping pole.

Figure 20 Thomas drilling holes in the poles to fit the brackets

7.2.2 Buffer Strips

Last year's project used Teflon stripping in order to prevent the circular cross-sectioned PVC from rotating within each other. This material will be reused in order to stabilize and prevent excess friction within the aluminum telescoping poles. Since there is a quarter-inch gap between the first and second segments on all sides, there needs to be something taking up this space in order for the intersections between the poles to be stable. This is where the buffer stripping will come into play. The material will be cut in short quarter-inch thick strips and mounted to the inside face of the first segment. This process will be repeated for the other segments.

Cutting the buffer strips to the exact width of the gaps will create unnecessary friction in the telescoping pole, making the winch work harder than it needs to, thus draining the car battery quicker. In order to alleviate some of this friction, a small layer of the buffer stripping will be sanded off allowing for an easier overall telescoping process.

In order to mount the buffer stripping to the inside face of the segments, the nuts were recessed into the Teflon stripping and the nuts were cut to the exact size needed. The recessed nuts within the buffer stripping can be seen in Figure 21. Performing this process will prevent metal to metal contact and allow the telescoping poles to only come into contact with the Teflon stripping.

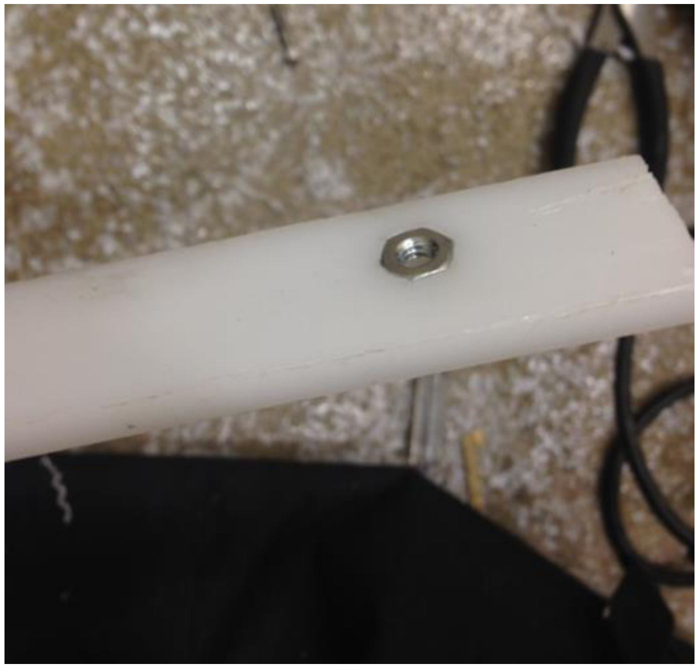

Figure 21 Buffer strip with nuts recessed inside

7.3 Lowering the Center of Gravity

Lowering the center of gravity of the poles allows for increased stability. The circular alignment block on the top shelf of the cart was removed, allowing a 5x5 segment to be mapped out in its place. Using a jigsaw, the square was removed from the top level of the cart. The sequence of events to lower the center of gravity is shown in Figure 22 below.

Figure 22 Process of removing material from the top shelf of the cart

In order to fit the poles into the square cut out, the edges of the square were sanded to allow extra room for the poles to slide in smoothly.

8. Remaining Work

8.1 Power Components

The complication that is presently at hand is the monitor is displaying "NO SIGNAL". It is not clear at this moment how to fix this because we are not able to determine if it is a user error or malfunctioning equipment. A meeting is scheduled for Monday, March 2nd, 2015 with a technical advisor to determine how we can repair and move forward with this portion of the project.

The motor and battery wiring will be similar if not identical to the wiring of the cutting mechanism to its power source. Further investigation and testing will be done when these devices arrive.

8.2 Pulley System

One of the challenges encountered while operating last year's mechanism was that the cables would not stay in the grooves of the pulleys. This caused the pulley system to fail multiple times during the process of assembly. This year, the team decided to encase the pulleys in order to prevent the cables from slipping off while assembling the mechanism. By attaching a metal piece with an arc like cross-section to the top of the pulley, the cable will maintain alignment with the pulley.

