FAMU-FSU COLLEGE OF ENGINEERING

Control Phase – Palm Harvester Project

A report submitted to Dr. Okenwa Okoli
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This report is the last of five progress reports. It displays the testing and analysis of the improved project following the Six Sigma methodology of "Define, Measure, Analyze, Improve, Control" (DMAIC). The Palm Harvester team will provide a full understanding of the assembly as well as the status and the remaining work on the testing and analysis of the mechanism.

Table of Contents

List of Figures

List of Tables

List of Equations

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 control phase consisted of finishing the assembly process. It was also the start of testing and analysis. Testing of the pulley system proved that the mechanism was able to attain its maximum height of 35 feet, without any trouble. The camera and cutting mechanism, as well as the maneuverability of the assembly were tested. Although the maneuverability of the cart was successful, the camera was proven to be out of commission and the cutting mechanism was not able to cut through a tree branch due to a low battery. A time analysis was done, comparing the assembly, disassembly, rise and fall times of the old and new mechanism. This analysis showed that the new mechanism saved approximately 5 minutes and 32 seconds to setup. Since the testing and analysis of the cutting mechanism and battery was not completed, the team will continue testing before the final presentation.

1. Introduction

Oil palms are oil-producing trees that grow in numerous countries including: Malaysia, Indonesia, and Colombia. After processing, the palm fruit becomes a natural source of vegetable oil used for cooking, lipstick, ice cream, and soaps. These trees can grow up to 12m, or 39ft, on plantations; accordingly, a palm harvester that can extend 35ft will reach a vast majority of oil palms on the plantation. The current harvesting methods are dangerous and inefficient making the opportunity to enter this market very promising. That being said, there is a need for a safe and efficient solution for harvesting the palm fruit. Along with the need for a safe and efficient device, the project sponsor desires a completely well-designed device that harvests the fruit of the palm oil tree. During the Define and Measure phases the client requests were first identified and prioritized using a house of quality. In addition, a website was made to record progress on the project along Gantt charts to keep the project on track. During the Measure and Analyze Phase, the procurement process began. Throughout these phases the group also took a closer look at the design and performance of the device. The improvements were a tedious process but all in line with the goals of safety and efficiency. This report covers the Control Phase, in which the palm harvester was assembled and tested. The resulting report will outline the recent tests that have been conducted to confirm the operation of the 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].

(a) **(b)**

Figure 1. (a) Worker climbing tree (b) Worker cutting palm fruit elongated sickle blade [2,3]

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.

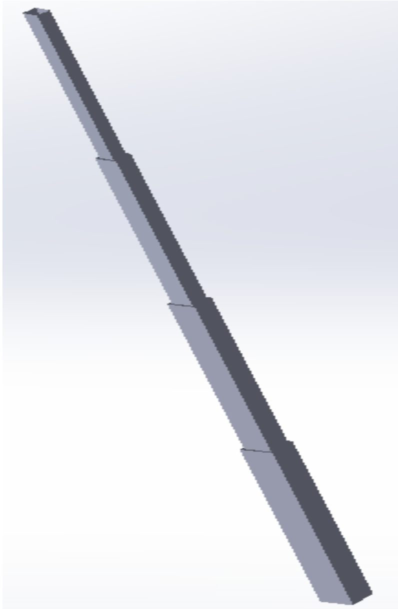
2.1.1 Background and History

Oil palm trees originated in the tropical region of West Africa [1]. 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 [1]. 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 [1]. The oil palm trees can grow up to forty feet and grow palm fruits in bunches that could weigh up to 55 lbs [1].

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 a plantation. A motor will be added to the cart, resulting 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.

(a)



(b)

Figure 2. (a) Previous year's pole (b) Design concept for this year's pole

2.1.3 Business Case

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, with a way to safely and efficiently harvest the fruit the industry would benefit greatly.

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 an edge over 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.

A Threat & Opportunity Matrix was developed 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	• Laborers will continue to sustain injuries using current harvesting methods	• Less workers will be injured • Opportunity for sponsor to patent design
Long Term	• Oil palm industry will not grow • Harvesting efficiency will not increase in order keep up with rising demands	• Abundance of palm oil due to automation of process • Device will become a necessity for palm plantations

If the palm fruit harvester is not completed, then the oil palm industry will not grow along with the rising demand of palm oil. In order to keep up with this demand, new technology must be implemented in order to fix the adherent issues associated with the harvesting of palm fruit. The current harvesting methods put workers in unsafe working conditions such as climbing tall oil palm trees with saw blades as well the risk of falling from the tree. The addition of the palm fruit harvester into the oil palm industry will limit the amount of injuries by preventing the workers from climbing the oil palm trees. If this product is entered into the palm oil market, then less injuries will occur to the workers, allowing the plantation to keep up with the international demand of products derived from palm oil. Opportunity for patenting the product will be a future option, allowing the mechanism to be mass produced by sponsor for oil palm plantations to use in the everyday harvesting process. 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 circular cross-section polyvinyl chloride (PVC) telescoping pole with square cross-section 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, and replacing the wheels with all-terrain, never flat tires.

2.2.2 Assumptions & Constraints

In order to complete this project, a variety of assumptions have been made. Since the mechanism is unable to be tested in Malaysia, the country that it will be used in, the team must assume environmental and working conditions found on the web are accurate. In addition to this, there are no oil palm trees in Tallahassee, Florida so the parameters of the average height, weight of the fruit bunches, and other key factors were found in dated statistical data as shown in Table 2. It is also assumed that the workers operate on an 8 hour work day and one to two workers are needed to operate the mechanism. During the harvesting process the mechanism will operate on horizontal ground in order to maintain proper stability. It is assumed that by successfully cutting the branch of a tree at the average height of an oil palm tree, the mechanism is successful.

Table 2. Oil palm trees statistical data [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
Average Maximum Growth Height	40 ft
Diameter	0.75 – 2.5 ft
Amount of Sunlight	4-5 hours/day
Amount of Rainfall	Year-round

The main constraints are the height the telescoping pole can reach and the size of the overall mechanism. The height of the entire mechanism extended is based upon the average height of an oil palm tree. Due to this, the height of the mechanism cannot be less than the average height of an oil palm tree as it would not be able to reach all the fruit bunches on the tree. In addition to this, the overall height of the mechanism should not be much greater than the average height of an oil palm tree as the mechanism will decrease in stability with a larger deflection and will be harder to store. The size of the overall mechanism is crucial, as it needs to be stored and have the ability to move between trees.

2.2.3 Deliverables

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

- Functioning Palm Harvester
- Operation Manual
- End-of-Phase Report
- Technical Poster

2.2.4 Milestones

During each phase of the palm harvester project, several milestones must be completed to stay on track and in order to successfully complete the goal of improving the palm harvester mechanism. The milestones for each phase are as follows:

Define Phase:

- Visit Prototype: Assemble and compile 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 method for automation of the mechanism.

Analyze Phase:

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

Improve Phase:

- Assemble Mechanism: Physically assemble the final palm harvester mechanism.
- Meet with Electrical & Mechanical Advisors: To assess any issues that have arose.

Control Phase:

- Finalize Building: Finish building the remainder of the mechanism.
- Meet with Project Sponsor: To determine if the project is still within the proper scope.
- Test Mechanism: Operate and observe final mechanism.

The Gantt chart is shown in Figure 3, below.

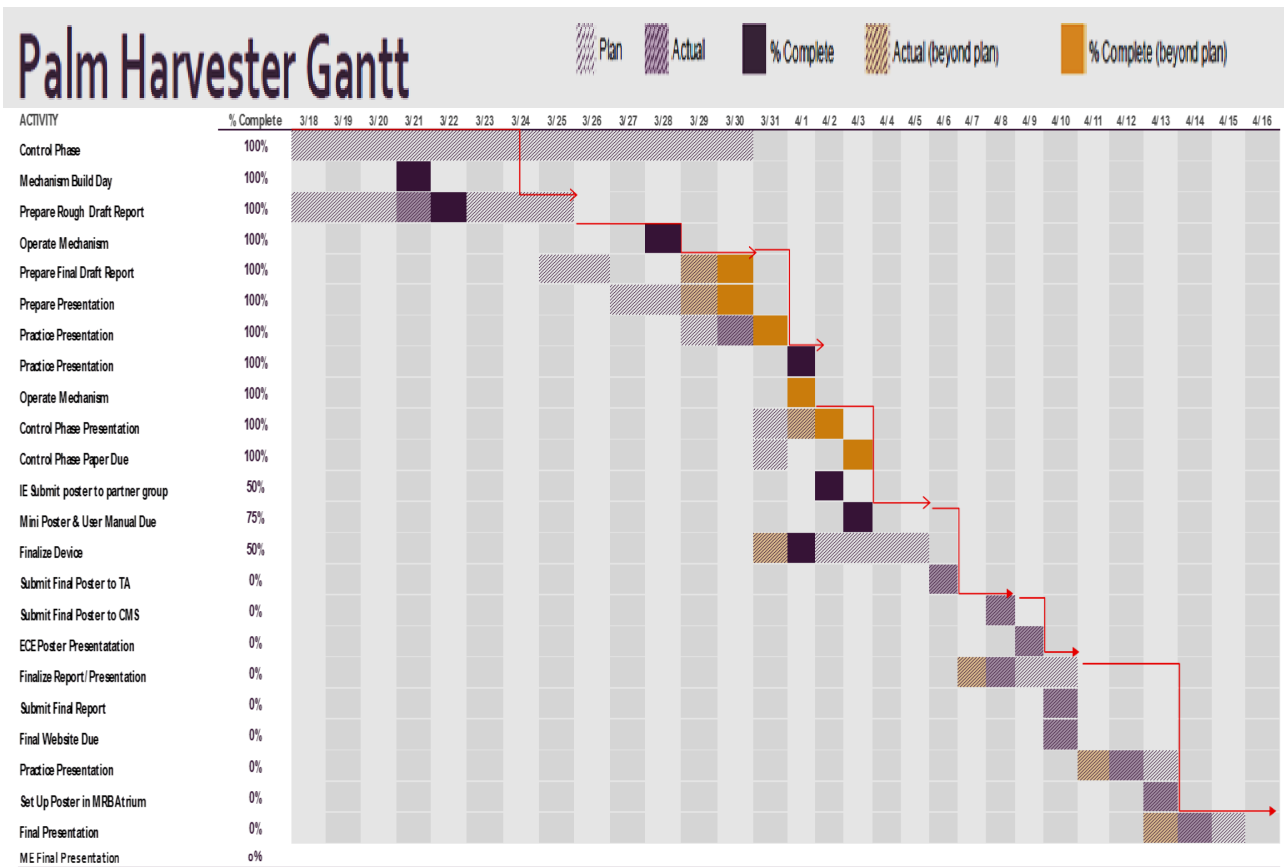


Figure 3. Gantt chart

This portion of the Gantt chart reflects the Control Phase until the completion of the final presentation. During this time the Palm Harvester was behind in finalizing the assembly of the mechanism however able to operate the mechanism at least twice before the final paper and presentation. After the operation of the mechanism the conclusion of the project will consist of prepare the poster, website, and final report and presentation for our sponsors, stakeholders, and peers.

2.3 Budget / Bill of Materials

Table 3 shows all the items, along with their description and company that have been purchased with the allotted $2,500 budget.

Table 3. Purchased items with the budget

Item	**Company**	**Description**	**Cost**
Wheels	Grainger	(4) Never Flat Wheel, 10-1/4 in, 350lb	$213.12
Motor	Lowes	Trakker 1-HP 2,000-lb Universal Winch	$104.26
Aluminum Pole	Discount Steel	6063 AL TUBE 5 X 5 X ¼ X 120”	$225.60
Aluminum Pole	Discount Steel	6063 AL TUBE 4 X 4 X 1/8 X 120”	$85.77
Aluminum Pole	Discount Steel	6063 AL TUBE 3 X 3 X 1/8 X 120”	$61.21
Aluminum Pole	Discount Steel	6063 AL TUBE 3 X 3 X 1/8 X 120”	$41.66
Shipping	Discount Steel	-	$225.00
Battery	O’Reilly Auto Parts	12 V Super Start Marine- Deep Cycle	$94.99
			Total : $1,051.61

The wheels purchased are called the “Never Flat Wheel” which are made of solid polyurethane, meaning if ever punctured, the wheels will not deflate. Each wheel has a 10-1/4 in diameter which fits perfectly in the brackets mounted on the legs of the cart. It should be noted that the wheels can each carry a maximum load of 350 lbs. All four wheels combined can carry a load of 1,400 lbs, which is significantly more than the weight of the entire system (253.92 lbs). The motor purchased was a Trakker Universal Winch which was connected to the first segment of the pulley system allowing the telescoping process to occur at the push of a button. Each of the four aluminum 6063 telescoping poles are listed individually in the table in order show that they each have different cross-sectional dimensions and costs. Since the poles had to be shipped from Minnesota, a shipping cost was added, as shown on Table. Lastly, the battery purchased was the Super Start Marine-Deep Cycle which is typically used for large scale purposes, such as travel trailers, thus providing enough amperes to power the motor. Overall $1,051.61 was used of the total $2,500 budget. The pie chart in Figure 4 shows the percentage of each component with respect to the overall budget.

