Palm Harvester Project – Measure

Cover Photo 1*[i]*

Submission Date: 12/2/14

Submitted To:

Dr. Okoli

Authors:

Thomas Baker (ME)

Christopher Chiros (IME)

Maurice Derius (IME)

Shaneatha Gates (ECE)

Talya Levin (ME)

Amber Smith (IME)

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Abstract

There is a need to improve the efficiency of harvesting palm fruits from oil palm trees in order to keep up with the demand of palm oil throughout the world. Current methods are extremely dangerous to the laborers that are working to harvest these fruits on oil palm plantations. Last year's senior design team built a mechanism, including a telescoping pole with an electric saw attached to the top in order to harvest the palm fruits. This year's senior design team was tasked with improving the mechanism in order to harvest the fruits safely and efficiently. Many ideas were made, some kept and some thrown out. Final improvements were made and analyzed in order to build the mechanism in spring 2015. Before the end of the current semester, parts will be ordered and a small scale model of the improved telescoping pole will be built.

1 Introduction

The establishment of oil palm plantations is often promoted as a way of bringing development to poor, rural regions that have tropical climate. In reality, this industry often has devastating impacts on the people in these areas. The palm oil industry is also linked to major human rights violations, including child labor. Heat exhaustion and cuts and bruises from climbing thorny oil palms are commonplace in this damaging workspace.

There is a need for a device that will improve the working conditions of plantation associates due to the ongoing turmoil involving unfit work conditions. Once a feasible design and device is prototyped manufacturing this device for commercial use will be the next step. The previous year's project resulted in the creation of a rough prototype. This year the goal is to identify key areas for major improvement.

The Define Phase resulted in the team surveying previous years' mechanism and identifying what essential items needed to be improved upon. As a result there were six key areas that the team would be capable of improving within the time frame of one academic school year. These areas include; automation, material selection, design of telescoping pole, changing wheels, designing an internal pulley system, and lowering the center of gravity.

The Measure Phase gives the opportunity to test the recommended improvements against the previous year device. This will prove the key areas of improvement were essential to having a more effective, efficient mechanism that will be one step closer to improving worker conditions on these plantations.

2 Project Information

2.1 Background Information

The oil palm tree originated in the tropical region of West Africa. Somewhere between the 14th and 17th century, oil palm plant migrated to the Americas and then to the Far East. The palm fruit that grows on these trees are used to produce palm oil. Nigeria, Malaysia, Thailand, Colombia, and Indonesia are the top five producers of this palm oil since these countries possess an ideal tropical climate. Oil palm trees grow in different kinds of plantations, from small scale to large scale plantations. The oil palm tree grow up to an average of 40 feet in and continue to grow palm fruit for 20 to 30 years [ii]. **Figure 1** shows what a 55 pound palm fruit bunch looks like.

Figure 1: A palm fruit bunch [iii]

Currently there are two main methods used to remove the bunches of fruit from the oil palm tree. The first method is shown in **Figure 2** (left) where the plantation worker has to physically climb the tree, with a cutting mechanism in hand, and cut down the palm fruit. The second method, shown in **Figure 2** (right) , consists of the plantation worker using an elongated sickle blade to remove the fruit. Both of these methods are considered highly dangerous, as the plantation worker can either fall off the forty-foot tree with a sharp blade in hand or a worker can get hit by 55 pound bunch of fruit that is falling from forty feet high. **Figure 2** accurately depicts the dangers of these methods

Figure 2: Palm plantation worker climbing tree to remove the bunches of fruit (left) [iv]; worker removing palm fruit bunches from oil palm fruit tree (right) [v]

2.2 Goals & Opportunities

2.2.1 Goals

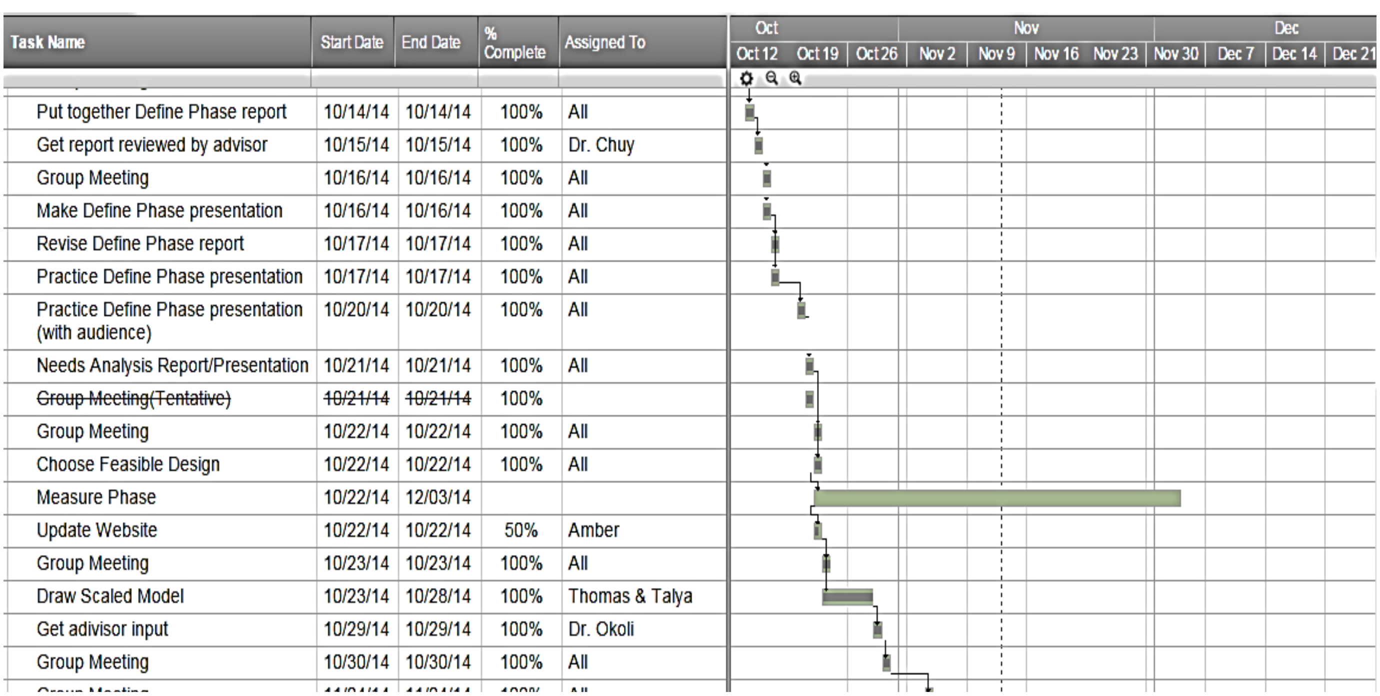
To reaffirm the objective of this project; we are improving the existing palm pruning device to enrich efficiency, lessen injury and increase output. Prior to this phase we stated that currently the labor force either climbs the tree and cuts the fruit down or uses elongated saws. In order for it to be implemented in the oil palm plantations, this device must also be able to maneuver on varying terrain. Therefore, we will aim to eliminate this labor. Among these improvements: maximizing stability of telescoping pole, reducing risk of injury, and increasing portability are essential to target when planning a vendible mechanism.

2.2.2 Opportunities

Condensed milk, coffee cream, ice cream and margarine are all partakers in the unfamiliar palm fruit. There is a secret opportunity in this industry because there is a need for a more efficient way to harvest this fruit. As of recent, India leads palm oil consumption with 14% globally; followed closely by Europe and China. With some of the wealthiest nations as top consumers, the chance take part in this market is at hand. Beneficiaries of such a device are widely are underdeveloped countries such as Malaysia and Indonesia. Consequently the need for an efficient palm harvester could thrive in this current market.

2.3 Gantt chart

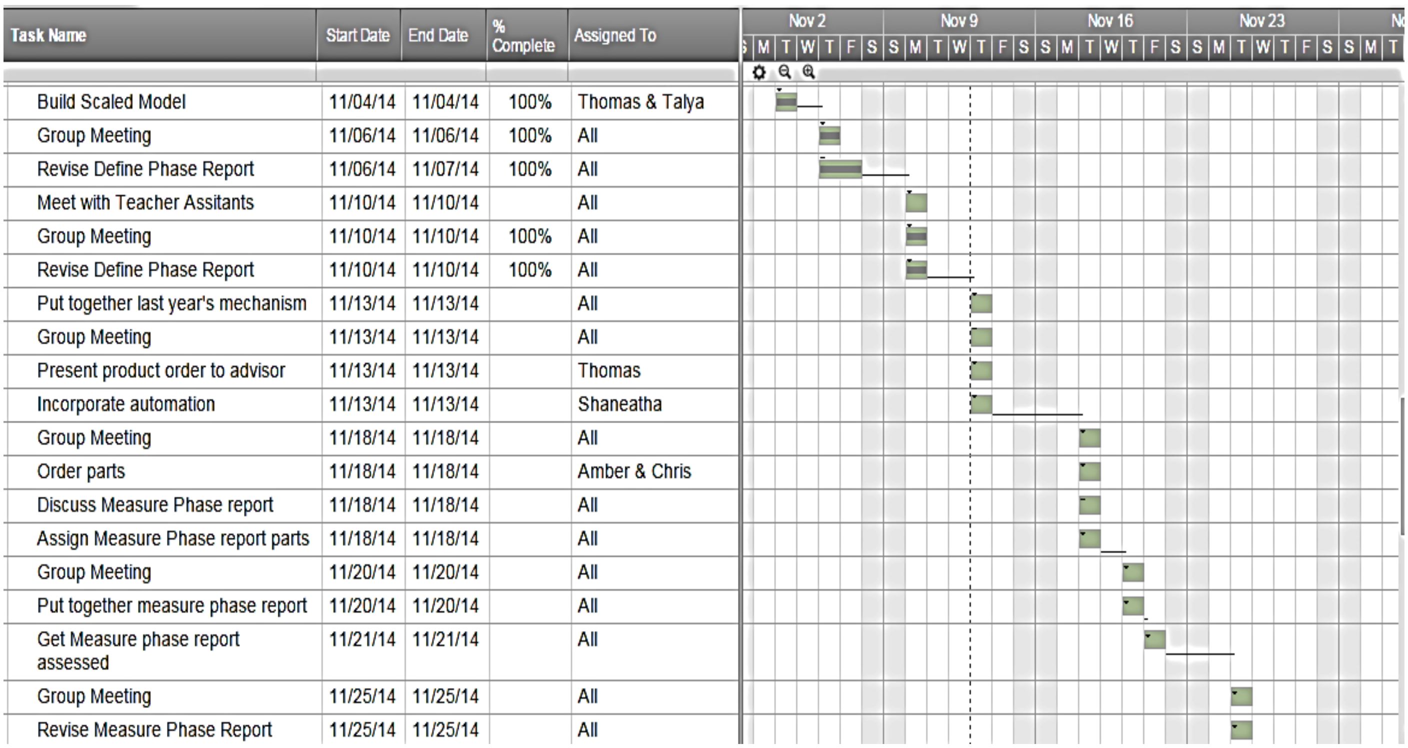
The project is be organized using a Gantt chart to ensure progress is being made towards a successful mechanism. Tasks are created based on the deadlines of the different phases. All tasks are assigned to individuals on the team or all team members may be needed to complete these tasks. The palm harvester group has two weekly meeting where the progress of the project is discussed and various action items are completed to ensure a productive use of time.