8.3 Weather Proofing

One of the main concerns of this mechanism is the environmental obstacles it will face. The main producers of palm oil include Indonesia and Malaysia, both of which exhibit tropical humid climates. Moisture is regularly encountered out on the oil palm plantations. This climate is a factor that must be accounted for. Wires used to power both the camera and the cutting mechanism will be placed inside the telescoping poles. Not only will the wires be inside the poles, but they will also be inside plastic tubing (shown in Figure 23) to minimize the chance of water intrusion [9].

Figure 23 PVC clear vinyl tubing [9]

8.4 Mounting the Poles

A square cross-section has been cut out of the top of the cart allowing the aluminum poles to fit into the section and rest on the lower shelf of the cart. The poles will be mounted on the bottom level to increase the stability of the cart during assembly process. The circular alignment block, used in the previous mechanism, will be cut into a square cross-section allowing it to fit into the bottom of the lower section of the telescoping pole. This alignment block will prevent the telescoping pole from shifting relative to the cart.

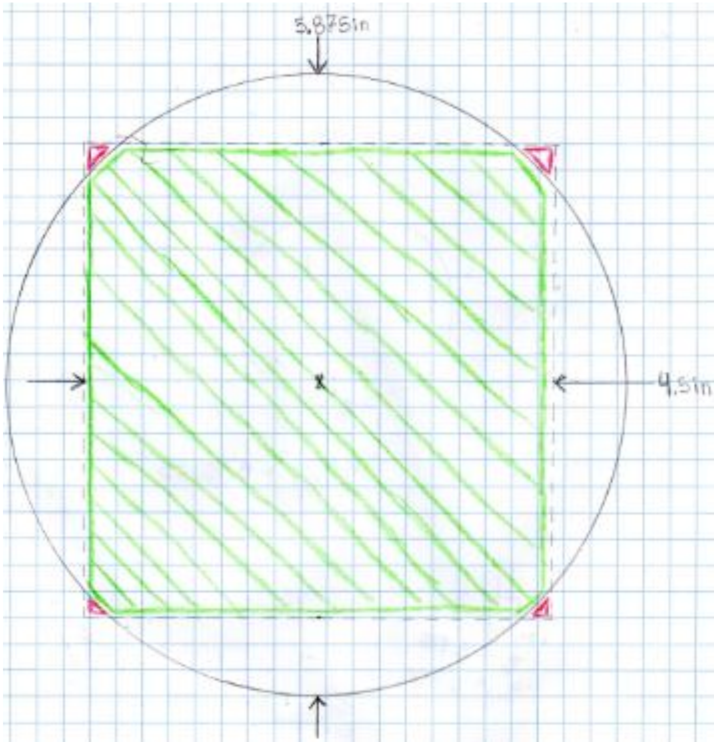

Figure 24 Cutting space of the alignment block

Figure 24 shows where the cuts will be made in order to fit into the inside dimension of the telescoping pole segment. Currently the alignment block is 5.875in in diameter and it will need to be cut into a square cross-section with 4.5in on each side. The cuts will be made along the dotted lines and the green portion will be the portion used. The excess material, colored in red, will make for rounded edges on the alignment block. The rounded edges will not be an issue because it will allow the telescoping pole to be easily removed for maintenance purposes.

In the event of malfunction, the telescoping poles will be easily removable by simply lifting the poles out of the cart. Once maintenance is completed, the poles can be reinserted back into the cart without the use of complex tools.

8.5 Encasing Lower Section

When the final product is in place, all the extra components, such as the battery and motor will be located on the bottom section of the cart. This bottom section also has the aluminum poles resting on the bottom shelf of the cart. In order to keep everything in place, the team has decided that, if time and budget allow, the bottom section will be encased with aluminum sheets. This will ultimately make the final product more aesthetically pleasing by shielding all the extra components from visibility. It is understood these components will have to be handled and removed for maintenance, which is why the team plans to make the sheets removable when necessary. This is only something that will be implemented once everything else on the project is completed and time and budget allows it.

8.6 Testing

Once everything is assembled, the functionality of the mechanism will be tested. The pulley system used to telescope the poles will be tested to make sure the cables remain in alignment with the pulley, the telescoping process allows for maximum height to be reached, and that the brackets are able to withstand the load applied. After this pulley system passes the testing phase, then it is time to test the pulley system that rotates the cutting mechanism.