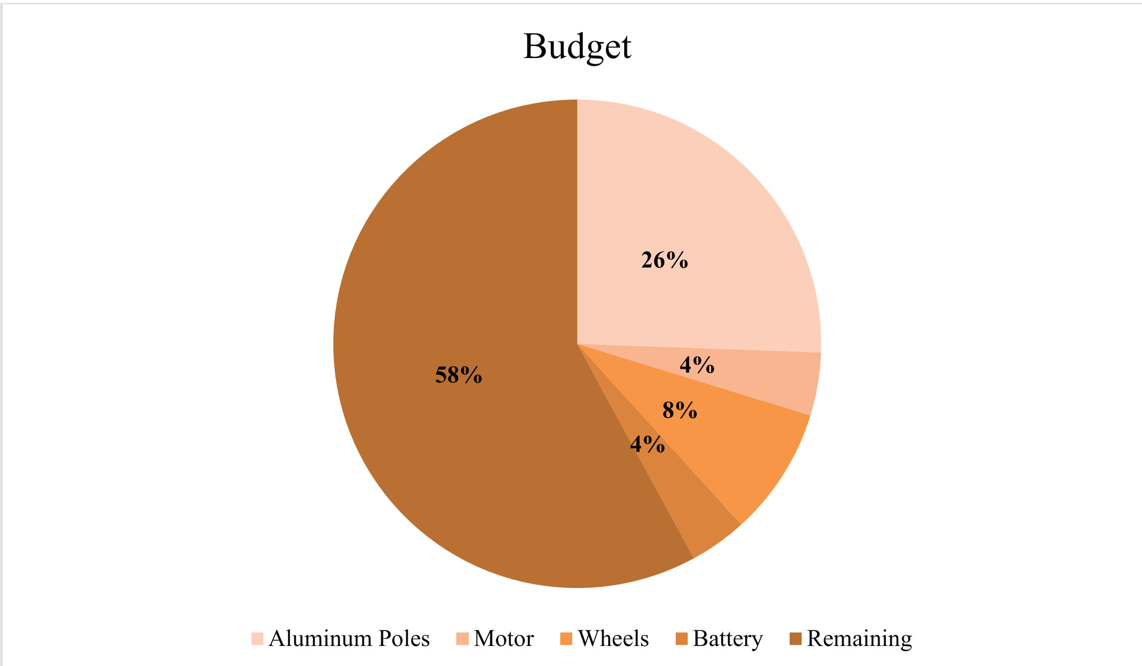


Figure 4. Pie of chart of budget usage

From Figure 4 it can be seen that 58% of the total budget still remains. Since all the parts have been purchased, the remainder of the money will not be used. It is important to note that the aluminum poles (including the shipping) take up more than a quarter of the budget, this is due to the fact they each are 10ft long and require a large amount of material to produce. Another factor is that since they had to be shipped to HPMI they incurred a large shipping cost of $225.00. The motor, battery, and wheels combined take up 16% of the budget, which is not very significant compared to that of the aluminum poles. It is important to note that many of the old parts have been reused such as the cart, pulleys, pulley cables, cutting mechanism, lazy susan, and camera thus saving the project a lot of money.

Table 4 shows the bill of materials for the mechanism, which includes all the parts reused from the previous year’s mechanism.

Table 4. Bill of materials

Component	Description	Quantity
Cart		
Pneumatic Caster	Fits 10.25" diameter wheels	2
Pneumatic Swivel Caster	Fits 10.25" diameter wheels	2
Perforated Tube	1 ½"x1 ½"x6'	1
Perforated Tube	1 ¾"x1 ¾"x6'	1
Edsal Service Cart	Steel, 24"x36"x32"	1
Square Tube	Aluminum, 1"x1",6', 1/8" thick	1
Corner Bracket	Zinc-Plated Steel, 3"	16
Motorized Winch	Tracker, 2000lb, 1-Hp	1
Battery	Super Start Marine	1
Telescoping Pole		
Pole Pulley	2" OD	3
Wire Rope	1/8"x100'	1
Oval Sleeve	-	50 pack
Stop Sleeve	-	50 pack
Angle Bracket	2" steel	4
SS Bolt	10-24x1"	50 pack
Washer	#10	50 pack
Nut	10-24	50 pack
HDPE Rod	¼"x1"	24
HDPE Rod	1"x1"x4'	1
Aluminum Tube	AL-6063 5"x5"x1/4"x10'	1
Aluminum Tube	AL-6063 4"x4"x1/8"x10'	1
Aluminum Tube	AL-6063 3"x3"x1/8"x10'	1
Aluminum Tube	AL-6063 2"x2"x1/8"x10'	1
Cutting Mechanism		
Aluminum Tube	AL-6061 1"x1"x1/8"x6'	1
Locking Shoulder Screw	10-24, 1 ¼" long	1
Turntable	Galvanized, 6.06"x6.06"	1
Pole Saw	Black and Decker	1
AL Plate	¼"x12"x1'	2
AL Bar	AL 6061, 2"x2"x1'	1
Pole Pulley	2" OD	4
Corner Bracket	Zinc-Plated Steel, 3"	6
Corner Bracket	Zinc-Plated Steel, 4"	4
Camera	Pyle PLCM7200	1

3. Defining Customer & Technical Requirements

In order to address the customer requirements, a House of Quality (HOQ), shown in Figure 5, was created.

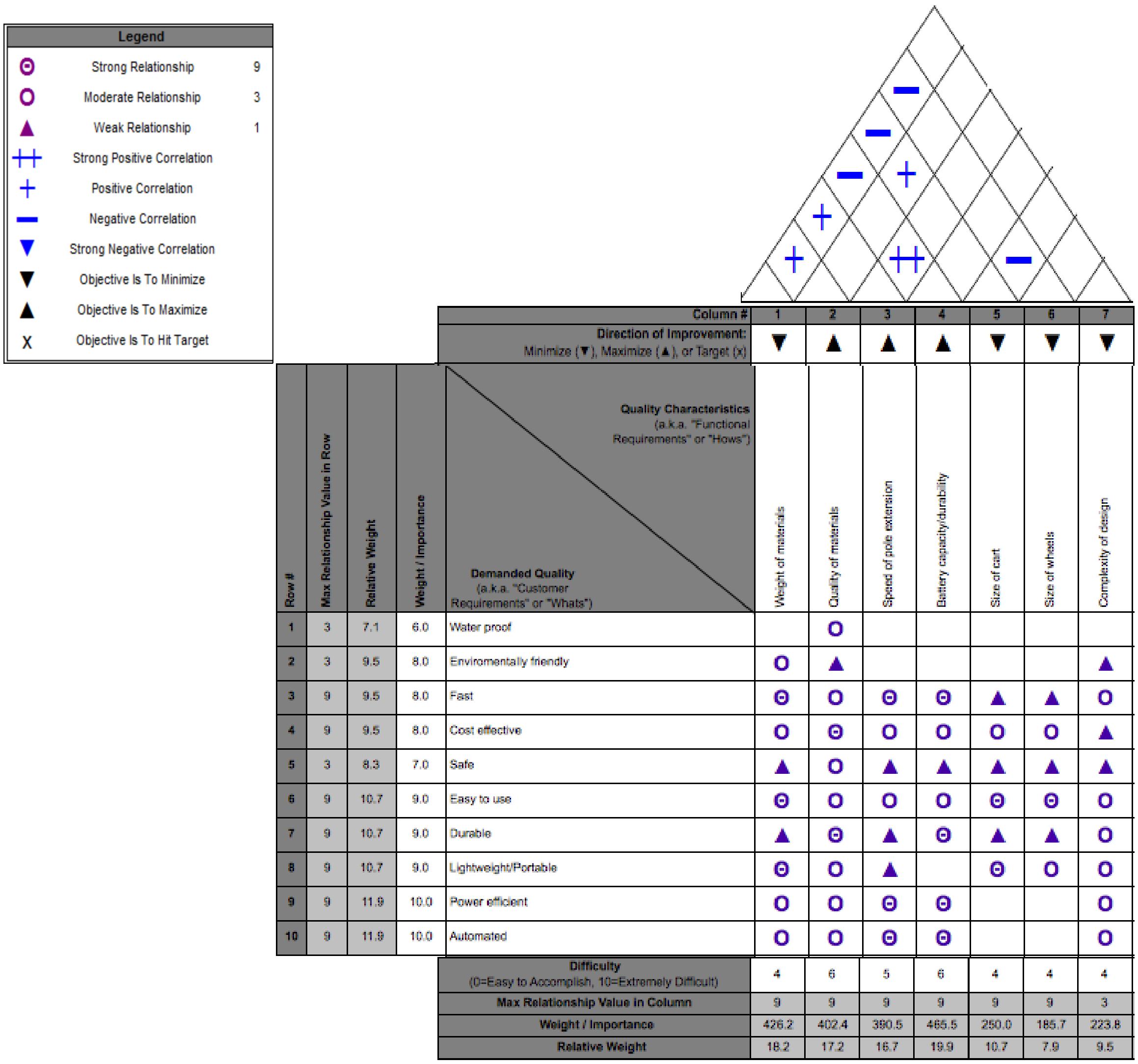


Figure 5. House of quality

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 5. After brainstorming with the team, a scale from 1 to 10 was created in order rank the customer requirements, with 10 being the most important and 1 the least important.

Table 5. 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
Cost effective	8.0
Fast	8.0
Environmentally friendly	8.0
Safe	7.0
Water proof	6.0

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 with an average distance of nine feet between the trees [2]. The cart should be compact because it will be difficult to transport and store if it is not compact. The wheels need to be sturdy enough to allow for stability and maneuverability of the cart. When the initial push force is applied, the contact between the tires and ground 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 84. For example, waterproof has a customer rating index of 6.0, dividing 6.0 by 84 will give 7.1%. 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 9.5, so multiplying 3 and 9.5 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 compared the proposed improvements against the previous year's device. This test proved that the key areas of improvement were essential to having a more effective and 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 as well as the stress experienced by the telescoping pole.

When the project began, the team agreed that an improvement to the process of assembling and disassembling of the cart was necessary. The excessive time consumed putting the palm harvester together is something that is 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 6 and the times are recorded in Table 6. It was concluded that automation will drastically cut this assembly time, as well as make the process smoother and safer.

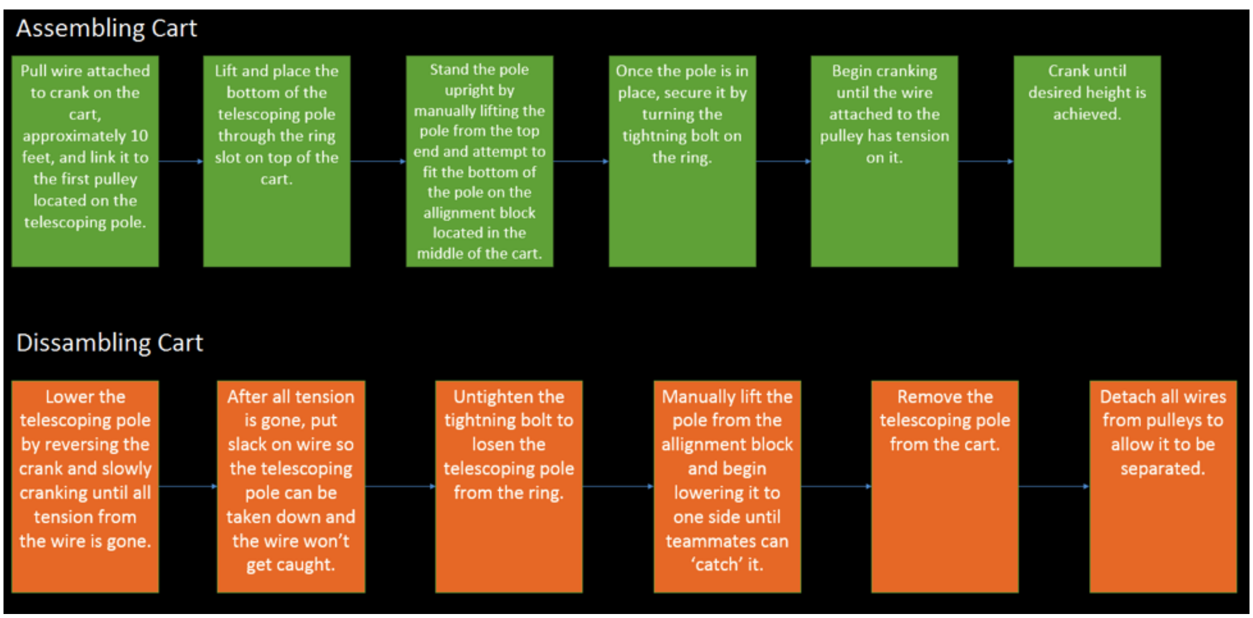


Figure 6. Steps to assemble and disassemble cart

Table 6. 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 circular cross-sectional to square-cross sectional. The material of the pole is being changed from PVC/steel to Aluminum 6063. 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 however this idea was changed in the Analyze Phase to an external pulley system. A stress analysis for each telescoping pole was performed using PTC 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 7. The PVC pole had stress values that ranged from 3.2 x 10-4 MPa to 113.76 MPa while the aluminum cross section's stress ranged from 4.8 x 10-4 MPa to 28.45 MPa, therefore making the aluminum cross sections a better option.