Task Name	Start Date	End Date	% Complete	Assigned To
Put together Define Phase report	10/14/14	10/14/14	100%	All
Get report reviewed by advisor	10/15/14	10/15/14	100%	Dr. Chuy
Group Meeting	10/16/14	10/16/14	100%	All
Make Define Phase presentation	10/16/14	10/16/14	100%	All
Revise Define Phase report	10/17/14	10/17/14	100%	All
Practice Define Phase presentation	10/17/14	10/17/14	100%	All
Practice Define Phase presentation (with audience)	10/20/14	10/20/14	100%	All
Needs Analysis Report/Presentation	10/21/14	10/21/14	100%	All
~~Group Meeting(Tentative)~~	~~10/21/14~~	~~10/21/14~~	100%	
Group Meeting	10/22/14	10/22/14	100%	All
Choose Feasible Design	10/22/14	10/22/14	100%	All
Measure Phase	10/22/14	12/03/14		
Update Website	10/22/14	10/22/14	50%	Amber
Group Meeting	10/23/14	10/23/14	100%	All
Draw Scaled Model	10/23/14	10/28/14	100%	Thomas & Talya
Get adivisor input	10/29/14	10/29/14	100%	Dr. Okoli
Group Meeting	10/30/14	10/30/14	100%	All

Figure 3: Portion of Gantt chart highlighting the end of the Define Phase and beginning of the Measure Phase

Figure 3 shows the ending of the Define Phase which included the following key action items being completed; submitting needs analysis report, giving the Define Phase presentation, and choosing a feasible design to move forward in the Measure Phase. The Measure Phase begins with updating the team website, this task is 50% completed because not all information was collected to update the site however the completion of this task is not critical until the due date of November 25th. The first critical task of the Measure Phase is drawing a scaled model of

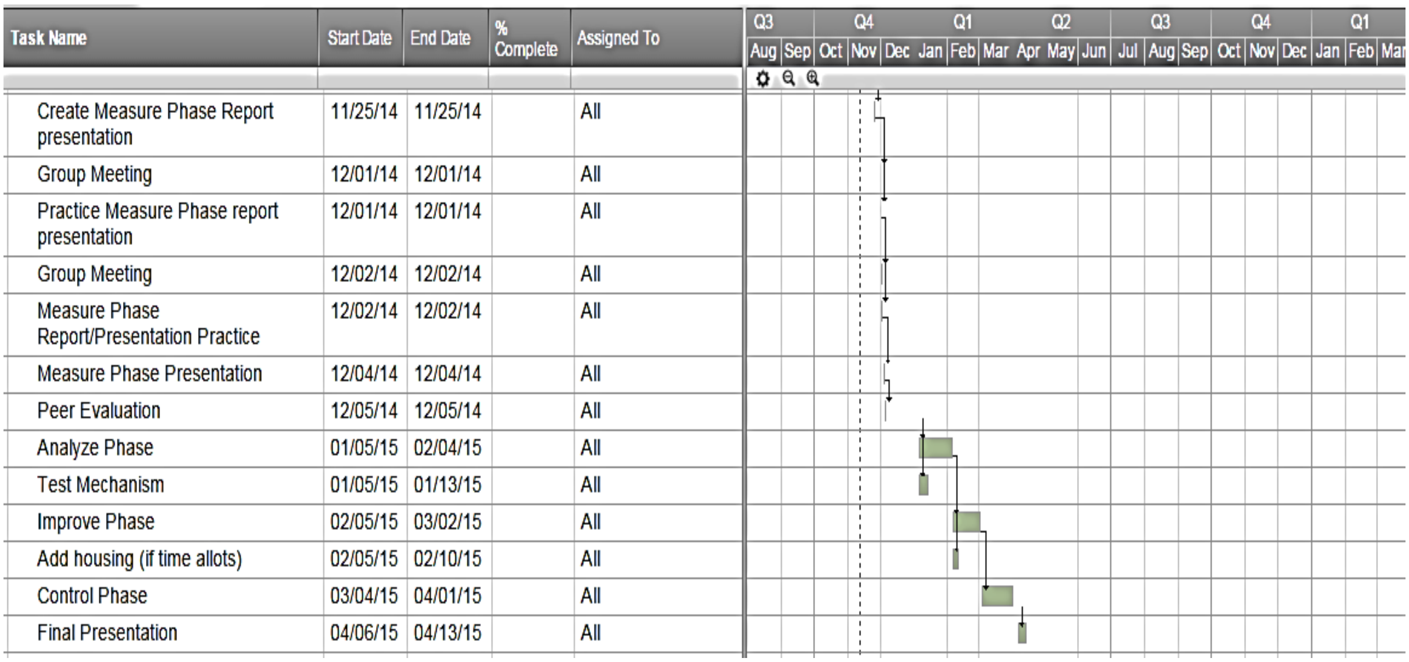


Task Name	Start Date	End Date	% Complete	Assigned To
Build Scaled Model	11/04/14	11/04/14	100%	Thomas & Talya
Group Meeting	11/06/14	11/06/14	100%	All
Revise Define Phase Report	11/06/14	11/07/14	100%	All
Meet with Teacher Assitants	11/10/14	11/10/14		All
Group Meeting	11/10/14	11/10/14	100%	All
Revise Define Phase Report	11/10/14	11/10/14	100%	All
Put together last year's mechanism	11/13/14	11/13/14		All
Group Meeting	11/13/14	11/13/14		All
Present product order to advisor	11/13/14	11/13/14		Thomas
Incorporate automation	11/13/14	11/13/14		Shaneatha
Group Meeting	11/18/14	11/18/14		All
Order parts	11/18/14	11/18/14		Amber & Chris
Discuss Measure Phase report	11/18/14	11/18/14		All
Assign Measure Phase report parts	11/18/14	11/18/14		All
Group Meeting	11/20/14	11/20/14		All
Put together measure phase report	11/20/14	11/20/14		All
Get Measure phase report assessed	11/21/14	11/21/14		All
Group Meeting	11/25/14	11/25/14		All
Revise Measure Phase Report	11/25/14	11/25/14		All

Figure 4: The current Measure Phase action items completed

the apparatus, this is important for the electrical engineer to move forward with the design of automation.

Currently the Measure Phase has the following key action items that have been completed; meeting with teacher assistants, revising the Define Phase report, and putting together last year's mechanism. Ordering parts has been a critical task that weighs heavily on the completion of the Analyze Phase. The arrival of the parts in time relies on the future assembly of the actual mechanism. Along with the sample mechanism, putting together the Measure Phase report is critical for meeting deadlines set by the department.



Task Name	Start Date	End Date	% Complete	Assigned To
Create Measure Phase Report presentation	11/25/14	11/25/14		All
Group Meeting	12/01/14	12/01/14		All
Practice Measure Phase report presentation	12/01/14	12/01/14		All
Group Meeting	12/02/14	12/02/14		All
Measure Phase Report/Presentation Practice	12/02/14	12/02/14		All
Measure Phase Presentation	12/04/14	12/04/14		All
Peer Evaluation	12/05/14	12/05/14		All
Analyze Phase	01/05/15	02/04/15		All
Test Mechanism	01/05/15	01/13/15		All
Improve Phase	02/05/15	03/02/15		All
Add housing (if time allots)	02/05/15	02/10/15		All
Control Phase	03/04/15	04/01/15		All
Final Presentation	04/06/15	04/13/15		All

Figure 5: The portion of the Gantt chart that shows the future plans of the project

Figure 5 briefly forecasts the future plans for the project. Once the Measure Phase is completed the Analyze, Improvement, and Control Phase will be completed next semester.

3 Measure Phase

3.1 Process Improvement Analysis

The design made by last year's group has some obvious design flaws that are our main concern when revamping this project. When attempting to assemble the palm harvester many problems arose. The first step of assembling this device was pulling the wire, which is attached to the crank on the cart, approximately ten feet out and attaching it to the first pulley on the telescoping pole. Ten feet is not an exact measurement, the wire just has to be able to reach the pulley and remain in place while the pole is stood up. The lack of tension on the wire makes it really easy for it to slip off the pulley when putting the pole up. The team ran into this problem multiple times when assembling the palm harvester. To avoid this problem, another group member was assigned to keep tension on the wire, by pulling on it, while the pole was stood up. The second step to this process is lifting the pole itself. The pole weighs around 100 lbs and it took two people to lift it as well as another person to aim it into the ring slot on the cart. Once the pole is in the ring, standing it up required two team members to push the top end, one person pulling the wire so it would not fall off the pulley, and another to guide the pole into the alignment block. Actually placing the pole on the alignment block is very dangerous, as it can crush someone's fingers. The team had a lot of trouble with this step, it required a lot of manual force and it was very dangerous. The next step is tightening the ring to keep the pole in place, which is not an ideal securing method. It focuses all the force on one spot of the pole and can end up damaging the pole itself. It also does not do much to keep the pole from swaying. The cranking of the wire is a very tedious process. Not only is it physically stressful, it is very time consuming as well. Extending pole to its ideal height, took 52 full circular rotations on the crank.