During the testing phase, the preexisting cutting mechanism will be tested. First it will be tested to make sure that it functions properly. Once it passes this test, the team will acquire permission to remove a limb from a tree near the engineering school. The cutting mechanism will then be mounted on the Lazy Susan (shown in Figure 25); which was previously used.

Figure 25 Lazy Susan mechanism

The wiring will be threaded inside the poles and connected to the respective power source, which is located on the bottom shelf of the cart.

Once our motor arrives, it will be hooked up to the car battery and tested to make sure it produces the desired results, automating the telescoping poles in a timely fashion. This motor will be housed on the bottom shelf of the cart along with the battery.

9. Gantt Chart

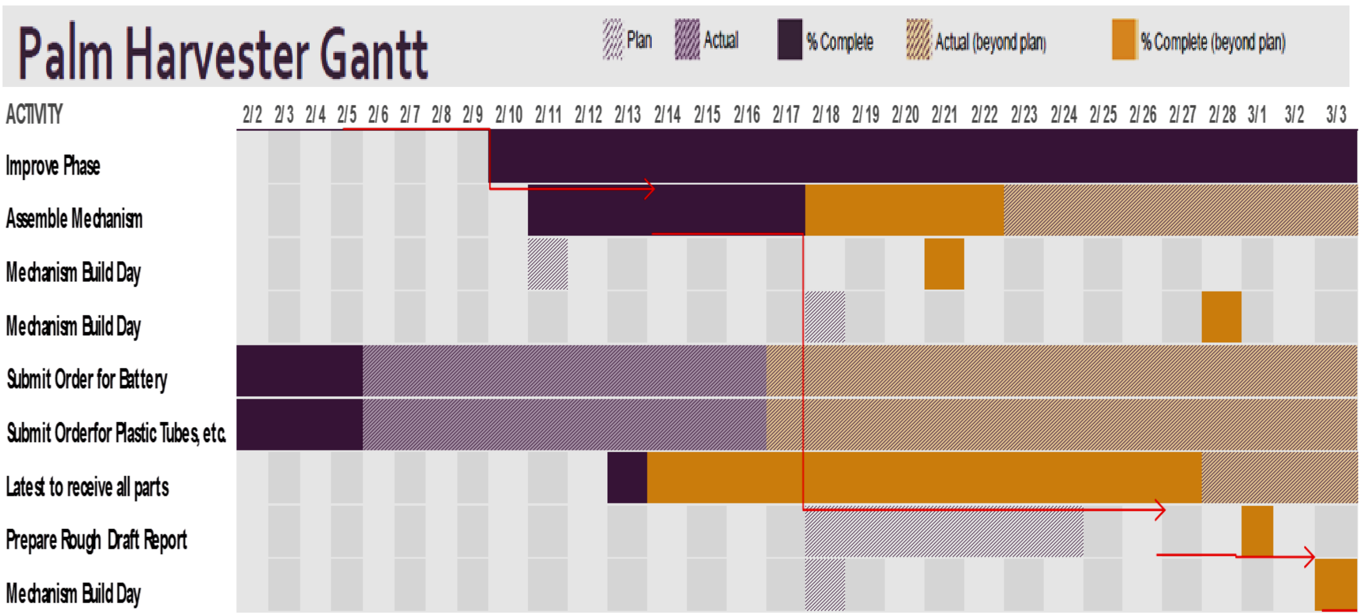

Figure 26 Gantt Chart of the Improve Phase

The Gantt Chart for the current phase is shown in Figure 26 above.As of March 3rd, 2015, the last day of the improve phase building of the mechanism is still underway. Due to the late arrival of parts and conflicting team member schedules the assembly of the mechanism is going slower than expected. The orders for the battery and motor were submitted on February 2nd, 2015 however were not officially submitted by administration until February 27th, 2015. Since the other components have not been completely assembled, this delay has not directly affected the timeline of the project. We anticipate our mechanism to be built by the end of the Control Phase.

10. Conclusion

The palm oil industry is growing quickly, therefore new technologies must be implemented in order to keep up with the demand. The team was tasked with analyzing and improving upon a palm fruit harvester that was designed and built by the 2014 senior design team. Ideas were taken to the drawing board and analyzed, improvements were made in order to increase the efficiency of the palm fruit harvester. The define phase allowed the team to plan an early list of improvements to be made for the cart. The measure phase pushed the team to pinpoint the exact areas that will be improved using data gathered from force and assembly simulation. In the analyze phase, all the planning was finalized and the required parts were ordered. During the improvement phase, the team was able to assemble the telescoping pole and modify the cart using the parts from the previous year's mechanism. The poles were replaced and the pulleys were attached to the new poles. The center of gravity of the mechanism was lowered increasing cart stability. All the remaining work will be completed in the control phase.