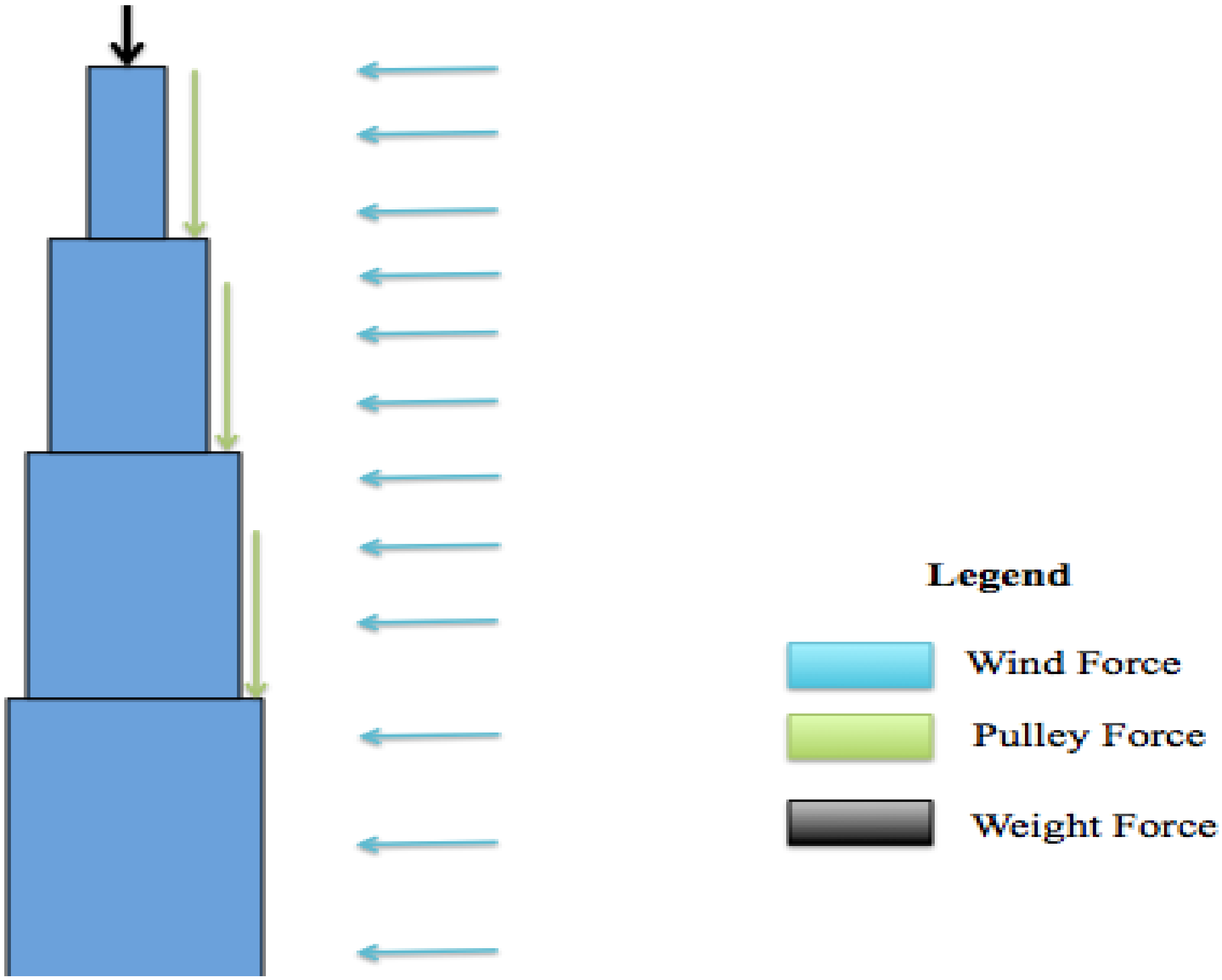


Figure 7. Forces acting on the telescoping pole

Overall, the Measure Phase allowed 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 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, decreasing 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 the material's brittle nature. After analysis the team decided to order four 3.05m (10ft) tall poles with cross sectional dimensions of 0.15m x 0.15m, 0.13m x 0.13m, 0.10m x 0.10m, 0.08m x 0.08m (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 previously used PCV poles and many parts can be reused to reassemble the pulley system, saving time and money. Before ordering the poles, a final analysis was completed to make sure the poles were exactly what was needed with 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.

$$\sigma = \frac{F}{A} \tag{1}$$

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.

$$\tau = F \times d \tag{2}$$

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 for smaller stress concentrations as well as, enhancing portability, and decreasing overall cost.

5.2 Wheels

The previous year’s palm fruit harvester utilized 0.25 m (10”) pneumatic swivel castor wheels, shown in Figure 8.

Figure 8. Previous year's deflated 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 9.

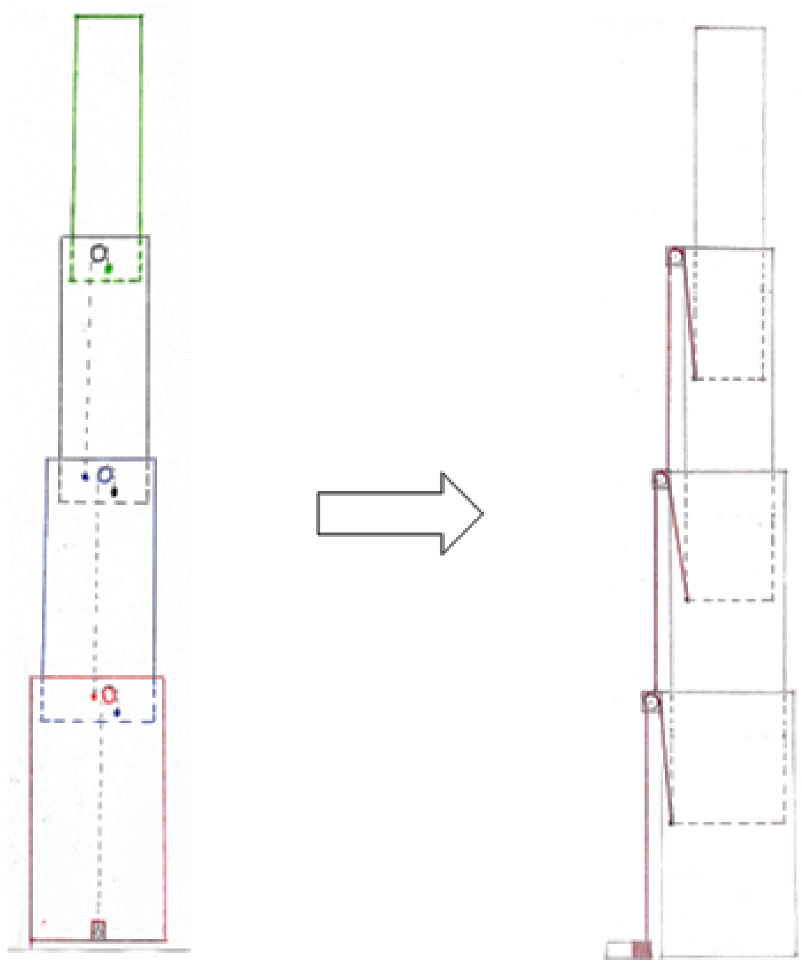
Figure 9. Zoomed in view of the deflated wheels from the previous year's mechanism

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 deflation. The new tires, shown in Figure 10, arrived on February 3, 2015[4]. The new tires have been installed on the mechanism and tested on multiple terrain (i.e. concrete, grass, dirt, and unleveled ground) and was able to easily maneuver across each setting.

Figure 10. Wheels ordered for the current mechanism [4]

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 11 (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.



(a) **(b)**

Figure 11. (a) Schematic of the internal pulley system (b) Schematic of the external pulley system

The schematic in Figure 11 (b), on the right, is the design for the external pulley system. Each cable is threaded through 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 telescoping pole segment located above it 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 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 12.

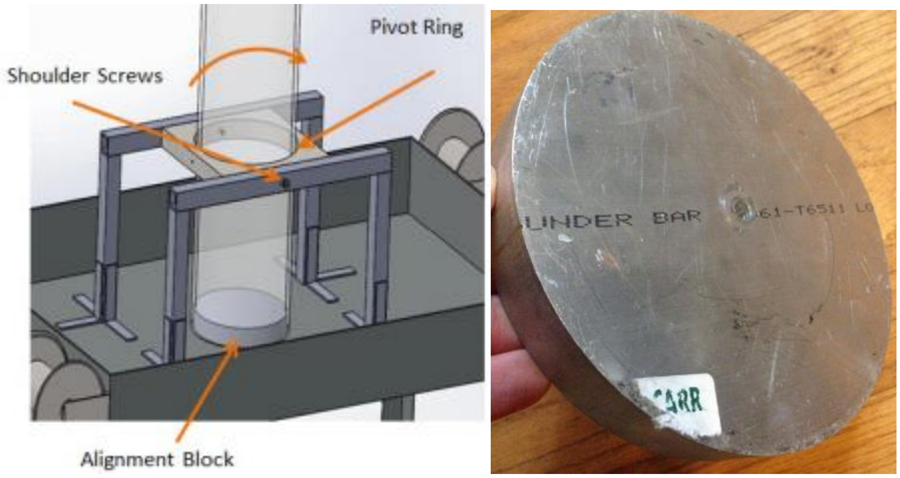


Figure 12. Alignment block assembly for the previous year's mechanism [5]

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

A model of the entire assembly (cart and pole) was created, as shown in Figure 13. This diagram depicts how the mechanism will be assembled and also provides workers with the most accurate location of stress on the device in order to ensure sensitivity during assembly.

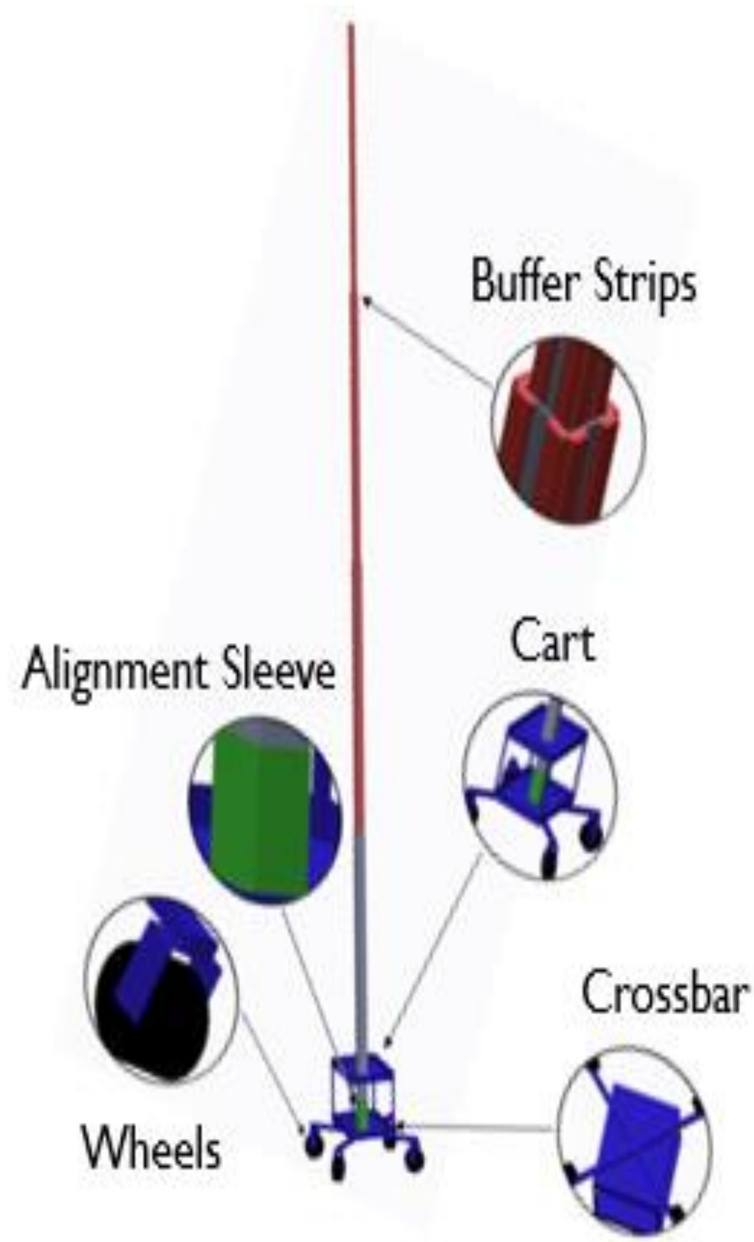


Figure 13. A schematic of the assembly of the new mechanism as of the analyze phase

Figure 13 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. The electric winch and battery are not depicted in Figure 13 due to the fact that final placement of these components was still in question. Weight distribution was a key factor in the placement of the battery because of its significant weight therefore motor placement was dependent upon placement of the battery.

5.5.1 Stress Analysis

Once the assembly was completed, it was time to put it to the test to determine whether it could withstand the wind and load forces placed on it. Figure 14 shows the Von Mises stress diagram in MPa of the entire assembly, consisting of the forces shown on the poles in Figure 7 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.

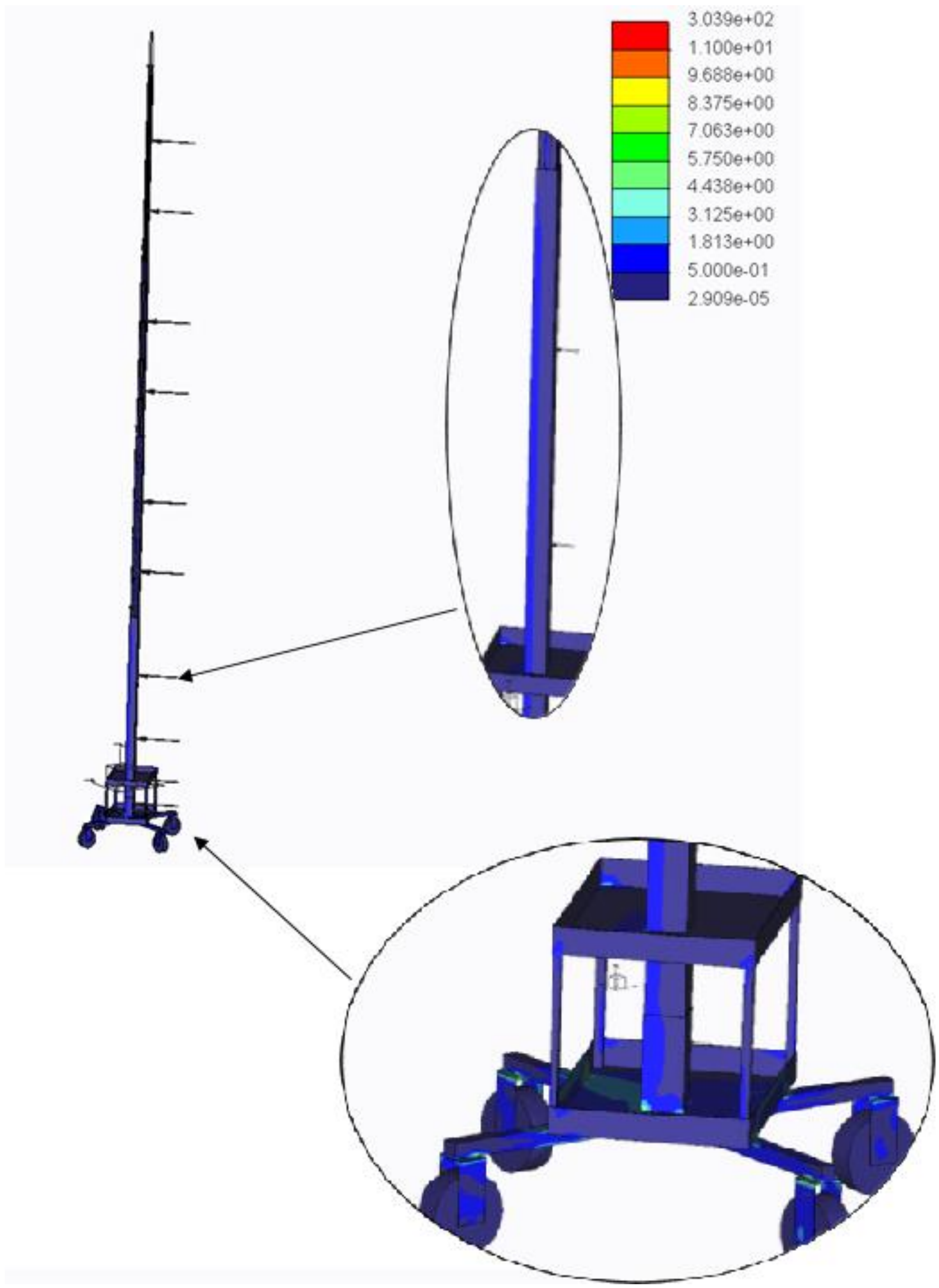


Figure 14. Stress analysis, in MPa, of assembled mechanism

Figure 14 shows that the maximum stress distribution occurs on the bottom shelf of the cart where the crossbar is located and where the telescoping pole as well as 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 15.