Disassembling the cart is also a hassle that does not seem viable for a worker to be doing out in the plantations. Lowering the telescoping pole in itself took. Similar to extending it, it took approximately 50 full turns on the crank to fully lower it down. After the pole is retracted, slack has to be put on wire in order for the pole to be taken down. This process again requires more cranking and it is hard to determine how much slack one should put on wire. The pole is then released by untightening the tightening bolt. The next process is to manually lift the pole so it is off the alignment ring while leaning the pole to one side. A team member has to catch the 100 lb pole as it falls down. This step again was very dangerous. Afterwards, the pole is then removed from the cart and the wires are detached. The Assembly Process flow can be seen in **Figure 6.**

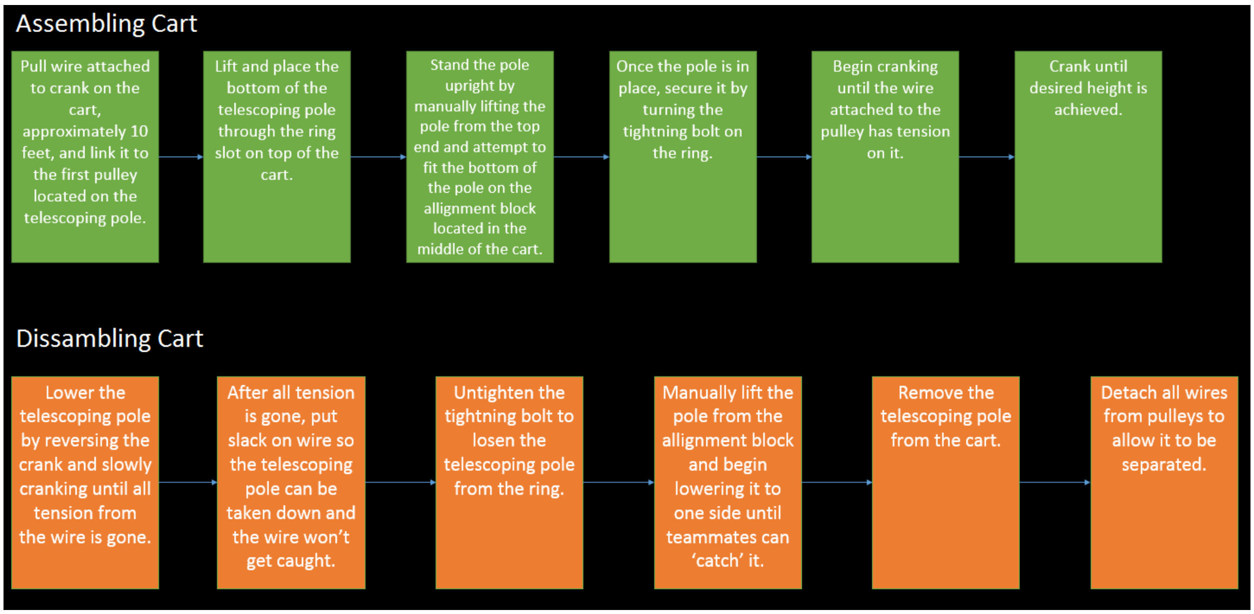


Figure 6: Process Flow Diagram of Assembly (top) and Disassembly (bottom) of the cart

Two separate trials of assembling and disassembling the palm harvester were recorded. On average it took 6 minutes and 15 seconds to assemble and 1 minute and 50 seconds to dissemble the harvester without setting up the cutting blade or the tree grippers. One of the trials had each step recorded individually to see where most of the time was taken up. **Table 1** displays the times needed for each step of assembling and disassembling the palm harvester without the cutting device or the tree grippers. In this trial there were no problems with the pulley system, most of the time was used in standing up the device. The reason the average time of assembly is so high, is due to a problem the team encountered with the pulleys in one of the trials. The wire slipped off one of the pulley, which is a problem that has occurred many times when assembling the palm harvester. The time for that assembly trial was not discarded, as this problem can easily occur and that time added is not irrelevant.

Table 1: Steps from Figure 6 and their respective times.

Steps	Assembling Time	Disassembling Time
1	0:00- 0:39	0:00- 0:40
2	0:39- 1:15	0:40- 1:12
3	1:15-2:15	1:12-1:22
4	2:15-2:25	1:22-1:50
5	2:25-3:10	1:50-2:05
6	3:10-3:50	2:05-2:20

The biggest problems the team faced when assembling and disassembling this device were the pulley wires getting caught, the weight of the device, and the amount of people required to operate this machine. When assembling the palm harvester it required multiple attempts due to a wire constantly coming off a pulley. This problem will be fixed when the wires and pulleys are placed inside the telescoping pole with the new design. The sheer weight of the device was a huge problem. It is hard to imagine a worker being able to maneuver all this weight around a plantation throughout the day. Lifting and taking down the telescoping pole was dangerous and required a significant amount of strength. This palm harvester should ease the job of the worker, not complicate it. In the plantation, it is not viable having four workers assigned to one palm harvester. Three group members were needed just to lift the heavy pole, place it in the ring, and stand it upright, as well as an extra member just to hold tension on the wire to ensure it did not fall off the pulley. This process is just not viable on the working field. These main concerns are being tackled with the new design. With the new design, the time of assembly and disassembly is to be improved significantly.

3.2 Mechanical Systems Overview

3.2.1 Telescoping Pole

3.2.1.1 Cross-Sectional Shape & Material

It was decided that one of the largest changes to the palm fruit harvester was the switch from circular to a square cross section for the telescoping pole. Having a square cross section will allow for easier mounting of the pulleys to the inside walls of the telescoping pole sections. This would be difficult to do if the cross section were circular because the back shield of the wall mounted pulley is flat, therefore not allowing the pulley to be attached to the pole in a safe and effective way. The gaps in between each section of the telescoping pole will be consistent from section to section allowing for the same pulleys to be used. A circular cross section will not allow for mounting pulleys on the inside.

Rotation of sections relative to one another in a circular cross section cannot occur due to the misalignment of pulleys. Without the pulleys aligned there is a possibility of the cables slipping off the wheel, preventing the pole from telescoping. A square cross section will prevent this rotation from occurring and allow all of the pulleys and cables to stay aligned. Last year's telescoping pole was made of PVC and steel. PVC was used for the bottom three sections and steel for the upper section. The team has decided to change the entire telescoping pole to Aluminum 6063 in order to increase the yield strength of the entire pole. Other materials such as plastic, carbon fiber, and steel were considered but aluminum seemed to be the best candidate. Plastic didn't provide the necessary yield strength, carbon fiber had all the necessary mechanical properties but was way too expensive, and steel was much to heavy. Aluminum was chosen as the best candidate as it has a high yield strength allowing the user to see the pole start to yield, incase the pole for begins to fail. By seeing the pole yield the user will not be surprised when the pole fails as it will not be abrupt like a brittle material. In addition to having a high yield strength, aluminum is lightweight and cost efficient.

3.2.1.2 Stress & Deflection Analysis

Before implementing the telescoping pole improvement design, analysis must be done on both the current and improved designs. Both stress and deflection analysis must be done on both mechanisms in order to perform a comparison, which will help ultimately decide whether the improvement design is even feasible. A stress analysis for each telescoping pole was performed using Creo Parametric, resulting in a Von Mises Stress diagram for each. In order to do an equivalent comparison, the same forces were applied to the two poles. These forces along with a legend are shown in the schematic in **Figure 7**.