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Appendix

A. House of Quality Calculations

$$Total\ Index = 7.0 + 8.0 + 8.0 + 8.0 + 8.0 + 9.0 + 9.0 + 9.0 + 10.0 = 86$$

$$Relative\ weight\ of\ water\ proof = \frac{water\ proof\ index}{Total\ index} = \frac{7.0}{86} = 0.081 = 8.1\ \%$$

$$Weight/Importance = \sum indices\ of\ relative\ weight\ on\ the\ left\ of\ HOQ \times$$

$$relationships\ between\ technical\ and\ customer\ requirements$$

$$For\ the\ Weight\ of\ materials$$

$$= 9.3 \times 3 + 9.3 \times 9 + 9.3 \times 3 + 9.3 \times 1 + 10.5 \times 9 + 10.5 \times 1$$

$$+ 10.5 \times 9 + 11.6 \times 3 + 11.6 \times 3 = 417.9$$

B. Drag Force Calculations

Square Cross Section:

Height:

$h := 10ft$

Side measurement:

$s1 := 6in$

$s2 := 5.75in$

$s3 := 5.5in$

$s4 := 5.25in$

Density of Air:

$p := 1.2922 \frac{kg}{m^3}$

Average wind speed:

$v := 3.8 \frac{m}{s}$

Drag Coefficient:

$Cd := 1.05$

Surface Area:

$A1 := s1 \cdot h = 0.465 m^2$

$A2 := s2 \cdot h = 0.445 m^2$

$A3 := s3 \cdot h = 0.426 m^2$

$A4 := s4 \cdot h = 0.406 m^2$

Drag Force:

$Fd1 := 0.5 \cdot p \cdot v^2 \cdot Cd \cdot A1 = 4.55 N$

$Fd2 := 0.5 \cdot p \cdot v^2 \cdot Cd \cdot A2 = 4.361 N$

$Fd3 := 0.5 \cdot p \cdot v^2 \cdot Cd \cdot A3 = 4.171 N$

$Fd4 := 0.5 \cdot p \cdot v^2 \cdot Cd \cdot A4 = 3.982 N$

Circular Cross Section:

Drag Coefficient:

$Cd := 1$

Diameter:

$d1 := 6in$

$d2 := 5.75in$

$d3 := 5.5in$

$d4 := 5.25in$

Radius:

$r1 := \frac{d1}{2} = 0.076 m$

$r2 := \frac{d2}{2} = 0.073 m$

$r3 := \frac{d3}{2} = 0.07 m$

$r4 := \frac{d4}{2} = 0.067 m$

Surface Area:

$A1 := \pi \cdot r1 \cdot h = 0.73 m^2$

$A2 := \pi \cdot r2 \cdot h = 0.699 m^2$

$A3 := \pi \cdot r3 \cdot h = 0.669 m^2$

$A4 := \pi \cdot r4 \cdot h = 0.638 m^2$

Drag Forces:

$Fd1 := 0.5 \cdot p \cdot v^2 \cdot Cd \cdot A1 = 6.807 N$

$Fd2 := 0.5 \cdot p \cdot v^2 \cdot Cd \cdot A2 = 6.524 N$

$Fd3 := 0.5 \cdot p \cdot v^2 \cdot Cd \cdot A3 = 6.24 N$

$Fd4 := 0.5 \cdot p \cdot v^2 \cdot Cd \cdot A4 = 5.957 N$

C. Torque Calculations

Weight of the top three poles (without the cutting mechanism)

$W := 69.28\,lbf$
$W = 308.173\,N$

Weight of the tope three poles (with the cutting mechanism)
$Wc := 109.28\,lbf$

$Wc = 486.102\,N$

The maximum weight force of the top three poles with the cutting mechanism (rounded up to take into account the friction of the pulleys)

$F := 500N$

The radius of rotation
$r := 3in$
$r = 0.076\,m$

Maximum torque required for the motor

$T := F \cdot r$

$T = 38.1 \cdot N \cdot m$