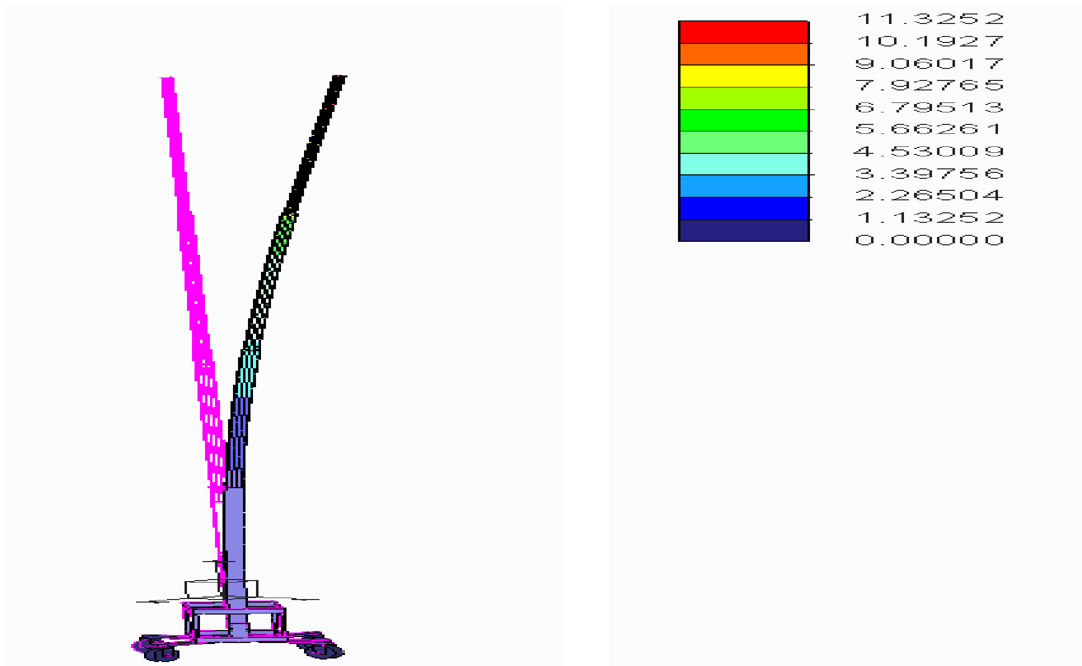


Figure 15. Deflection analysis, in mm, of assembled mechanism

In Figure 15, 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. Based on the torque and power ratings, the electrical engineer will have enough criteria to select a probable motor. 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 15 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 16. As a result of the ratings, the motor should perform well during test and should be able to lift and lower the poles together in less than 3 minutes.

Figure 16. Motor selected for the mechanism [8]

6. Improving the Current Process

6.1 Electrical Components

6.1.1 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. Basic testing of the camera was done; including connecting positive and negative terminals to achieve power. Upon completion of this test 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 power 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, however with these connections there was still no progress.

6.1.2 Motor, Battery, and Cutting Mechanism

The remaining electrical components are the battery and winch motor. As of Friday, February 27, 2015 the office notified the team that the components had just been ordered. Testing began upon the arrival of these components. The cutting mechanism was also reused from last year's design. It was accompanied by an 18V battery that provided the necessary power for operation.

6.2 Mechanical Components

6.2.1 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 17 shows the old wheels compared to the new ones.

Figure 17. Comparison of last year's wheel to the current 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 18 below.

Figure 18. The wheels being tested on different terrain (concrete, asphalt, and grass/dirt)

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.

6.2.2 Buffer Strips

Last year's project used high density polyethylene (HDPE) stripping in order to prevent the circular cross-sectioned PVC from rotating within each other. This material was reused in order to stabilize and minimize friction within the aluminum telescoping poles. Since there is a quarter-inch gap between the first and second segments on all sides, there needed to be something filling this gap, in order for the intersections between the poles to be stable. This is where the buffer stripping came into play. The material was cut in short quarter-inch thick strips and mounted to the inside face of the first segment. This process was repeated for the remaining segments.

Cutting the buffer strips to the exact width of the gaps resulted in unwanted friction in the telescoping pole. This occurrence forces the winch work harder than it needs to, thus draining the battery quicker. In order to alleviate some of this friction, a small layer of the buffer stripping was 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 HDPE stripping and the bolts were cut to the exact length. The recessed nuts within the buffer stripping can be seen in Figure 19. Performing this process prevented metal on metal contact and allowed the telescoping poles to only come into contact with the HDPE stripping.

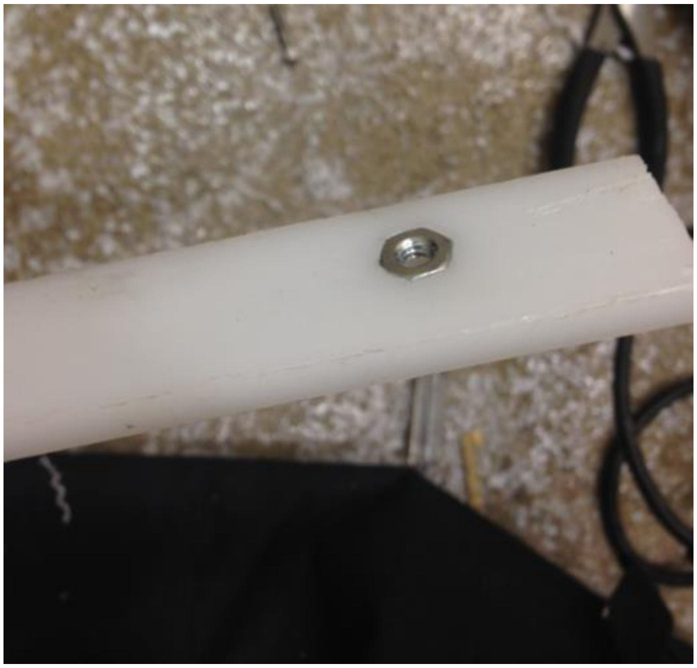


Figure 19. Recessed buffer strip

6.2.3 Lowering the Center of Gravity

Lowering the center of gravity of the poles allowed 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 20 below.

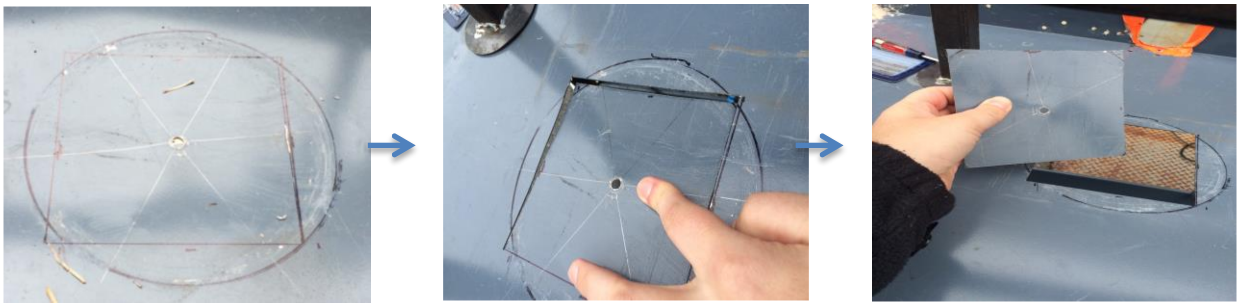


Figure 20. Process of lowering the center of gravity

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.

7. Controlling Process Improvement

7.1 Testing the Mechanism

7.1.1 Pulley System

In order to test the pulley system, the poles and motor had to be mounted to the cart. First, the motor was mounted to the bracing of the top shelf of the cart. Then the largest pole was mounted on the cart making sure that the pole fit over the alignment block. This is shown in Figure 21.

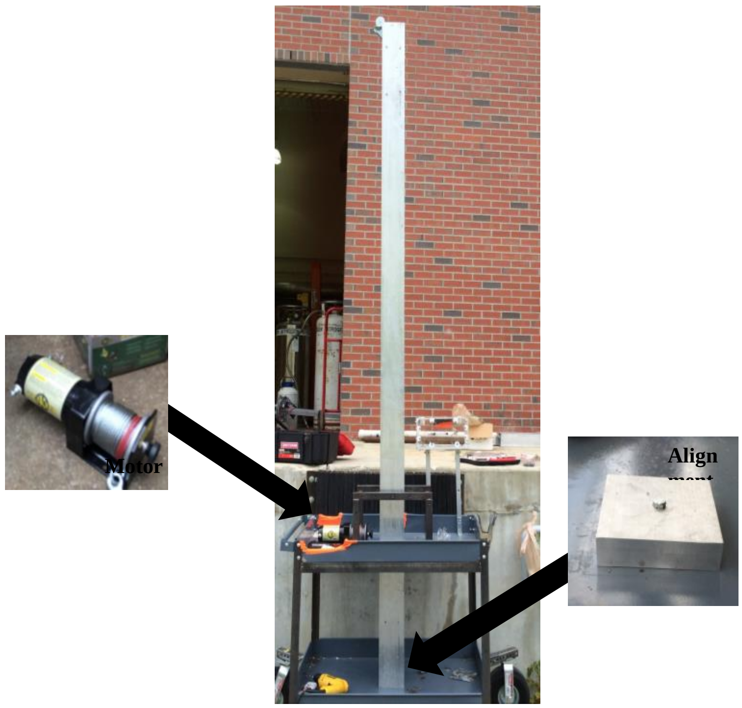


Figure 21. Motor and largest pole mounted on the cart

Once the first pole was mounted to the cart, the pulley system was assembled. Figure 11 shows how the pulley system was assembled. After the entire pulley system was connected, the battery (located on the bottom shelf) was connected to the motor using the red and black cables extending from the motor controller. A better understanding of this is shown in Figure 22 where Chris is holding the controlling buttons.

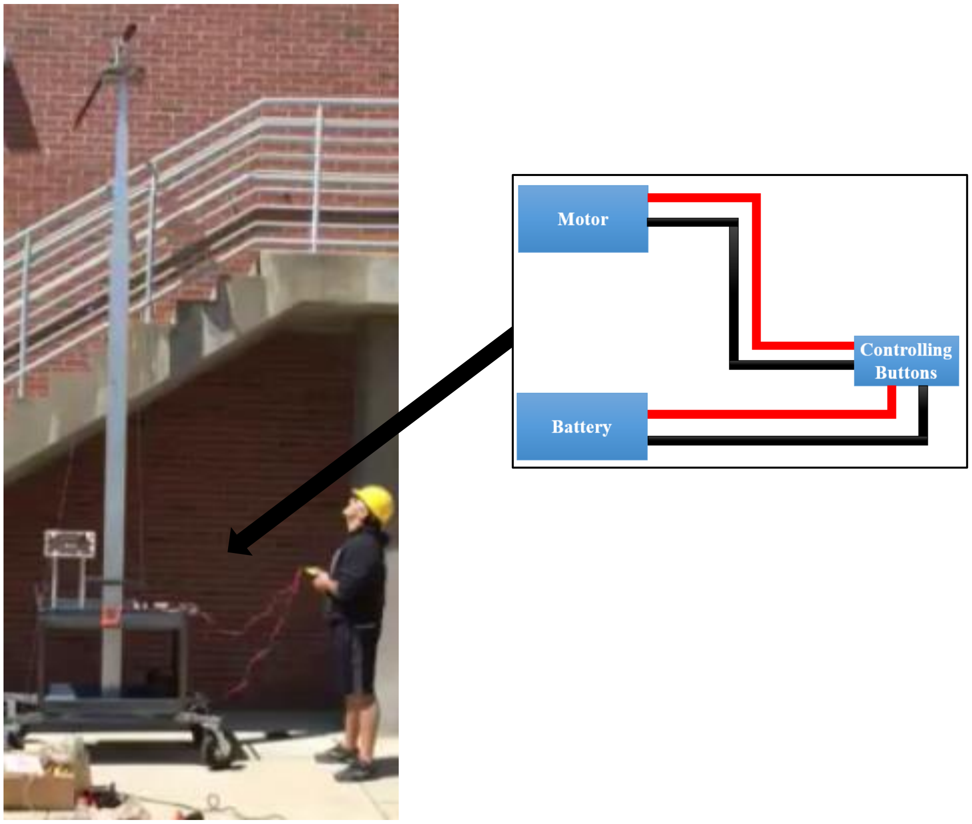


Figure 22. Wiring of the motor controller, battery, and motor

Using the control buttons, the pulley system was tested by pressing the up button and making sure that each pole extended successively. In order to prove that the pulley system was successful, the pulley system was tested at different heights, making sure the poles extended as expected. Once the control button was released, the telescoping pole height should remain consistent. Figure 23 shows the pulley system being tested at different heights.