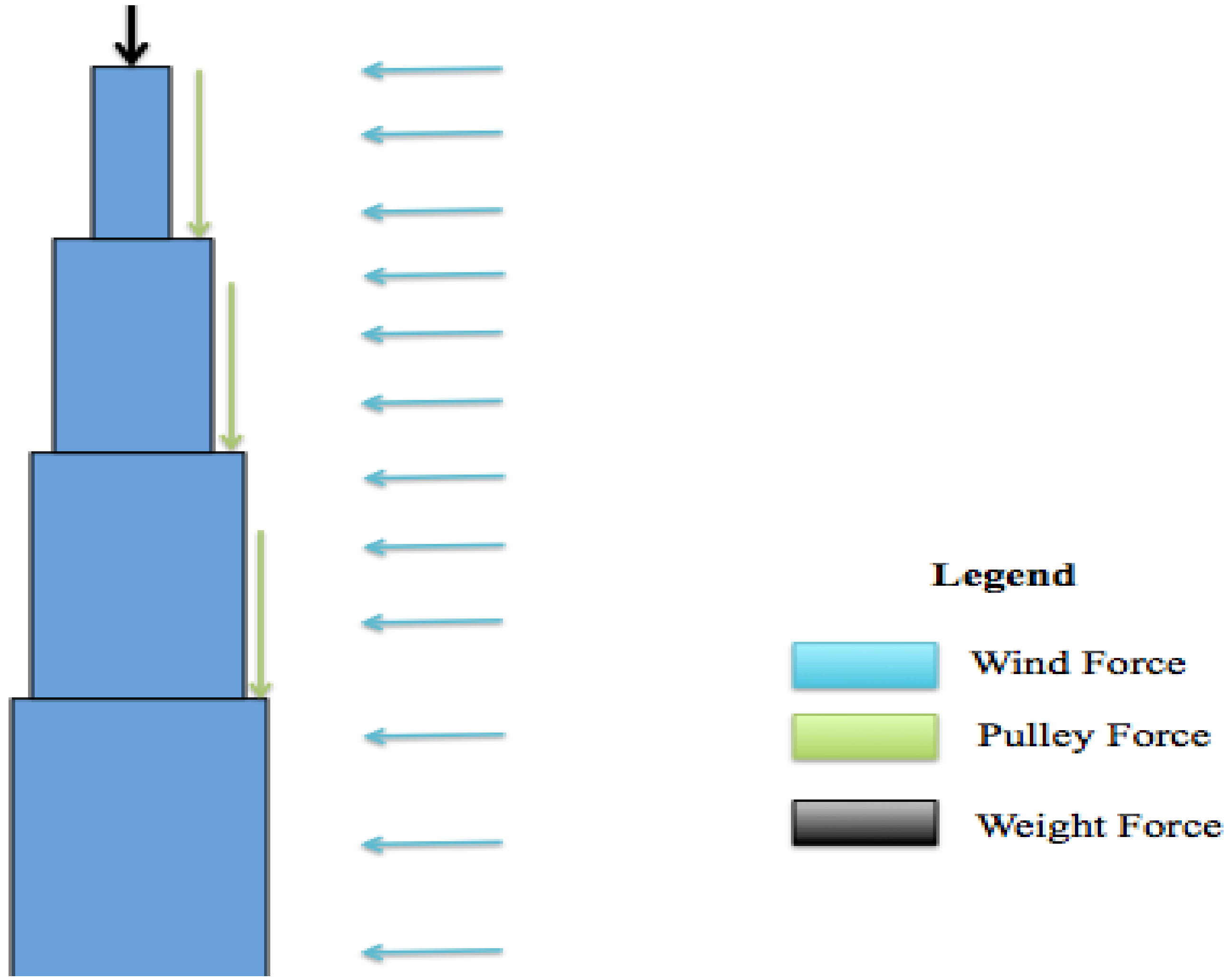


Figure 7: Schematic of forces on telescoping pole

The wind force applied to the telescoping pole was found using the average maximum wind velocity in Malaysia (given that most oil plantations are located there) and using the coefficient of drag to find the force of drag. These calculations are shown in section 7.4 of the Appendices. The pulley forces shown are based on the weight applied to each section of the pole. For instance, the pulley force applied on the first section is due to the weight of the three poles above it and the weight of the cutting and camera mechanism that rests at the top of the pole. Lastly there is a weight force at the top of the pole due to the weight of the cutting mechanism and the camera. The pulley forces were placed on the same side of the mechanism that the wind force were blowing on in order to receive maximum results.

Using these forces shown in **Figure 8**, a Von Mises Stress Diagram was attained for each telescoping pole, the current and the improved one. **Figure 8** shows the Von Mises Stress Diagram for the current mechanism, which is made up of three PVC pipes and one steel tube (top section).

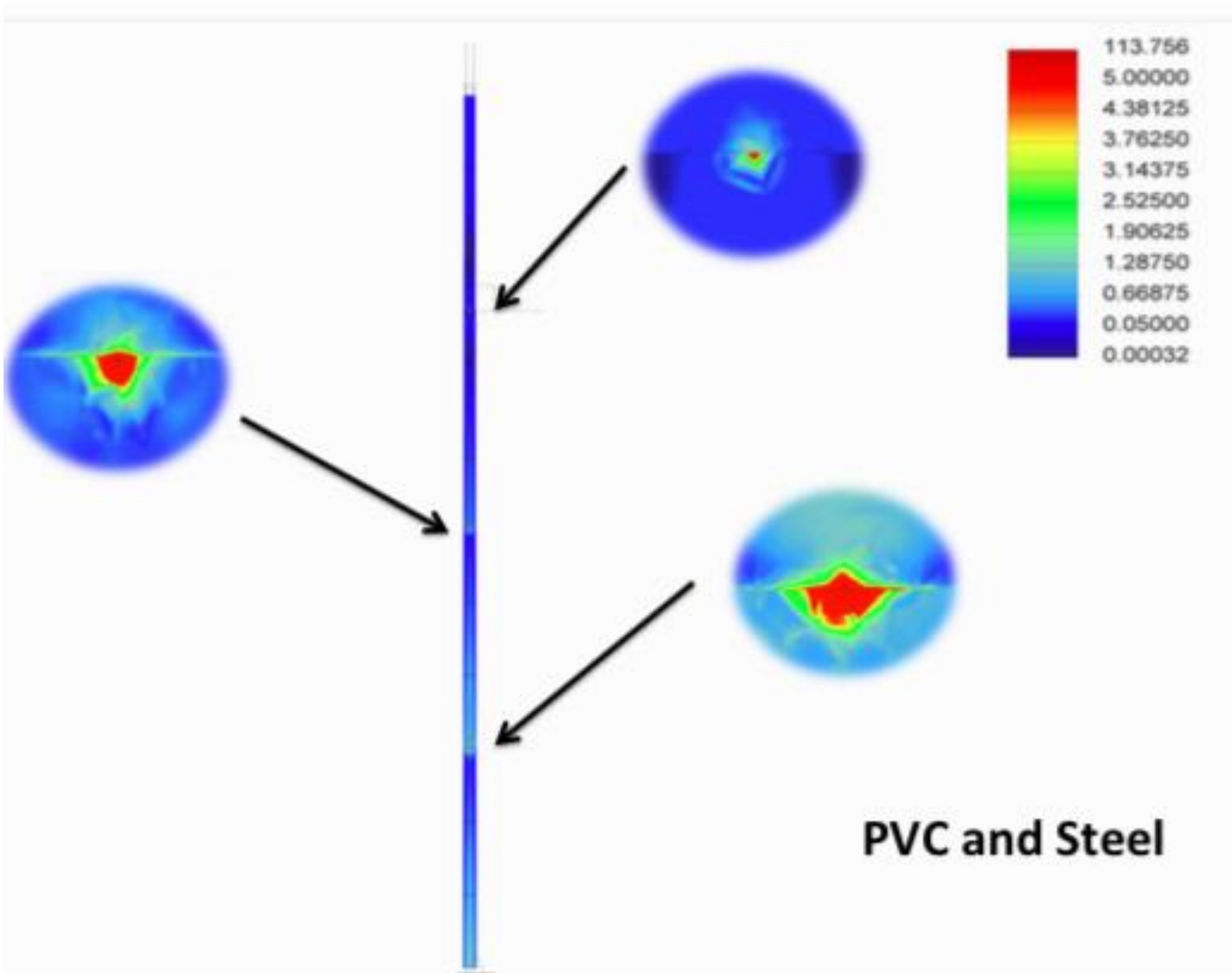


Figure 8: Von Mises Stress diagram of the current telescoping pole design

The stress values shown in **Figure 8** are in units of megapascals (MPa) where 113.76 MPa is the maximum stress and 3.2×10^{-4} MPa being the minimum stress. Each bubble shown in the figure is a zoomed in view of the section between two poles. These bubbles show the stress distribution at the connection of each pole where the pulley forces are applied. The lower bubble has the largest distribution of red since at that point the largest pulley force is applied. The middle bubble still has a fair red distribution and the top bubble has a tiny red stress distribution since it has the smallest pulley force applied to it.

Figure 9 displays the Von Mises Stress diagram for the improvement telescoping pole design, where all four tubes are made out of aluminum.

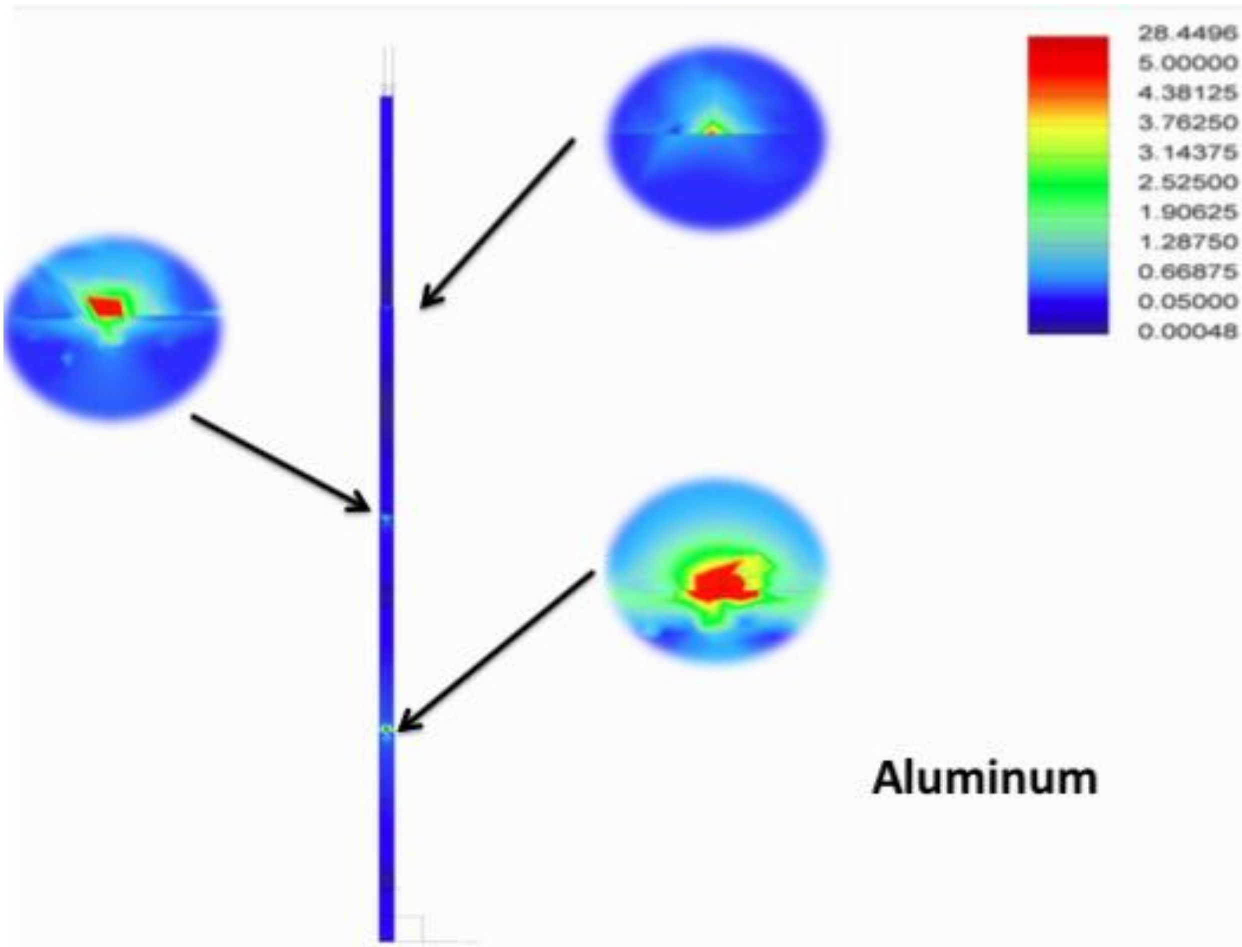


Figure 9: Von Mises Stress diagram of the improvement telescoping pole design

The stress values shown in **Figure 9** are in units of megapascals (MPa) where 28.45 MPa is the maximum stress and 4.8×10^{-4} MPa being the minimum stress. Each bubble shown in the figure is a zoomed in view of the section between two poles. These bubbles show the stress distribution at the connection of each pole where the pulley forces are applied. The lower bubble has the largest distribution of red since at that point the largest pulley force is applied. The middle bubble still has a fair red distribution and the top bubble has a tiny red stress distribution since it has the smallest pulley force applied to it.

Although the stress diagrams for the current and improvement design look similar, the important thing is to keep in mind the stress distribution scale. The current mechanism experiences a much larger maximum stress than the improvement design, a little more than four times its value. More specifically, the larger the stress applied the more complications that arise. A component exposed to a large stress will be more susceptible to failure, thus making the improvement design a better candidate.

Since the telescoping pole can be modeled as a vertical cantilevered beam in bending (due to the wind forces), it is important to analyze the deflection of the telescoping pole. Deflection is very important because the higher the deflection the larger the chance becomes for pole to bend and snap. A comparison of the deflection of the current and improvement design of the telescoping pole is shown in **Figure 10**, where the displacement is measure in meters.

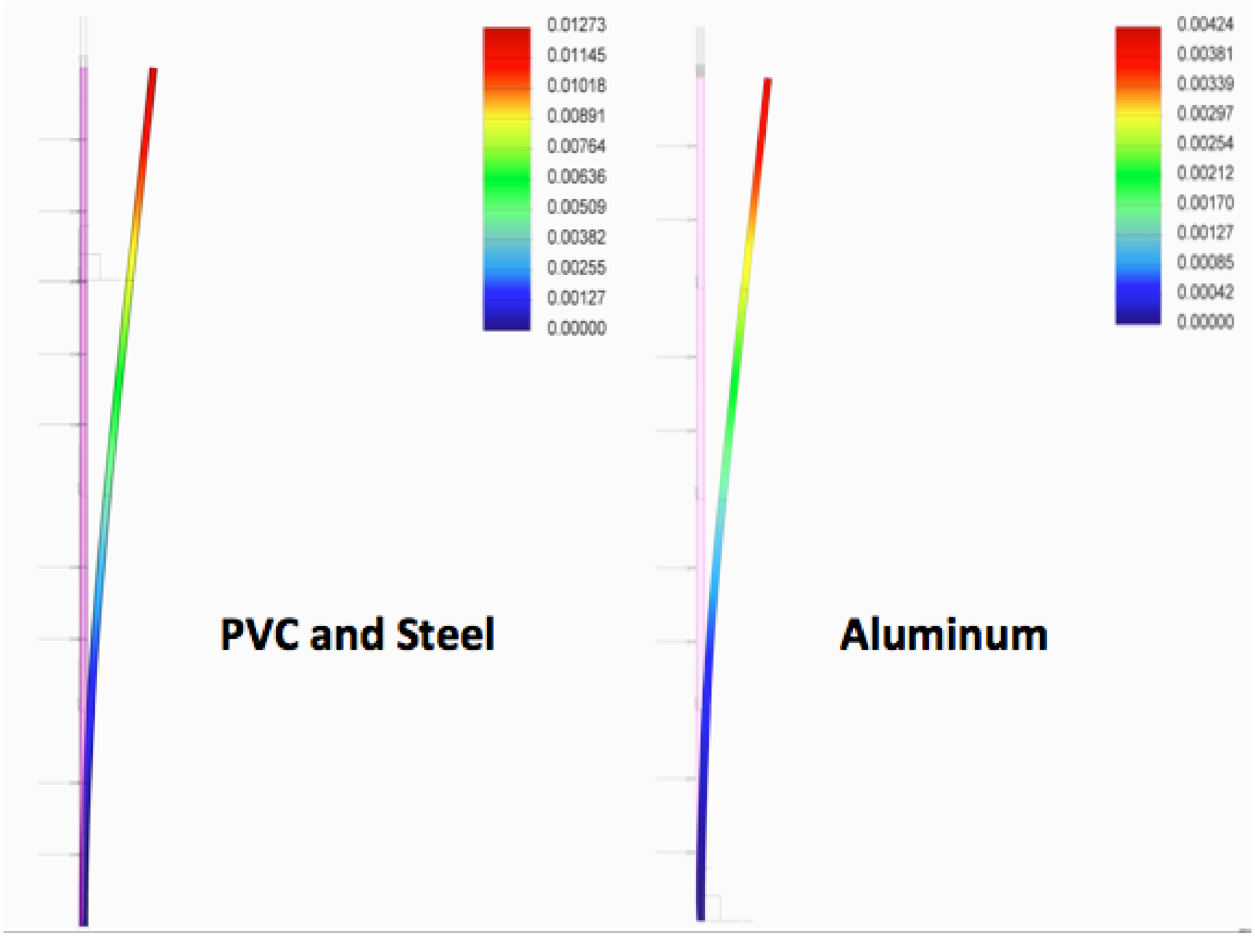


Figure 10: Deflection diagram comparison in meters

From the comparison deflection diagram shown in **Figure 10**, it can be seen that the deflection distribution in both designs are very similar. The bottom of the pole barely deflects and as you reach the top of pole the largest deflection is attained thus being the most critical part. The maximum deflection of the aluminum-telescoping pole is 4.24 mm and the PVC/Steel poles maximum deflection is 12.73 mm thus making the improvement design a better candidate. Overall the improvement design has proved to be the best candidate as it sustains lower stresses and has a low deflection.

3.2.1.3 Cost Analysis

In order to create the improvement-telescoping pole, four 10 foot aluminum square tubes must be purchased. The first tube will have a 6inch by 6 inch cross section, then 5 by 5, 4 by 4, and 3 by 3 with a thickness of 1/8 inch. These square tubes will be purchased from Discount Steel for a total of $787.07, which includes tax and shipping. Last year's mechanism's combination of PVC and aluminum circular cross section tubes cost a total of $79.55 [vi].

3.2.2 Cart

3.2.2.1 Lowering Center of Gravity

The cart being used for this mechanism has two levels, the top level where the telescoping pole rests and the bottom level which is used for storage purposes. **Figure 11** shows the current cart setup.

Figure 11: Current setup of cart

Since our improvement of the palm harvesting mechanism requires the telescoping pole to be in the upright position most of the time, it is not ideal for the compressed pole to stick up from the cart by a large amount. In order to minimize the amount of pole sticking up from the cart, it has been decided by the team to move the resting position of the pole to the lower level, which will minimize the amount the pole sticks up from the cart by 0.762 m (2.5 feet). In return, this will lower the center of gravity, increasing the stability in the pole. To do this, a square cross section will be cut out of the top level of the cart to allow the pole to stick out of the top layer. This square cross section that will be cut out of the cart will have just enough clearance to fit the cross section of the telescoping pole. There will be no additional cost for lowering the center of gravity.

3.2.2.2 Wheels

In order to improve the mobility of the cart, it would be advantageous to purchase new wheels. Currently, the palm harvesting mechanism uses 10 inch pneumatic swivel caster wheels, as shown in **Figure 12**.

Figure 12: Current cart wheels[vii]

This issue with these wheels are that they are prone to continuous deflation thus making the cart hard to maneuver in a smooth manner. While on rough terrain, such as grass and muddy ground, these wheels frequently get stuck needing a quick jolt in order to continue moving. Although these wheels satisfy their objective by making the cart mobile, they do not do so in an efficient manner. Taking this into account, as a team, it was decided that these wheels should be replaced with ones that are not prone to deflation. The wheels chosen to replace the current ones are shown in **Figure 13**.

Figure 13: Improvement wheels [viii]

These wheels that were chosen are made out of polyurethane thus minimizing the chance for a flat tire. By making the $119.97 investment, the user will have an easy time pushing the cart from tree to tree.

3.2.2.3 Locking Mechanism

Another aspect that will be improved is the pole locking mechanism. Since the current mechanism is for a circular pole it must be redesigned to fit the improved square design. The existing pole locking mechanism consists of a circular solid piece that is attached to the cart where the pole rests. This circular solid piece is about the same diameter as the inner diameter of the pole, allowing the pole to rest around this piece. In addition to this, there is a piece that assists in pivoting the pole as well as allows the pole to rest on the circular solid piece and be tightened using a threaded tightening bolt. **Figure 14** shows the current locking mechanism.