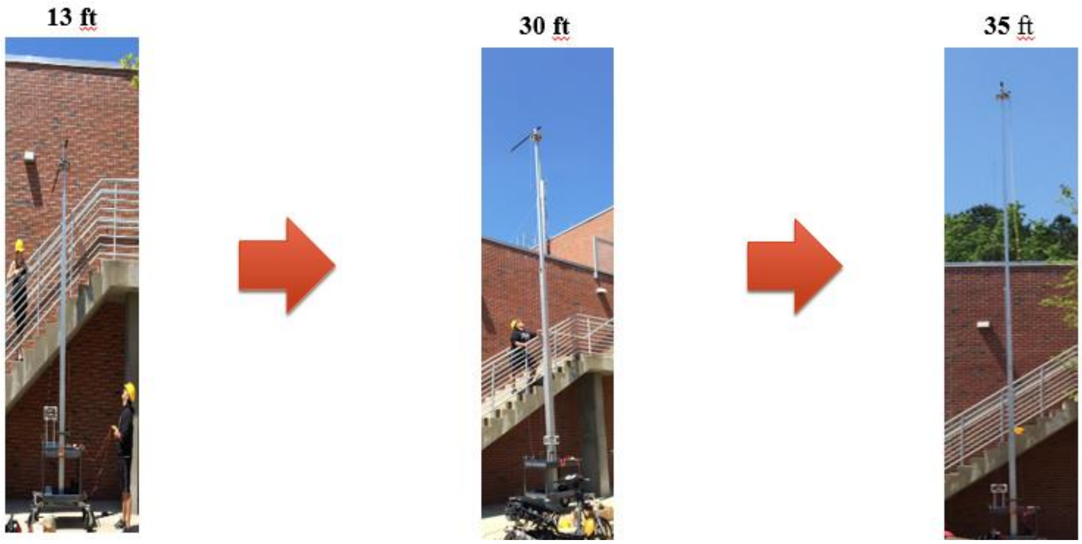


Figure 23. Pulley system being tested at different heights

It was concluded that the pulley system was very successful, as the poles extended with no issues. More specifically, the cables were able to withstand the tensile forces due to the weight of the poles, the pulleys stayed in place and did not show any form of yielding, and most importantly the poles stayed aligned and no visible form of deflection was present.

7.1.2 Cutting Mechanism

Once the pulley system was tested and proven successful, the telescoping pole was fully compressed in order to assemble the cutting mechanism. A better understanding of the cutting mechanism assembly is shown in Figure 24.

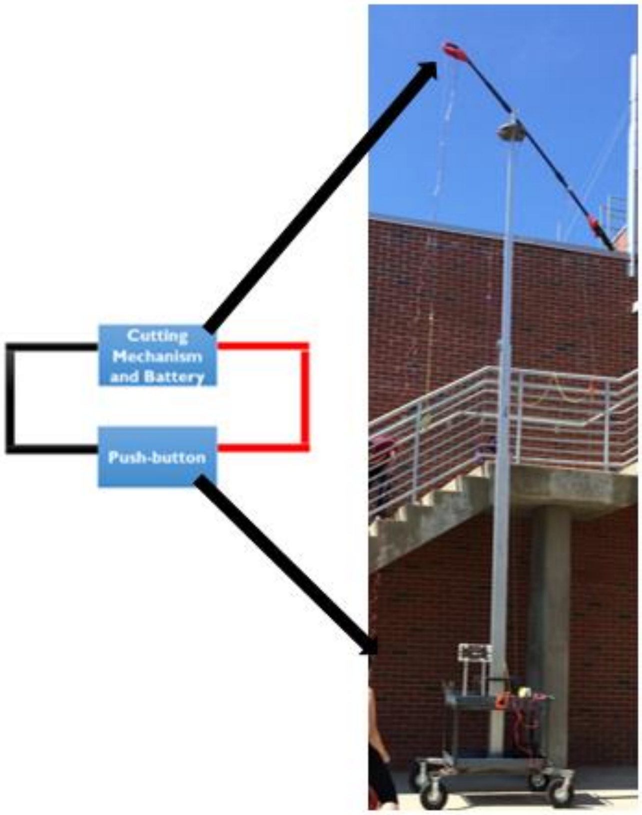


Figure 24. Wiring of the cutting mechanism

After the cutting mechanism was wired and successfully powered on, the mechanism was tested on a tree limb. The cutting mechanism was tested by cutting a tree branch instead of a bunch of palm fruit, as a palm fruit bunch is not readily available. In order to align the cutting mechanism on the desired branch, the preexisting pulley system attached to the lazy susan and cutting mechanism, implemented by the previous year's team, was used. This pulley system used to align the cutting mechanism will be operated at ground level by the worker. The cutting mechanism being aligned on a branch using the pulley system is shown in Figure 25.

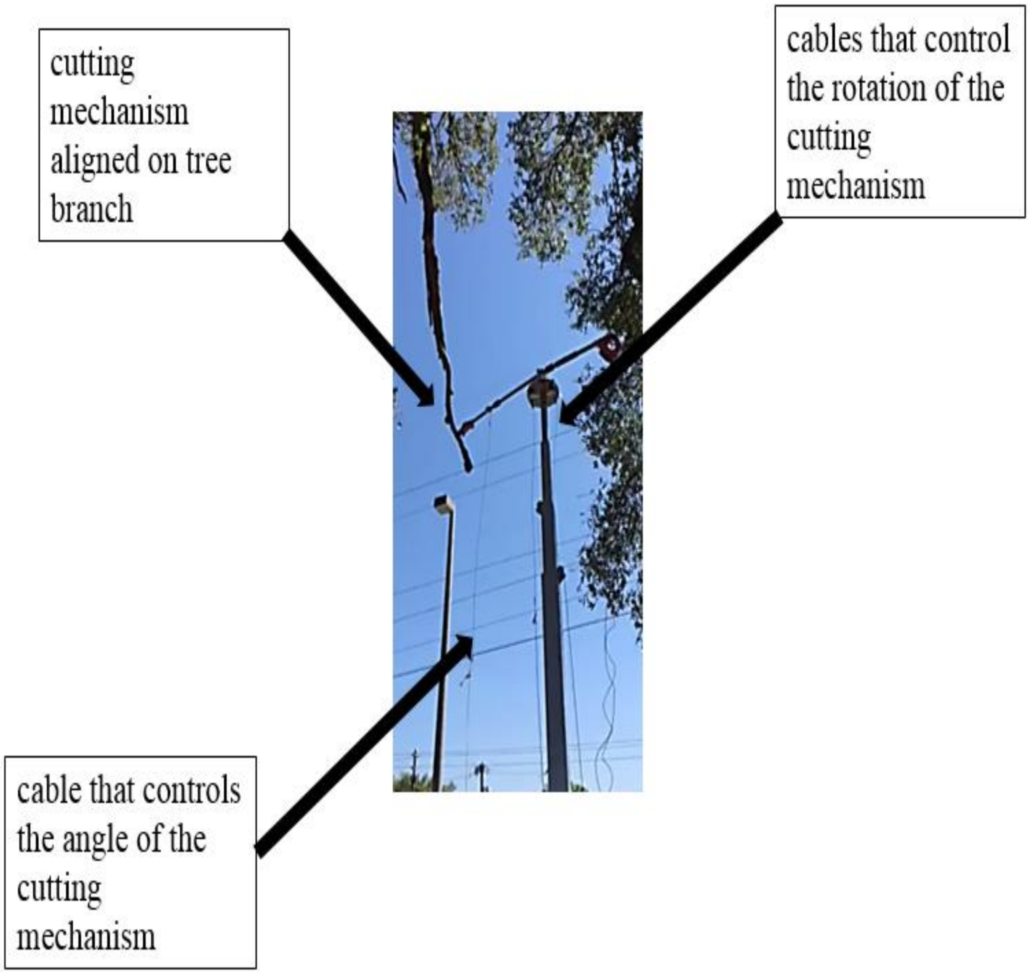


Figure 25. Cutting mechanism aligned on tree branch

While testing the cutting mechanism on a branch, the cutting saw became lodged in the branch requiring the user to wiggle the cables in order to free the saw. Once the saw was freed, the cutting mechanism was realigned on the branch but wasn't able to cut the remainder of the branch off, as the battery on the saw was depleted. Ideally, the cutting mechanism would align itself with the cutting surface and cut through the surface within seconds, without the need to readjust and worry about the battery running low.

7.1.3 Camera Mechanism

The camera mechanism, implemented by the previous year's team, is shown in Figure 26.

Figure 26. Camera mechanism from previous year [9]

During the improve phase, the camera mechanism was tested to ensure that it turned on and displayed an image on the screen. Although the camera turned on when powered by the battery, the screen displayed “No Signal”. The connection between the screen and camera was broken, which did not allow the screen show an image. Unfortunately the camera was unable to be fixed and due to time constraints and the long ordering process, a new camera was not able to be purchased.

7.1.4 Maneuverability

Before testing the maneuverability of the entire mechanism, a theoretical analysis was completed on the assembly to determine the amount of force required to push the fully assembled cart. Figure 27 shows a free body diagram of the mechanism with all the forces labeled.

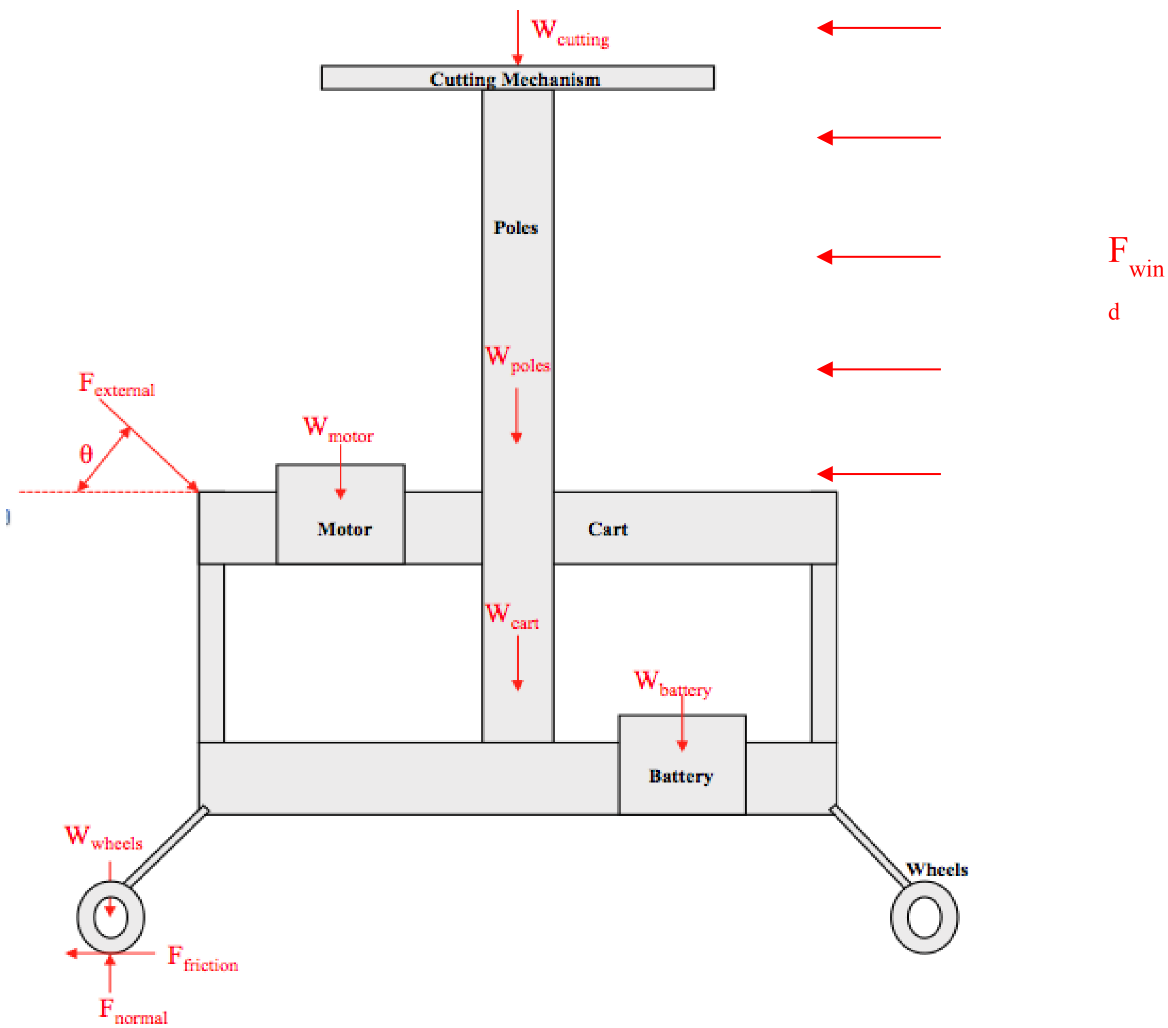


Figure 27. Free body diagram of assembled mechanism

In the above free body diagram, W corresponds to the weight forces and F corresponds to the forces applied to the mechanism. $F_{external}$ is the amount of force required to push the cart by the user and this force is at an angle of θ which was found using averaged statistics with regards to the height of Malaysian males and their arm length. The calculations for this angle are shown in Appendix D. F_{wind} is the wind force applied to the telescoping pole in the opposite direction of the cart motion, in order to receive a maximum external force needed to push the cart. The value for the wind force was calculated in Appendix E based on the average wind speed found on a Malaysian government meteorology website. $F_{friction}$ is the frictional force the wheels feel due to contact with the ground, which is shown in equation where μs is the coefficient of static friction and F_{normal} is the opposing force the ground applies to the wheels.

$$F_{friction} = \mu_s \times F_{normal} \quad (3)$$

In order to find the amount of force required by the user to push the cart, the forces were summed in the x and y directions. The known variables were replaced with their actual values shown in Table 7.

Table 7. Known free body diagram variables

Variable	Description	Value
$W_{battery}$	weight of the battery	59.5 lb_f
W_{cart}	weight of the cart	65 lb_f
$W_{cutting}$	weight of the cutting mechanism	21.3 lb_f
W_{motor}	weight of the motor	13.2 lb_f
W_{wheels}	weight of the wheels	18 lb_f
μ_s	coefficient of static friction	0.35
F_{wind}	wind force	0.85 lb_f
θ	angle of the external force	41.4°

Once the known variables were replaced with their corresponding values, the only unknown variables left were $F_{external}$ and F_{normal}. Since there are two equations, x direction and y direction, and two unknowns, the unknown values were able to be solved for. The method to calculate these values are shown in Appendix F. The normal and external forces were calculated for two cases, with and without the wind force applied. The force required by the user to push the cart, with the wind opposing it, is 246.6 lb_f and without any wind force is 237 lb_f. There is only a 9.6 lb_f difference which means the wind force does not have a significant effect on the maneuverability of the cart. After doing some research, it was found that the external force required to push the cart is similar to that of a human bite. Since this amount of force is hard to visualize, a physical test was completed on dirt/grass terrain, as shown in Figure 28.