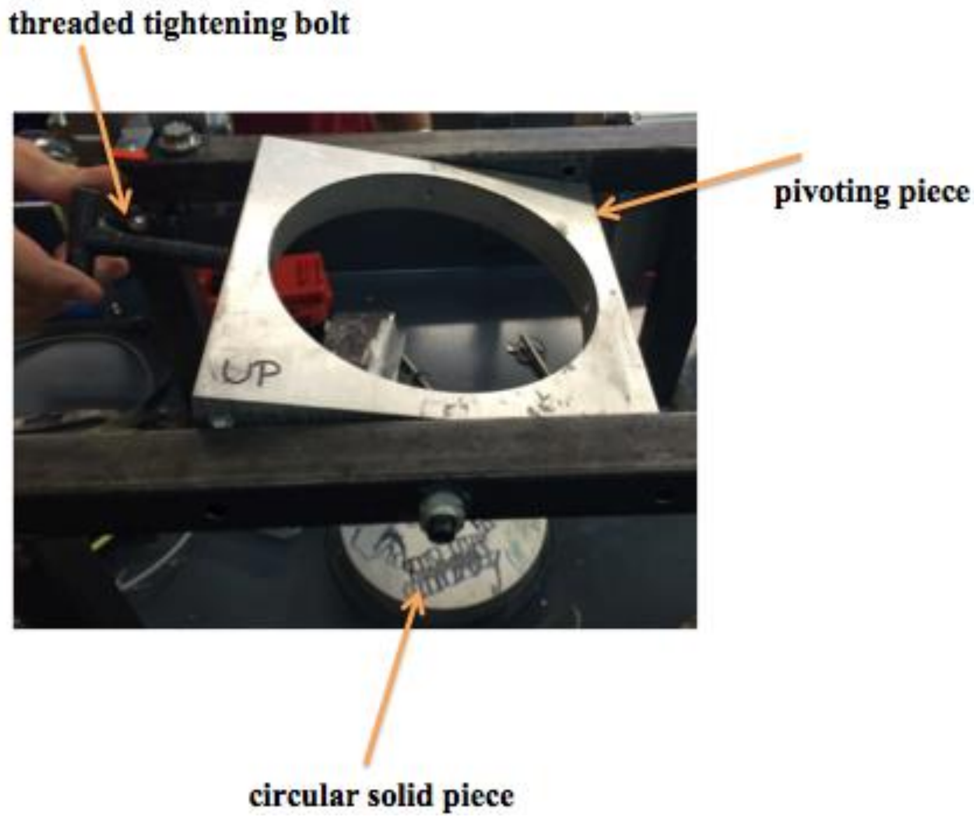


Figure 14: Current locking mechanism

The improved design for the locking mechanism is shown in **Figure 15**. The new locking mechanism consists of four walls, a threaded tightening bolt, and a pressure plate. Three out of the four walls will fit snug around the telescoping pole and the fourth wall will have a space between it and the pole. In this space there is a pressure plate which acts as the snug fourth wall of the mechanism when threaded bolt is tightened, allowing the pressure plate to fit snug on the fourth side of the pole. By having a locking mechanism that tightens around all four sides of the pole, each side essentially feels the same amount of force removing the chance of a concentrated stress point.

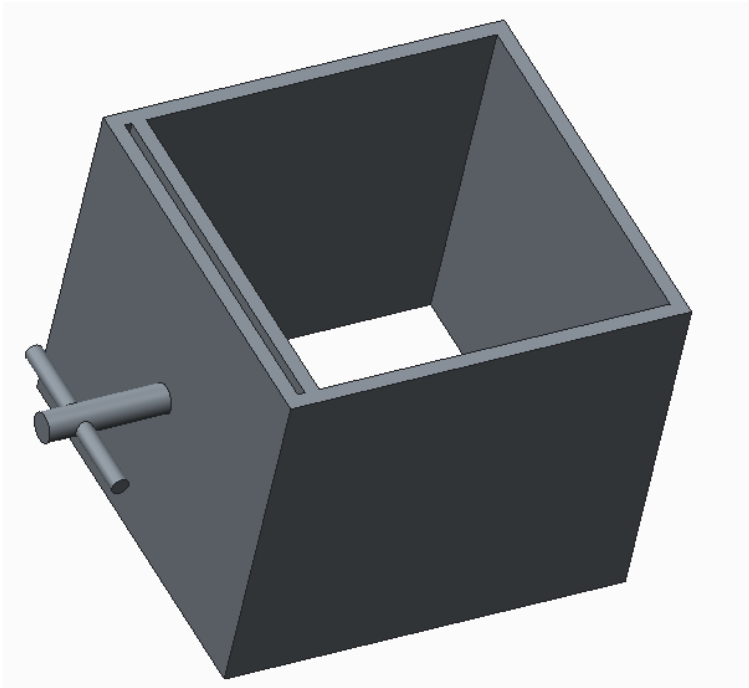


Figure 15: Improved pole locking mechanism

3.2.2.4 Cost Analysis

The wheels used for the improvement design are 10 inch No-Flat Replacement Turf Tires that can be purchased from Amazon for $29.99 each. Since four wheels are needed, the total cost for the improvement wheels is $119.96 [viii]. The cost of the deflating tires of last year's mechanism was $63.96 [vii]. Although the new tires are more expensive, long term this will save money from having to replace the old tires that wear faster. Since the locking mechanism is a new concept, the cost analysis has not been done on it however it is projected to cost less than $100. The locking mechanism will be assembled after the telescoping pole, therefore a more in-depth cost analysis will be included in the future reports.

3.2.3 Pulley System

3.2.3.1 Design

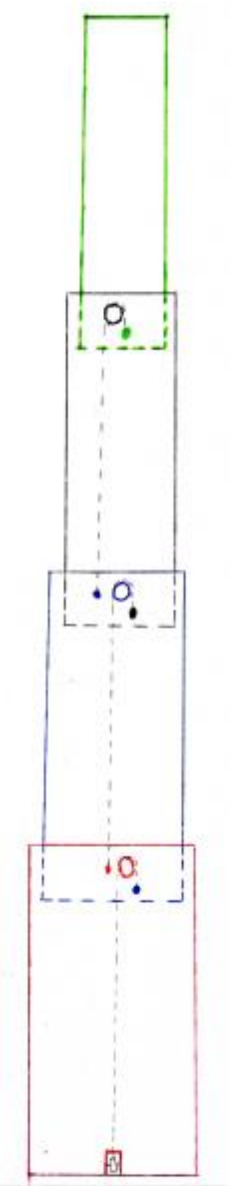


Figure 16: Pulley Schematic

The use of a series of pulleys along with an electric motor will raise and lower the telescoping pole. The goal is to keep all of the cables and pulleys inside of the square cross-section in order to prevent the cables from becoming tangled in the surrounding trees. The telescoping pole will be made up of four sections and each pair of sections (Ex. sections 1 and 2, sections 2 and 3, etc.) will have its own pulley system. A diagram of the pulley configuration can be seen in Figure 16. The cable protruding from the bottom of section one (red) will be pulled by the electric motor. Sections one through three will each have a wall mountable pulley attached to the top inside wall for each respective section. For each separate pulley section, the beginning of the cable will be attached to the inside face of the previous section, wrap around the wall mounted pulley on the current section, and finally the end of the cable will be attached to the bottom outside face of the next section. This pulley configuration will allow for each section to begin telescoping as soon as the electric motor is turned on; allowing for the quickest pole extension time. Note that Figure 16 is not drawn to scale and the pulleys, along with the beginning and end of the cables are in relative positions. This figure is only meant to depict the cable wiring setup.

An advantage to putting the pulley system inside of the telescoping pole is the decrease in the moment applied to the bottom section. Last year's design used a hand crank which mounted to the side of the cart in order to raise and lower the telescoping pole. The cable went from the winch to the pulley mounted at the top of the lower section of the telescoping pole. When the winch was turned to extend the telescoping pole, a moment was generated on the pole, making the entire mechanism tilt toward the user cranking the winch. The new pulley design will not generate this moment because the pulley at the bottom of the first section will direct the force in the cable directly upward.

Since the lengths of each section are the same between last year's project and this year's project, the same cables can be used in order to simplify the ordering process and save the team money. The cabling that is being used is made of galvanized steel rope of 0.118in diameter. There will be one inch of spacing in between the sections of the telescoping poles. This will allow for a wall mounted pulley thickness of less than one inch. **Figure 17** shows an example wall mounted pulley that works with the current design. This particular pulley can be found in town at a Lowes or Home Depot to allow for saving on shipping costs. The maximum rope size is 0.375in which is well suited for the diameter cable being used. All of the pulleys will be attached using low profile stainless steel bolts in order to minimize the possibility of interference between the bolts and the telescoping process.

Figure 17: Wall-mounted Pulley (left) [ix] and Pulley Cable (right) used in the current design

3.2.3.2 Cost Analysis

For the pulley system, many of the old parts such as the pulley cable will be reused.

Seven new pulleys will be purchased from Lowes, where each pulley costs $4.90. The total cost for all the pulleys will be $34.46. Approximately $30 will be set aside in case the pulley system requires new nuts, bolts, etc. The cost for the entire pulley system is approximately $64.46. The cost of last year pulley system was $151.78 including all the nuts and bolts thus adding to the improvement of total cost of the mechanism.

3.2.4 Power and Automation

3.2.4.1 Design & Control

As the previous team concluded, the power outline of this project is dependent on the devices that need to be powered. After careful analysis it looks as though all of the equipment needed to power the palm harvester from the previous design can be reused in this years' improvements. As a recap, **Table 2** is an overview of the components that will be reused. It is important to note that the other changes in the project: material, cross-sectional shapes and pulley system, do not have a direct effect on these components. This means their power consumption will remain unchanged.

Table 2: Overview of Components being reused

Component	Function	Power Consumed (W)
Pole Saw	Cuts down Fruit	800
Camera	Allows Operator to see fruit	0.72
Monitor	Allows Operator to see fruit	8

The prior years' model was able to incorporate the above constituents and yield a prototype focused on manpower; with this years' design we would like to reduce if not eliminate this. We will do this by replacing the hand crank with an automated system controlled by a push button. Currently the telescoping pole expands and retracts manually, however upon completion our device will operate with the push of a button. This change will reduce manual labor, increase efficiency and minimize injury. Complimenting this improvement we plan to make the connection between the camera wireless and as see in **Figure 18** This will diminish the amount of wires we have residing inside of the pole. This will also give the overall design a more qualified look, as our goal is to make a marketable device. With these enhancements we can aim to compete with local practices of retrieving the fruit; making this device merchandisable in industry.

Figure 18: Wireless Monitor and Camera Transmitter [x]

In order to integrate automation and reduce manual labor we will use a DC brush motor. This DC motor will perform the duties and be most cost effective. Careful consideration is still going forth in choosing which type of motor to use however, the numbers have already been calculated to narrow this search. From a mechanical aspect, the torque calculated is 38.1 Nm. Given the 10% of flexibility, we have an overall torque of approximately 42 Nm; this will be taken into account when choosing our motor. These calculations may undergo review as was want to purchase the correct motor and not spend unnecessary funds. Also, accurate torque must be measured to overcome stall or startup torque; this is important because the motor must overcome the initial force that it has to carry.

We want our machine to be competitive with current harvesting processes, therefore the lowering and raising of the pole should be hasty. The rotations per minute (RPM) in the motor will come into play here. Most motors that were researched have a 1750 RPM yielding an efficient and competitive extend and retreat for the pole. Other considerations with the motor are to find a motor with a built-in worm gear or rack and pinion so that when the pole retreats it can be controlled process and not abrupt as this could cause severe damage to the machine and the operator.

Figure 19 shows the preliminary, yet ideal, motor to be used for this project. This is a standard DC powered gear motor; it is: rugged, compactly built, and has a built in worm gear. Weighing in at 23.6 lbs this condensed motor has the projected power consumption of 24-36V. The source of power will be the generator from previous years' and will power the motor for the allotted amount of time. These type of motors can be pricey, however the projected range is $400.00- $500.00. After purchase if we find that we need to increase or decrease the torque we may need to buy a gearbox to regulate speed as needed.

Figure 19: Proposed DC Gear Motor [x]

3.2.4.2 Cost Analysis

As stated earlier, much of the previous years' design is being reused. This works to our advantage as we need to stay on budget. The motor price isn't set in stone therefore the price is only approximated between $400.00-$500.00. The purchase quantity is 1 and doesn't include shipping, handling or taxes that may be added.

4 Voice of the Customer Analysis

4.1 Customer Requirements (HOQ)

The House of Quality (HOQ) is used to have a better understanding of the customer requirements. HOQ is divided into two main categories: The "Whats" and the "Hows". The "Whats" section lists the customer requirements, in other words what the customer wants from the product. The "Hows" depicts the technical 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. These requirements are ranked from a scale of 1 to 10, with 10 being the most important and 1 the least important.

Table 3 Customer requirements by order of importance

Automated	10.0
Power efficient	10.0
Light-weight/ Portable	9.0
Durable	9.0
Easy to use	8.0
Safe	8.0
Cost effective	8.0
Fast	7.0
Environmentally friendly	7.0
Water proof	6.0

Notice that in the above **Table 3** Automation and Power efficient are high ranked since the customer wants the final product to be both automated and power efficient. Waterproof is the only customer requirement that has lowest rank.

4.1.1 Customer Requirements (HOQ)

After discussing with the team about the requirements, the group came up with the "HOWs" which are the processes required to satisfy the customer requirements. In addition, the House of Quality, in **Appendix 7.2,** was created to help facilitate the order of importance of the quality characteristics.

The team came up with several quality characteristics, which are 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 much force and power to push the cart and cause musculoskeletal disorders to user, in other world it will not be ergonomically safe to select heavy materials as it will cause injuries to the user. The quality of the material needed for this design need to good in order to accommodate with the climate changes where the final product will be used which can be sometimes humid and hot. The size of the cart is another important factor in this design because it was assumed the users own several palm trees, therefore it should not be too big because it will be difficult for transportation. The wheel size needs to be at optimal size for stability and movement of the cart. When the initial push force is applied, the tires will absorb some friction since the plantation's soil can be muddy or rocky sometimes. The final product is going to be designed for owners of plantations where the palm trees grow the most (West and Central Africa), therefore it must be easy to use and have low maintenance cost. The speed of the pole extension of final mechanism needs to be really quick in order to compete with the current harvesting methods, which is the human climbing the palm tree and elongated pole. Furthermore, the goal of this team is to come up with a product that will be more efficient than the human climbing the tree.

The most important quality characteristics the design team came up with 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.

4.2 SWOT Analysis

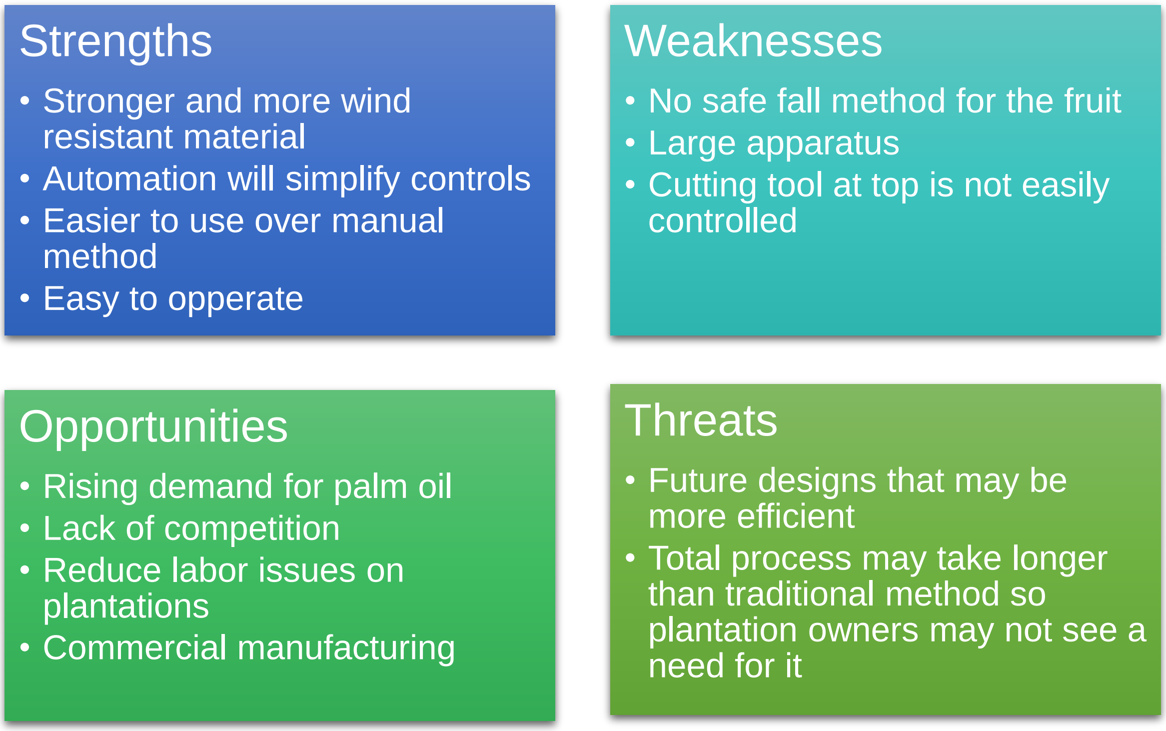


Figure 20: SWOT Analysis of design

To further assess customer requirements a SWOT analysis, seen in **Figure 20**, was performed to determine the strengths, weaknesses, opportunities, and threats of the overall system. SWOT analysis gives our sponsor an overall scope of the health of the project; it identifies the internal and external factors that are favorable and unfavorable to achieve the objective. Strengths, the characteristics of the project that give an advantage over others, are automation, ease of operation, stronger material. Weaknesses, the characteristics that place the project at a disadvantage relative to others, are a large apparatus, lack of control of the cutting tool, and no fall method for the fruit. Opportunities, elements that the project could exploit to its advantage, are the rise of demand of palm oil, nothing currently on the market, possibility to reduce labor issues, and commercial manufacturing. Threats, elements in the environment that could cause trouble for the project, are the potential competitive models could be more efficient and the total process is longer than traditional method.

As discussed the material of the telescoping pole is one of the major changes to this apparatus that will help with the overall wind resistance in variant tropical climates. Along with the change of material, a new pulley system located on the inside of the telescoping pole, this is a strength because it will reduce tangling and simplify operation.

4.3 Design Improvements

4.3.1 Current Plans (Prototype 2.0)

Automated Telescoping Pole

By automating the telescoping it eliminates the need to pivot and lift the 100 pound pole when assembling and disassembling. This reduces the amount of manual labor and the number of workers needed to use the device.

Square Cross-Section

The square cross-section of the telescoping pole gives the pulley system more leverage and relieves pressure on one major stress point. Thus minimizing the chances of the pulleys getting tangled since the poles will not rotate within each other.

Aluminum Telescoping Pole

Aluminum is a stronger more sturdy material that will have a lower bending rate than PVC making it ideal under strong wind conditions and varying climates.

Lowering Center of Gravity

By cutting a hole in the cart and placing the poles on the second level gives the poles more balance and helps to form a more unified device.

Internal Pulley System

Making the cables operate on the inside of the pole lowers the likelihood of entanglement of the wires and adds to the concept of creating a more integrated device.

Polyurethane Wheels

The sturdier material eliminates the risk of flat tire from movement of various terrain. Since it is a complete tire there is no need to continually inflating it to achieve the ideal tire pressure.

4.3.2 Prototype 1.0

Manual Telescoping Pole

This prototype was designed so that manual input controls most of the mechanism. This system involves manually cranking the pole, which requires substantial force from the operator.