Figure 28. Assembled cart being pushed for testing purposes

Although the values for the external force seemed high based on their magnitude, it was concluded after testing that the amount of force needed to push the cart felt like pushing a sofa across a room.

7.2 Time Analysis

A time analysis of the assembly and disassembly procedure for the previous year's palm harvester mechanism was completed during the Measure Phase. The steps and breakdown of the time involved in these procedures can be seen in detail in Figures 6 and Table 6. The setup time includes the time taken to mount the pole to the cart as well as raise the pole to the maximum achievable height. In total, the setup time for the old mechanism was 3:10, with an additional 40s being the time spent cranking the winch in order to raise the pole to 25ft. The total disassembly time was 1:40. Since the new telescoping pole mechanism is mounted onto the cart during transportation, the setup and disassembly time is completely eliminated. In order to compare the rise time of both the old and new mechanisms, the new mechanism was raised to the maximum height achieved by last year's mechanism, which was about 25ft. The rise time of the new telescoping pole to a height of 25ft took a total of 16s, which is over half the total rise time of the old mechanism. The total lowering time of the new telescoping pole was 12s, compared that of the old mechanism with a time of 40s. Overall, the time from the completely lowered position to a height of 25ft was cut by more than 50% by automating the telescoping pole. The total time saved by automating the raising and lowering of the telescoping pole to and from 25ft was calculated to be 5:42. Not only was there a drastic increase in saved time, but the amount of effort required to complete these processes was condensed down to the push of a button. A table comparing the times of assembly, disassembly, and rise/lower times of the old and new telescoping poles can be seen in Table 8.

Table 8. Time analysis

Process	Old Mechanism (min:sec)	New Mechanism (sec)	Time Difference (min:sec)
Assembly	3:10	0	-3:10
Disassembly	1:40	0	-1:40
Rise to 25ft	0:40	0:20	-0:20
Lower from 25ft	0:40	0:18	-0:22
		Total Saved Time	5:32

7.3 Safety Precautions

While using the palm fruit harvester a few safety precautions are needed in order to operate the mechanism:

1. A hard hat and safety glasses must be worn by all operators when in the vicinity of the palm fruit harvester
2. The harvester will only be operated on level ground
3. The mechanism will not be operated in harsh weather conditions
4. Do not move the cart without the telescoping pole being in the fully lowered position
5. Before the harvesting process beings the telescoping legs must be fully extended in order to prevent tipping
6. At least two operators will be present during the harvesting process. One operator will control the raising and lowering of the pole as well as the cutting of the oil palm fruit bunch. The other operator will act as a spotter to ensure the mechanism and operator are working in safe operating conditions.

Failure to abide by these safety precautions could result in serious injury or even death.

The operator should follow the following steps to properly use the palm fruit harvester:

1. Visually inspect the palm fruit harvester for any defects in the telescoping poles, pulley system, cart, and wiring. If any defects found, then do not operate until issue is fixed.
2. Maneuver the cart to five feet from the base of the oil palm tree.
3. Extend telescoping legs outward.
4. Connect electric winch controller to battery.
5. Extend the telescoping pole upwards by pressing the appropriately labeled button on the controller.
6. Allow pole to extend to desired height. Height can be measured using reflective stickers on outside face of second pole segment. Note: Initial height of harvester is 13ft.
7. Once desired height is reached, release extension button on controller to allow the electric winch to maintain the telescoping pole height.
8. The electric saw is powered using the grey push button. Once electric saw is turned on, the movement on the saw can be maneuvered using the provided strings.
9. Once the harvesting process is completed, turn off saw by releasing grey push button.
10. Lower the telescoping pole to fully contracted position using the retract button on electric winch controller.
11. Return legs to normal position.

Move cart to next tree in order to being process again, starting with step 1

7.4 Customer's Needs

The main customer of the palm fruit harvester will be oil palm plantation owners. In order for the palm fruit harvester to be commercially viable, a few expectations are considered:

- Cutting mechanism reaches the desired height with minimal time and effort.
- Rise and fall times of the telescoping pole are comparable to that of a worker using current harvesting methods.

- The telescoping pole sustains minimal deflection while at maximum height.
- Stability of the mechanism allows for safe working conditions.
- Mechanism is environmentally safe.

When an oil palm plantation owner is in the market to purchase the palm harvester, the comparison to the current method of harvesting will be made. If the palm harvester does not improve upon the harvesting process, then the plantation owner will not purchase the product. The telescoping pole must be able to achieve maximum height in less time than the laborer climbing the tree by hand. It is extremely unlikely that a worker climbing an oil palm tree can ascend the tree to 25ft in less than 16s, as the data shows in Figure 8. Hypothetically speaking, even if a worker was able to climb the tree in an amount of time comparable with that of the palm harvester, then the amount of effort used in climbing the tree will not be able to be sustained for multiple trees at a time. This amount of effort expelled by the worker is much greater than that of holding a button for 16s.

An oil palm plantation owner will also consider the safety of the workers when purchasing the palm fruit harvester. Since there is minimal deflection at maximum height, the stability of the palm harvester is desirable when compared to the risk of falling from the tree while a worker is at that same height. The stability of the mechanism is only increased when the telescoping legs are extended to their full length. The risk of severe injury is extremely likely when the worker is harvesting atop the oil palm tree.

The palm harvester is environmentally friendly in that there are no exhaust gases expelled from the mechanism. Rechargeable batteries are used in order to protect the environment in which the plantation owner gains profit. The customer will desire a mechanism that is not only efficient at harvesting oil palm fruits, but also increases the safety of the workers.

8. Business Analysis

8.1 Economic Analysis

The aluminum poles used in the telescoping pole consisted of 26% of the overall budget. This was an integral component of the mechanism as it allowed the cutting mechanism to reach the proper height. The poles required a large amount of material, increasing the cost and cost of shipping. In order to achieve the telescoping process, a motor was needed to drive the pulley system. According to required torque calculations, the motor was selected in order to not only provide this amount of torque, but also more torque in order to overcome any extraneous frictional forces. A battery is needed to power the motor. This battery must be able to provide the necessary current and voltage to operate the motor as well as continue operation throughout the workday. Due to poor conditions of previous wheels, new wheels needed to be purchased. The inherent risk of puncture is highly likely during transportation, therefore solid polyurethane tires were purchased. Self-inflating tires were used on the previous model of the palm harvester causing them to deflate over time; solid polyurethane tires were used in order to prevent this issue.

The total cost to manufacture the palm harvester would be approximately $1,500. A total of $1,051 was used in order to build the current mechanism, not including the parts that were reused from the previous palm harvester. The costs of the main reused components such as: the cutting mechanism, utility cart, and steel reinforcement bring the cost up to about $1,400 and will the inclusion of extraneous parts the total manufacturing cost would be about $1,500.

Regular maintenance costs would be the replacement of the buffer stripping as they are the component of the palm harvester that incurs the largest amount of friction. This buffer stripping material is cheap and simple to replace. Other components, such as the pulleys and cabling, will need to be replaced when signs of wear and tear are visible. These components are cheap and can be bought in bulk and stored until needed. The batteries that power the electric winch and electric saw will need to be replaced when the end of the battery life cycle has been reached. Overall, the maintenance cost of the palm fruit harvester is minimal because these components are readily available at low costs.

8.2 Environmental Impact

The palm fruit harvester is designed to harvest palm fruit in sub-tropical areas. One of our sponsor's main requirements was the overall safety of the oil palm. With this in mind, the final product should not damage the tree or the soil. It is important that the final product is sustainable, energy efficient and friendly to the areas it being used. Since the prototype will be mainly operated outdoors and the materials that it is made of are heavy, it is suggested to place a piece of plywood in the harvesting area in order to protect the soil surrounding the oil palm tree. The prototype will be battery powered which is cleaner, cheaper and quieter than a generator. The use of a generator will expel poisonous exhaust gases into the atmosphere. The users will properly dispose or recycle the batteries when they reach the end of their life cycle. The materials used to build the prototype are not corrosive and will not destroy any living organisms that they may come in contact with.

8.3 Ethical Considerations

This product is designed exclusively for agriculture use. The product will have a sharp cutter, mechanical pulley system, and a relatively heavy cart. Any use represents a potential risk to the worker. The product should be used for exclusively harvesting purposes and the user should have proper training and knowledge of the device.

8.4 Health and Safety

Scientific evidence shows that effective ergonomic interventions can lower the physical demands of Manual Material Handling (MMH) work tasks, thereby lowering the incidence and severity of the musculoskeletal injuries they can cause. MMH tasks may expose workers to physical risk factors. If these tasks are performed repeatedly or for a long period of time, they can cause fatigue and injury. Injury may include damages to muscles, tendons, ligaments, nerves and blood vessels. These types of injuries are known as musculoskeletal disorders. With this in mind, the team has designed a product that is a safer alternative to harvest palm fruits.

When designing the prototype, some ergonomic factors were taken into consideration, such as awkward postures (e.g. bending, twisting), repetitive motions (e.g., frequent carrying, lifting and pushing). By limiting the stress on the body, the occurrence of repetitive strain injuries can be prevented which could ultimately lead to long term disability.

In order to accurately assess the prototype, two ergonomic tools were used. The first one is called the National Institute of Occupational Safety and Health (NIOSH) Manual Material Handling, the other one is the Rapid Upper Lamb Assessment (RULA).

8.4.1 NIOSH Analysis

The team used the Psychophysical table, Figure 29, from the NIOSH Manual Material Handling to determine if the palm plantation worker’s tasks are within the recommended guidelines. Figure 29 is used for two-hand push data. This table presents the maximum forces that can be exerted by 75% of the female population based on task characteristics; the first column of the table has the height notations, it can be at shoulder level, elbow level and knee level. For this prototype, the elbow level is used because the handles of the cart are at this level. The second column has the push distance in feet, in other words the distance from one point to another or the distance between the palm trees is about 30 feet (9 meters). An interpolation between 25 and 50 feet at the elbow level might be necessary. The third column gives the frequency of how often the worker has to perform the task during the day. It is assumed that the worker will perform the task for an entire workday of 8 hours. The two values given are the forces with the first number being the maximum initial acceptable push force that can be exerted. The number in parentheses is the sustained push force that can be acceptably maintained across the distance/duration of the push. It was found that the prototype requires initial and sustained forces of 237 lbs., which is greater than all the listed values in Figure 29 at the elbow level. This is due to the fact the materials used to build the cart and the poles are very heavy for one worker to push from one tree to another.

II D9. **Two-Hand Push Data, cont.**

Guidelines **Table II.40.** Maximum Acceptable Two-Hand Push Forces (lb) Initial (Sustained) Forces, (Snook and Ciriello, 1991; Mital, et. al., 1993).

Floor-to-Hand Height	Push Distance (feet)	Frequency: One Push Every ...						
		6 sec	12 sec	1 min	2 min	5 min	30 min	8 hr
Shoulder Level	7	37(18)	40(22)	46(31)	48(31)	53(35)	55(37)	59(46)
	25	X	X	42(24)	44(24)	48(26)	51(29)	53(35)
	50	X	X	37(18)	37(20)	42(22)	44(24)	46(29)
	100	X	X	33(13)	35(18)	37(20)	42(20)	46(26)
	150	X	X	33(13)	35(18)	37(18)	42(18)	46(24)
	200	X	X	X	31(9)	33(13)	37(13)	42(20)
Elbow Level	7	37(15)	40(20)	46(29)	48(29)	53(33)	55(35)	59(42)
	25	X	X	44(24)	44(24)	48(29)	51(29)	55(37)
	50	X	X	37(18)	37(22)	42(24)	44(24)	46(31)
	100	X	X	33(15)	35(20)	40(20)	42(22)	46(29)
	150	X	X	33(13)	35(18)	40(18)	42(20)	46(26)
	200	X	X	X	33(9)	35(13)	37(15)	42(20)
Knee Level	7	31(13)	33(18)	37(24)	37(24)	42(29)	44(31)	46(37)
	25	X	X	37(22)	37(24)	42(26)	44(26)	46(33)
	50	X	X	31(18)	33(20)	35(22)	37(22)	40(29)
	100	X	X	29(13)	31(18)	33(18)	35(20)	40(26)
	150	X	X	29(13)	31(15)	33(18)	35(18)	40(24)
	200	X	X	X	26(9)	29(13)	31(13)	35(18)
	Note: An "X" in a cell indicates the push distance cannot be performed for the push frequency							

Figure 29. NIOSH Table II.40 used to determine if the pushing forces are within range [10]

8.4.2 RULA Analysis

The Rapid Upper Limb Assessment (RULA) tool is utilized to evaluate the exposure of the users to ergonomic risk factors associated with upper extremity Musculoskeletal

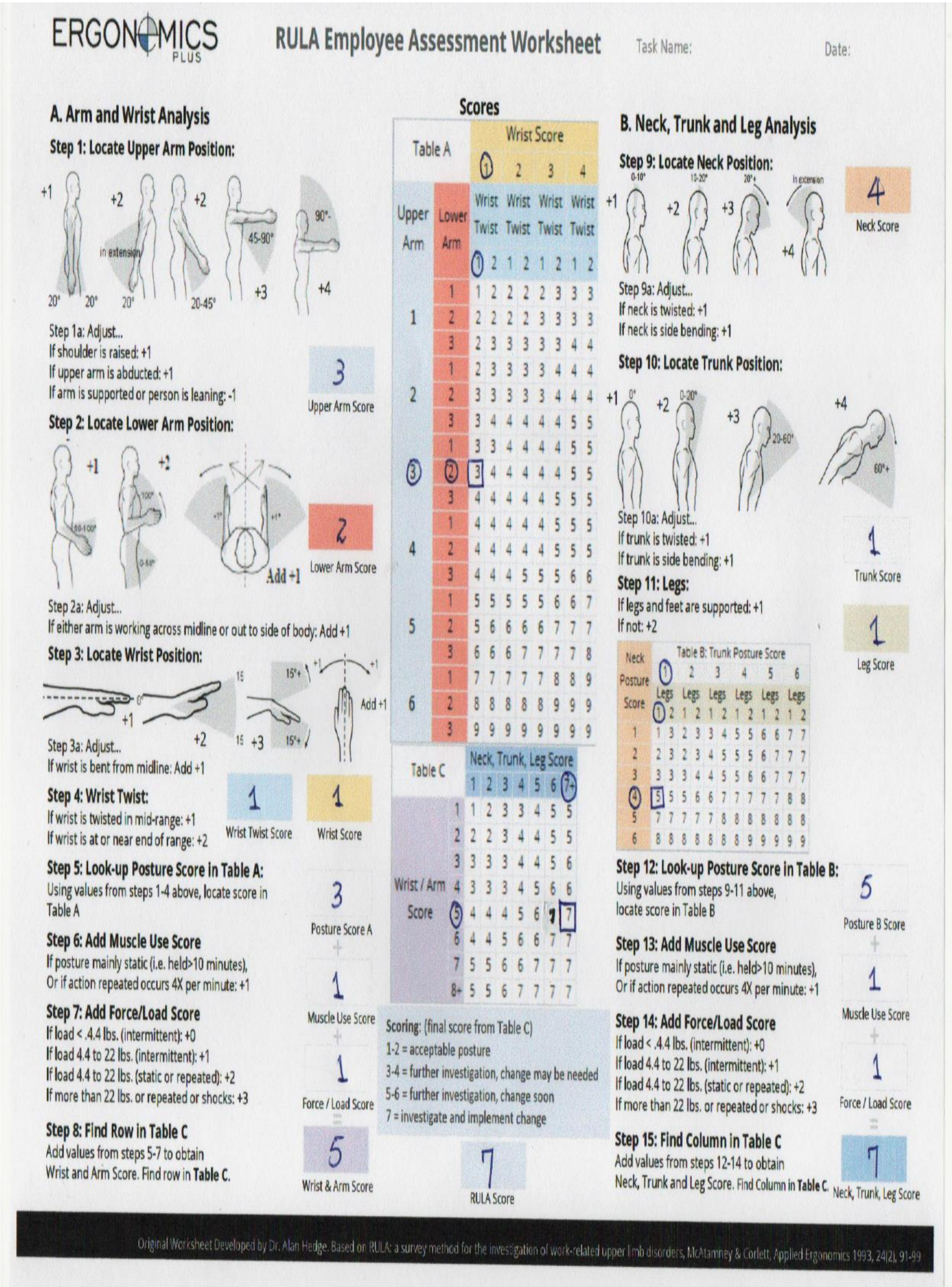
Disorders (MSDs). This tool considers biomechanical and postural load requirements of job tasks/demands on the neck, trunk and upper extremities. Using the RULA worksheet, a score will be assigned for each of the following body regions: upper arm, lower arm, wrist, neck, trunk, and legs. After the data for each region is collected and scored, tables on the form are then used to compile the risk factor variables, generating a single score that represents the level of MSD risk as outlined in Figure 30.

Score	Level of MSD Risk
1-2	negligible risk, no action required
3-4	low risk, change may be needed
5-6	medium risk, further investigation, change soon
6+	very high risk, implement change now

Figure 30. Image of a table showing the score associated with level of MSD risk [11]

In step 1, for arm and wrist analysis, a score of +3 was used for the upper arm position (45-90 degree). For step 2, a +2 was given for the lower arm position (< 60 degrees). The step 3 wrist score was +1 for wrist flexion and the wrist score was also +1. These values were then input in Table A. The intersection between upper arm score and wrist twist score rows will give the score for the arm and wrist analysis, which results in a final score of 3. Muscle and force scores were added to the final arm and wrist analysis score. The same procedure was done for neck, trunk and leg analysis. The final RULA score for the prototype is 7, which indicates high risk and calls for engineering and/or work method changes to reduce or eliminate MSD risk as outlined in the above chart.

Although the prototype is not fully ergonomic, the team thinks that it is more important that it is fully functional. For this reason, the team is going to build the prototype for ease of manufacture regardless of its ergonomic risks. Future considerations for total weight of mechanism should be implemented into future designs.



ERGONOMICS PLUS

RULA Employee Assessment Worksheet

Task Name:

Date:

A. Arm and Wrist Analysis

Step 1: Locate Upper Arm Position:

+1 20° in extension 20° +2 20° +2 20-45° 45-90° +3 90°- +4

Step 1a: Adjust...
If shoulder is raised: +1
If upper arm is abducted: +1
If arm is supported or person is leaning: -1

Upper Arm Score: 3

Step 2: Locate Lower Arm Position:

+1 60-100° +2 100°+ 0-60°

Add +1

Lower Arm Score: 2

Step 2a: Adjust...
If either arm is working across midline or out to side of body: Add +1

Step 3: Locate Wrist Position:

+1 0° +2 15° +3 15°+ Add +1

Step 3a: Adjust...
If wrist is bent from midline: Add +1

Step 4: Wrist Twist:
If wrist is twisted in mid-range: +1
If wrist is at or near end of range: +2

Wrist Twist Score: 1

Wrist Score: 1

Step 5: Look-up Posture Score in Table A:
Using values from steps 1-4 above, locate score in Table A

Posture Score A: 3

+

Step 6: Add Muscle Use Score
If posture mainly static (i.e. held>10 minutes),
Or if action repeated occurs 4X per minute: +1

Muscle Use Score: 1

+

Step 7: Add Force/Load Score
If load < 4.4 lbs. (intermittent): +0
If load 4.4 to 22 lbs. (intermittent): +1
If load 4.4 to 22 lbs. (static or repeated): +2
If more than 22 lbs. or repeated or shocks: +3

Force / Load Score: 1

=

Step 8: Find Row in Table C
Add values from steps 5-7 to obtain Wrist and Arm Score. Find row in **Table C.**

Wrist & Arm Score: 5

Scores

Table A		Wrist Score 1		2		3		4	
Upper Arm	Lower Arm	Wrist Twist 1	Wrist Twist 2	Wrist Twist 1	Wrist Twist 2	Wrist Twist 1	Wrist Twist 2	Wrist Twist 1	Wrist Twist 2
1	1	1	2	2	2	2	3	3	3
	2	2	2	2	2	3	3	3	3
	3	2	3	3	3	3	3	4	4
2	1	2	3	3	3	3	4	4	4
	2	3	3	3	3	3	4	4	4
	3	3	4	4	4	4	4	5	5
3	1	3	3	4	4	4	4	5	5
	2	3	4	4	4	4	4	5	5
	3	4	4	4	4	4	5	5	5
4	1	4	4	4	4	4	5	5	5
	2	4	4	4	4	4	5	5	5
	3	4	4	4	5	5	5	6	6
5	1	5	5	5	5	5	6	6	7
	2	5	6	6	6	6	7	7	7
	3	6	6	6	7	7	7	7	8
6	1	7	7	7	7	7	8	8	9
	2	8	8	8	8	8	9	9	9
	3	9	9	9	9	9	9	9	9

Table C		Neck, Trunk, Leg Score 1	2	3	4	5	6	7+
Wrist / Arm Score	1	1	2	3	3	4	5	5
	2	2	2	3	4	4	5	5
	3	3	3	3	4	4	5	6
	4	3	3	3	4	5	6	6
	5	4	4	4	5	6	7	7
	6	4	4	5	6	6	7	7
	7	5	5	6	6	7	7	7
	8+	5	5	6	7	7	7	7

Scoring: (final score from Table C)
1-2 = acceptable posture
3-4 = further investigation, change may be needed
5-6 = further investigation, change soon
7 = investigate and implement change

RULA Score: 7

B. Neck, Trunk and Leg Analysis

Step 9: Locate Neck Position:

+1 0-10° +2 10-20° +3 20°+ +4 in extension

Neck Score: 4

Step 9a: Adjust...
If neck is twisted: +1
If neck is side bending: +1

Step 10: Locate Trunk Position:

+1 0° +2 0-20° +3 20-60° +4 60°+

Step 10a: Adjust...
If trunk is twisted: +1
If trunk is side bending: +1

Trunk Score: 1

Step 11: Legs:
If legs and feet are supported: +1
If not: +2

Leg Score: 1

Neck Posture Score	Table B: Trunk Posture Score 1		2		3		4		5		6	
	Legs 1	Legs 2	Legs 1	Legs 2	Legs 1	Legs 2	Legs 1	Legs 2	Legs 1	Legs 2	Legs 1	Legs 2
1	1	3	2	3	3	4	5	5	6	6	7	7
2	2	3	2	3	4	5	5	5	6	7	7	7
3	3	3	3	4	4	5	5	6	6	7	7	7
4	5	5	5	6	6	7	7	7	7	7	8	8
5	7	7	7	7	7	8	8	8	8	8	8	8
6	8	8	8	8	8	8	8	9	9	9	9	9

Step 12: Look-up Posture Score in Table B:
Using values from steps 9-11 above, locate score in Table B

Posture B Score: 5

+

Step 13: Add Muscle Use Score
If posture mainly static (i.e. held>10 minutes),
Or if action repeated occurs 4X per minute: +1

Muscle Use Score: 1

+

Step 14: Add Force/Load Score
If load < 4.4 lbs. (intermittent): +0
If load 4.4 to 22 lbs. (intermittent): +1
If load 4.4 to 22 lbs. (static or repeated): +2
If more than 22 lbs. or repeated or shocks: +3

Force / Load Score: 1

=

Step 15: Find Column in Table C
Add values from steps 12-14 to obtain Neck, Trunk and Leg Score. Find Column in **Table C.**

Neck, Trunk, Leg Score: 7

Original Worksheet Developed by Dr. Alan Hedge. Based on RULA: a survey method for the investigation of work-related upper limb disorders, McAtamney & Corlett, Applied Ergonomics 1993, 24(2), 91-99

Figure 31. RULA assessment worksheet of the prototype [11]

8.5 Social and Political Considerations

Palm oil is a cash crop that provides a huge source of employment in third world countries such as Malaysia and Indonesia. The industry allows for small landholders to participate in a huge industry which helps small communities grow and prosper. The business improves local infrastructure allowing for these rural areas to have access to schools, hospitals, and many other necessary institutes. It allows for people who would not normally have an opportunity to grow economically, achieve social levels they never would imagine to reach. Introducing a safer, affordable, and more efficient method of harvesting palm fruits will only help these countries advance and flourish. Introducing a mechanism such as this could in the long run hinder smaller organizations that can't afford such an advanced mechanism. The project goal is to make the process as affordable as possible and help the industry grow as a whole.

8.6 Sustainability

The improvements mentioned in the Controlling Process Improvement section were done to enhance the current mechanism. A development that would further improve this mechanism would be a self-catching system, in which the fruit would fall into. This system would prevent the fruit from falling to the ground thus preventing injury to worker and the produce. To ensure Palm Harvester mechanism will successfully operate for the next five to twenty years general maintenance will need to be done. On a monthly basis, nuts, bolts, screws, pulleys, wheels, motor, and battery need to be checked and replaced as needed.

9. Project Evaluation

9.1 Project Success

Many road blocks were encountered throughout the course of this project, however with these issues, solutions were found. The biggest achievement of the process was the telescoping pole mechanism. The telescoping pole being made of PVC/steel put the operators at serious risk of injury, if failure of the mechanism were to occur. This being said, changing the material of the telescoping pole was crucial. Square cross-sectioned aluminum 6063 was used in replacement of PVC/steel. The new and improved telescoping pole was mounted onto the cart using a motorized winch to operate the pulley system, instead of a hand crank winch. At the push of a button, the telescoping pole extended up from an initial height of 13ft to a maximum height of 35ft. The electric winch that was purchased included a mechanical brake that allows the operator to stop the telescoping pole at the desired height. Reflective stickers were put onto the telescoping pole in order for the operator to easily see the height of the cutting mechanism. These stickers also allow the user to see if its maximum safe operating height has been reached.

Initial testing of the cutting mechanism was completed on a branch with an approximate diameter of three inches. The electric saw was able to cut a majority of the way through the branch, but became lodged in the branch towards the end. The cause of this issue was that the saw was running low on battery causing the saw blade to seize inside of the branch. Additional testing will be completed in the near future with a fully charged battery.

With success also comes failure in some portions of the project. The camera that was used with last year's palm fruit harvester was tested and found to be non-functional. Throughout multiple attempts of repair by the team and outside resources it was determined that the monitor was fully functional, leaving either the cabling or the camera to be the cause of the issue. With no discontinuities to be found in the wiring, the probable cause of malfunction was determined to be the camera itself. Due to time constraints, purchasing a new camera that was able to work with our monitor or an entirely new camera/monitor system was not an option. Therefore it was decided that use of the camera and monitor will not be implemented into this year's palm harvester design.

The main issue that the team wanted to fix was the setup process that was required for last year's mechanism. Before the cutting process could begin with the old palm fruit harvester, the entire telescoping pole and cutting mechanism needed to be mounted to the cart. This process required four team members to rotate the 100lb telescoping pole into place while maintaining proper cable and pulley alignment. This process is not practical to be implemented on the palm fruit plantations, therefore it was decided that the telescoping poles will be mounted directly to the cart, eliminating the setup procedure. Once the old telescoping pole was mounted to the cart, the use of a hand crank winch was needed in order to extend the pole to the desired height. When the old telescoping pole needed to be lowered, the hand crank winch was switched to reverse and the weight of the poles summed with the force of gravity needed to be counteracted by the user in order for the winch handle to not spin out of control and cause damage to the poles. The implementation of an electric winch was used in order to replace the effort of cranking the telescoping poles up and down with the push of a button. The issue of the setup process as well as the raising and lowering of the telescoping pole has not only been solved, but it has been improved upon by drastically, cutting the amount of time and effort required for rise and fall, by 20 and 22 seconds respectively.

A large moment or torque was applied to the old telescoping pole during the telescoping process causing the telescoping pole to deflect. This deflection was increased as the pole was cranked to its maximum height. Since PVC is a naturally brittle material, there was no way for the operator to know when failure was going to occur, putting the operator and anyone nearby in extreme danger. Changing the telescoping pole material from circular cross-sectioned PVC to square cross-sectioned aluminum eliminated this deflection as well as increased the ductility of the mechanism. The increase in ductility allows the operator to visually notice any changes in the alignment of the telescoping pole, allowing the operator cease the harvesting process and react accordingly to prevent injuries.

The old telescoping pole rested on the top shelf of the cart and was restricted from rotation by an alignment block and pivot ring. The location of the telescoping pole put the mechanism's center of gravity (COG) above the handle where the force is applied during transportation, allowing the mechanism to easily tip over. The new aluminum-telescoping pole was lowered to rest on the bottom shelf of the cart, bringing the COG down to below the height of the handle. During transportation, this low COG will aid in the stability of the mechanism during transportation. Before the harvesting process is initiated, the legs of the cart will be telescoped outwards. This will increase the stability of the cart during the cutting process, allowing the palm harvester to be operated safely and efficiently.

In order for the palm fruit harvester to function perfectly for use on an oil palm plantation a few modifications will need to be made. The first and arguably most important modification is the mobility of the palm harvester. The palm harvester needs to be able to traverse a wide range of terrain anywhere from grassy fields to moist muddy ground. Increasing the size of the tires will aid in the maneuverability of the mechanism by increasing the size of the contact patch between the tires and the ground, allowing the weight to be more evenly distributed. This is the same reason one does not ride a racing bike on the beach. While racing, one would want to minimize the contact patch in order to minimize the rolling resistance. The opposite is true on sand, wider tires on a beach cruiser will distribute the weight of the bike and rider over a wider contact patch in order to not sink into the sand. Pushing the current palm harvester over the range of distance of an oil palm plantation would become an extremely laboring task. Modifying the current cart into a trailer design would allow the palm harvester to be towed via a truck, minimizing the effort of the worker as well as allow the harvester to operate on a wider range of terrain. The addition of a truck would eliminate the need for multiple sets of batteries to be used to run the mechanism. A gas generator could be used from the bed of the truck to power the motorized winch, cutting mechanism, and camera/monitor.

The use of an electric saw may not be needed in future modifications to the palm harvester mechanism. Since the battery of an electric saw has a finite run time, only a certain amount of palm fruit trees can be operated on before the battery is depleted of charge. The electric saw is ten feet in length and could obstruct the movement of the harvester if caught on tree limbs. Instead of using an electric saw, a tree limb pruner can be used. The tree limb pruner consists of a scissor like mechanism that cuts using a rope and pulley system. The rope and pulley system would be replaced with a motor that drives the scissors together, cutting the stem of the oil palm fruit bunch. The operator would be responsible for aligning the stem with the scissors of the cutting mechanism.

Since operation of the harvester cannot occur unless it is level, there must be a method that can be implemented if the ground is not level in the area where harvesting occurs. One method of fixing this issue would be to include a system that allows the distance between the wheels and the bottom cross bar to be varied. This system could be as simple as a threaded bolt that, when tightened, raises the respective corner of the cart or including a hydraulic system in conjunction with a digital three dimensional level that will automatically level the cart at the push of a button.

The assumptions that were made are based on statistical averages of the oil palm tree and where it grows such as the weight of the fruit bunch, growing temperatures, dimensions of the oil palm tree, and size of the oil palm plantations. All calculations are based solely on these averages. Since access to an actual oil palm tree is not feasible, all testing on the cutting mechanism must be completed using tree limbs of varying diameter. Since the size of the stems of oil palm fruit bunches vary with the size of the bunch, the testing of the cutting mechanism will be valid using varying sizes of tree branches. The operation of the palm fruit harvester while the mechanism is not level is not an option. If the ground is not level before the harvesting process begins, then some means of leveling the mechanism must be put into effect such as the ideas proposed earlier.

The goal given to this year's palm harvester team was to improve last year's design. Improvements have been made to the mechanism that increase the safety and ease of operation of the palm harvester. The backbreaking setup process of the telescoping pole has been eliminated as well as the simplification of the raising and lowering of the telescoping pole. The time of rise and fall has been cut down to a fraction of what it was. The stability and ductility of the telescoping pole has also been increased, making the mechanism safer to operate. The definition of success is the accomplishment of a goal or process and with the extensive amount of hard work put into this project along with the goals of the project being completed, success has been indefinitely accomplished.

9.2 Lessons Learned

Over the past year, the Palm Harvester team has gone through a major learning curve. As a multidisciplinary team, consisting of predominantly Industrial and Manufacturing Engineering students, two Mechanical Engineering students, and an Electrical Engineering student, each member of the team has learnt how different and similar each discipline really is.

9.2.1 Communication

One of the major factors in this project is communication which includes both communication among the team and communication with the sponsor/advisors of the project. At the beginning of this project, the team set up a shared dropbox folder and group text. The dropbox folder was implemented to allow each member to upload their assigned parts for the reports and any other documents beneficial to the project. In addition to this, the dropbox folder has served as a storage for all the final reports and presentations. This dropbox folder is constantly being used and has successfully served its purpose. The group text has given the team the ability to notify each other of meetings, personal conflicts, status of the parts and assembly, ask questions, and communicate any other project related items. For the most part, the group text has served its purpose but one issue that has arisen from time to time is that sometimes texts go unacknowledged or some team member do not participate in the conversation. One way this could have been avoided was to add a paragraph in the signed code of conduct submitted to the Mechanical Engineering department stating that each member must reply to the group text within an hour of receiving a text. By doing this each member is held responsible, as this document must be signed by each member.

As far as the communication with the sponsor and advisors is concerned, there are many lessons learnt. Throughout the past year, the team has had very few meetings with the sponsor, Dr. Okoli. The reason for this is partly because Dr. Okoli is a busy and important professor so it is hard to get in contact with him and also to find a common meeting time. Another reason for this is that the team has gotten caught up in individual priorities as well as working on the project and has lost track of time since the previous meeting with Dr. Okoli , not realizing another meeting is necessary. A way this problem could have been avoided was the team should have set up permanent bi-weekly meetings with Dr. Okoli at the beginning of the fall semester, which would have prevented the team from having to continuously find Dr. Okoli. By doing this, Dr. Okoli would always know the status of the project and the team would know if the sponsor's expectations are being met.

The communication with the Mechanical Engineering department could also have been improved. The team's first time meeting with Dr. Gupta, Mechanical Engineering advisor and professor, was on March 18, 2015 which is very late in the semester. During that meeting, the team realized that Dr. Gupta had a variety of good suggestions for the project, many of them too late to implement. This being said, it would have been in the team's best interest to have setup meetings with Dr. Gupta from the very start of the project. The Mechanical Engineering Senior Design class requires each Mechanical Engineering led project's team to attend bi-weekly staff meetings with Dr. Gupta, in order to allow Dr. Gupta to give the teams his opinion on the status of their project and to allow the team to ask questions. It would have been helpful if the Mechanical Engineering department required multi-disciplinary projects to partake in these meetings. Throughout the fall semester, the available team members attended monthly meetings with Dr. Chuy, which proved to be very helpful. During the spring semester, the team did not meet with Dr. Chuy as frequently. Overall if the team scheduled bi- weekly staff meetings with the Mechanical Engineering department, the team would have been able to receive multiple opinions from the Mechanical Engineering standpoint which could have possibly improved or added components to the mechanism.

Lastly, the communication between the team and the Electrical and Computer Engineering department could also have been improved. The team was not able to setup a meeting time with Dr. Frank, the Electrical Engineering advisor and professor, as a common meeting time was not found. A few individual meetings occurred with Dr. Edrington, an Electrical Engineering advisor. The team wasn't aware that Dr. Edrington was appointed as one of the advisors for the project until the beginning of the spring semester. The team could have incorporated more electrical components had the communication between the team and Electrical Engineering department been more consistent.

The common problem between the departments and the team was a lack of concrete meetings thus resulting in minimal input from the departments. Although it is very hard to schedule a regular meeting with each individual advisor due to scheduling conflict, a biweekly meeting with each department and the sponsor should have been scheduled. The team has learnt that communication is key to any successful project and had our communication amongst the team and the advisors/sponsor been better, the project could have possibly reached its full potential.

9.2.2 Scheduling

As previously mentioned, scheduling has been a huge problem amongst the team. Since this is a multidisciplinary team, each members class schedules tended to conflict with one another's, as well as personal schedules. This was the same problem with the sponsor and advisors schedules. The only solution to this problem, is that some team members should have rearranged their schedules to accommodate the sponsor, advisors, and the majority of the team members.

9.2.3 Ordering of Parts

The process of ordering parts has been an easy one but certainly not the fastest. Since the company who sold the aluminum poles was not on the approved vendor list, it took over a month to receive them, critically delaying the assembly process. Although the motor came from an approved vendor, it also took over a month to arrive. In order to have received them on time, the team should have sped up the design process and ordered these parts at the end of the fall semester.

9.2.4 Resources

Once spring semester began, the team became familiar with resources available such as the machine shop and HPMI. Since most of the design for the mechanism didn't require intricate machining, the machine shop was not needed. The only component that needed machining was the alignment block which was machined by Mr. Larson, a Mechanical Engineering instructor, in his spare time. The team made the most use out of HPMI for storage and assembly purposes. The entire mechanism has been stored and assembled at HPMI. The most valuable resource was Thomas Baker's vast amount of mechanical tools. Overall there haven't been any issues experienced in regards to the resources available.

9.2.5 Assembling the Mechanism

Due to the delay of the arrival of the parts, the assembling process of the mechanism was also delayed. The main issue with the assembly of the mechanism is that nothing else could be done until the buffer strips were attached to the poles, which took a significant amount of time. Also the addition of the buffer strips were done during spring break which was when most of the team members were unavailable. Since the assembled mechanism did not fit through the doorway of HPMI, the mechanism had to be disassembled after each building session, which wasted a significant amount of time. This being said, if the forecast predicted rain for part of the day, the team were not able to continue the building process that day, as power tools were needed and the mechanism needed to be outside. Besides expected trial and error instances, the assembly of the mechanism did not pose any significant problems.

9.2.6 Budget

The project's budget is the last key factor. A small issue regarding the budget, is that in order to attain a part, it must be put through an ordering process. The palm harvester mechanism required a variety of nuts and bolts, which were unable to be ordered because it wasn't clear what was needed until the assembly process was underway, thus requiring some of the team members to purchase parts with their own money. Other than that, the budget hasn't caused any significant issues, especially because the project is well under budget.

9.2.7 Suggestions for Next Year

In order to improve the Palm Harvester project next year, the team has come up with a few suggestions for the sponsor and the Industrial and Manufacturing department. The palm harvester project requires a mechanism to be made that is able to withstand a variety of forces, be portable, reach a height of 35 ft or more, and cut a palm fruit bunch off the tree at that height in a safe manner. This being said, in order to create a mechanism that truly captures all these factors, there would need to be more mechanical and electrical engineering students. From the current team's standpoint, a successful palm harvester team would consist of three to four mechanical engineering students, two electrical/computer engineering students, and one industrial/manufacturing engineering student. This would allow the design for the mechanism to be more technically inclined and require less manual labor. Another suggestion would be to make mandatory bi-weekly meetings so that the sponsor is always up to date on the status of the project. By implementing these suggestions in the future, the project will run a lot smoother and hopefully produce a marketable product.

10. Summary/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. For the control phase, verification of the design was conducted, consisting of testing and analyzing. Testing revealed that the prototype was able to achieve 88% of the targeted height. From procurement to patience, the team learned a great deal throughout the course of this Control Phase. Due to a low battery, the team was not able to conduct a thorough cutting analysis. Before completion of this project, additional testing will be conducted.

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Appendix A

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

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

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

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

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

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

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

Appendix B

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:

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

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

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

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

Appendix C

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

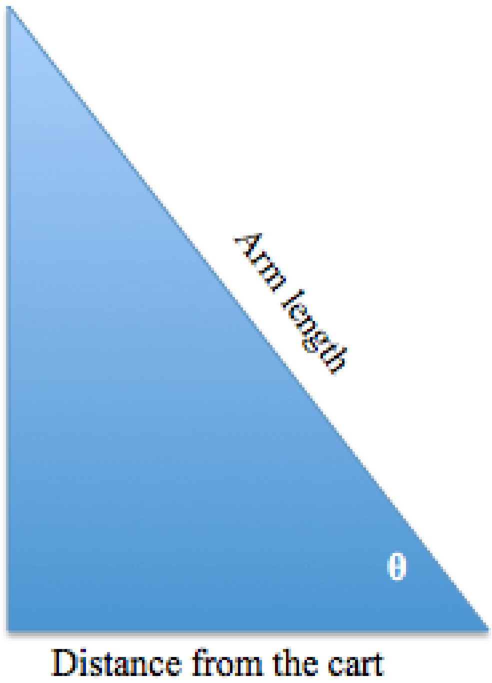
$r := 3in$
$r = 0.076\,m$

Maximum torque required for the motor

$T := F \cdot r$

$T = 38.1 \cdot N \cdot m$

Appendix D



Average height of a Malaysian male is 5.4 feet
Average Malaysian males arm length is 2 feet
With fully extended arms the distance from the workers feet to the cart is 1.5 feet

$\theta = \cos^{-1}(\text{distance from the cart / arm length})$

$\theta = \cos^{-1}(1.5 \text{ feet}/ 2 \text{ feet})$

$\theta = 41.4°$

Appendix E

Square Cross Section:

Height:

$h := 10ft$

Side measurement:

$s1 := 5in$

$s2 := 4in$

$s3 := 3in$

$s4 := 2in$

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:

$A1 := s1 \cdot h = 0.387 m^2$

$A2 := s2 \cdot h = 0.31 m^2$

$A3 := s3 \cdot h = 0.232 m^2$

$A4 := s4 \cdot h = 0.155 m^2$

Drag Force:

$Fd1 := 0.5 \cdot p \cdot v^2 \cdot Cd \cdot A1 = 3.792 N$

$Fd2 := 0.5 \cdot p \cdot v^2 \cdot Cd \cdot A2 = 3.034 N$

$Fd3 := 0.5 \cdot p \cdot v^2 \cdot Cd \cdot A3 = 2.275 N$

$Fd4 := 0.5 \cdot p \cdot v^2 \cdot Cd \cdot A4 = 1.517 N$

Appendix F

$$\sum F_x = 0$$

$$-\mu_s \times F_{normal} + F_{external} \times \sin(\theta) - \ F_{wind} = 0$$

$$\sum F_y = 0$$

$$F_{normal} - W_{cut} - W_{cart} - W_{motor} - W_{poles} - W_{battery} - W_{wheels} + F_{external} \times \cos(\theta) = 0$$