Circular Cross-Section

The design of a circular cross-selection promotes uneven and inconsistent stress around the pole. It is harder to predict and measure the overall pressure points and areas of support. The circular cross-section allows the poles to rotate within each other causing entanglement of the pulleys.

PVC pipe Telescoping Pole

This was a cost-efficient material since the budget was limited; more items were needed for the overall function of the device, therefore only leaving the option to purchase the most cost effective material.

External Pulley System

Given the limited amount of space between the telescoping poles and materials available to create the pulley system, it was placed on the outside of the pole.

Pneumatic Swivel Caster Wheels

The issue with these wheels are that they continuously deflate throughout its use. This makes the cart hard to maneuver across rough terrain.

4.3.3 Ergonomic Approach

Focusing on improving ergonomic procedures is an important aspect in this project. Last year's project used a crank, which required a certain magnitude of force to make the poles go up. This action was not ergonomically safe for the user because it involved three main factors that usually cause work related injuries:

1. Force
2. Frequency
3. Posture

The telescoping pole weighs about 100 pounds which requires high force loads on the human body. Musculoskeletal Disorders, or MSD, are negative effects of body activity on nerves, tendons, joints and ligaments. Substantial muscle effort due to high force requirements increases associated fatigue which can lead to MSD.

Considering that plantation owners have several palm trees, operating such a mechanism will lead to high task repetition. A job is considered highly repetitive if the cycle time is 30 seconds or less.

Operating the crank places the user in an awkward posture. Awkward postures place excessive force on joints and overload the muscles and tendons around the effected joint. Joints of the body are most efficient when they operate closest to the mid-range motion of the joint. High task repetition, when combined with other risks factors such high force and/or awkward postures, can contribute to the formation of MSD. Risk of MSD is increased when joints are worked outside of this mid-range repetitively or for sustained periods of time without adequate recovery time.

Minimizing the risk of MSD can be done by a Rapid Upper Limb Assessment (RULA) tool which is utilized to evaluate the exposure of the users to ergonomic risk factors. 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 **Table 4**.

Table 4: Score associated with level of MSD risk

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

Another ergonomic risk the team has encountered is the fact the telescoping pole is not embedded in the cart; it has to be picked up separately from the cart. This operation consists of bending, lifting at elbow level and carry it to the cart, then lifting again above shoulder level. These operations can cause some serious injuries on the user's back considering the fact that the pole weights about 100 pounds. In order prevent these types of injuries from happening, the team will:

- Eliminate or minimize Manual Material Handling (MMH)
- Reduce stress associated with MMH:
    - Handling method
    - Placing the pole at the lower level of the cart
- Minimize stressful postures:
    - Bending
    - Twisting

- Horizontal reaches
- Above shoulder work
- Hand and arm posture

The **Figure 21** shows the RULA assessment for the current mechanism. In step 1, a score of +4 was used for the upper arm position (90+ degree). For step 2, a +2 was given for the lower arm position (< 60 degrees). The step 3 wrist score was +2 for wrist flexion and +1 was added for ulnar deviation.

In this case the final RULA score of 7 indicates high risk and calls for engineering and/or work method changes to reduce or eliminate MSD risk as outlined in the above chart. As a result, this team is currently working on implementing an automated pole in order to eliminate the magnitude of the force required to make the telescoping pole go up and reduce awkward posture associated with it.

Figure 21 RULA assessment worksheet of current mechanism [xi]

5 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 charged with analyzing and improving upon a palm fruit harvester that was designed and built in fall 2013 through spring 2014. Ideas were taken to the drawing board and analyzed, improvements were made in order to increase the efficiency of the palm fruit harvester. Changing the wheels will increase mobility in order to effectively traverse the oil palm plantation's rough terrain. The telescoping pole will be moved to the lower section of the cart in order to lower the center of gravity of the cart and improve the telescoping process. Currently, the telescoping pole is cranked by hand in order to be extended upward, the team will add in a motor to make the process completely automated. Square cross sectioned Aluminum 6063 will be used in replacement of the circular cross section PVC and steel in order to increase the yield strength of the telescoping pole. In order to decrease to chances of tangling, the pulley system will be moved from the outside to the inside of the telescoping pole. Before the end of the semester is completed, a fully working small scale model will be built in order to simulate the new and improved version of the telescoping pole. Parts will be ordered through the Industrial Engineering department before the end of the semester in order to assure that the building process will begin as soon as Senior Design II starts in the spring.

6 References

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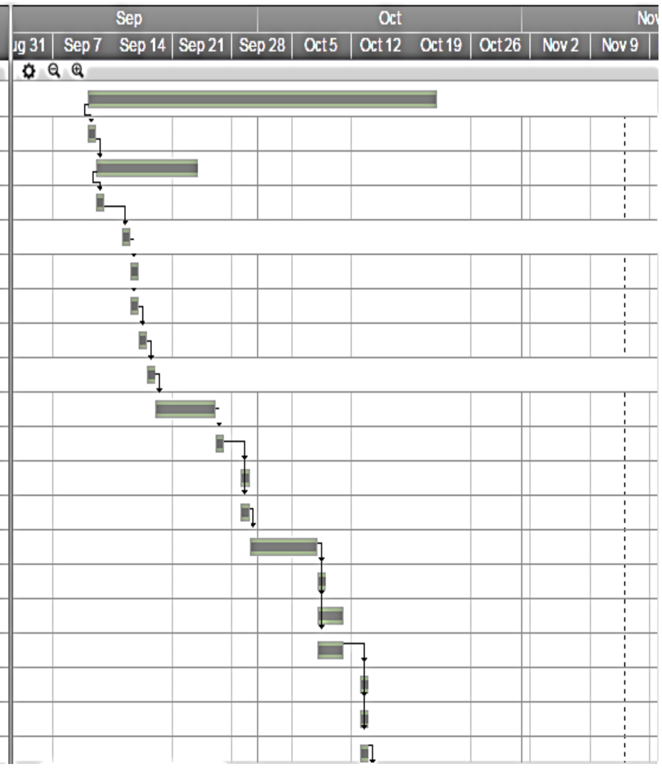
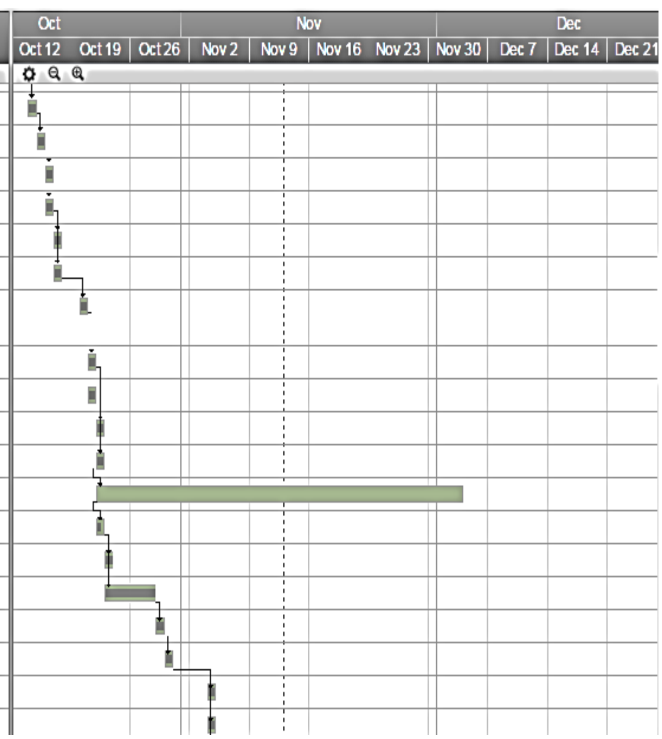
7 Appendix

7.1 Gantt chart

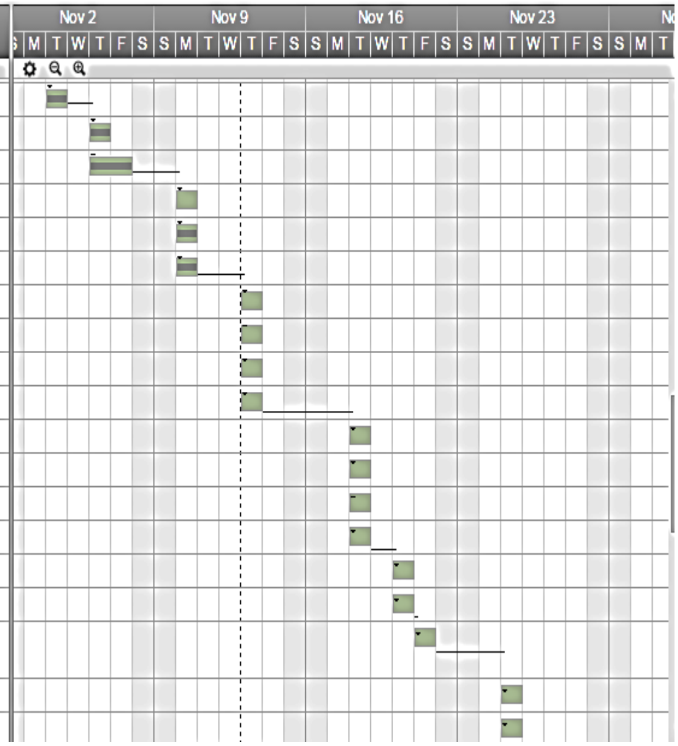
Task Name	Start Date	End Date	% Complete	Assigned To
Define Phase	09/11/14	10/21/14	100%	All
Meet with Dr. Okoli	09/11/14	09/11/14	100%	All
Research Palm Harvester	09/12/14	09/23/14	100%	All
Meet with Dr. Chuy	09/12/14	09/12/14	100%	Shaneatha & Talya
Group Meeting	09/15/14	09/15/14	100%	All
Discuss automation	09/16/14	09/16/14	100%	Shaneatha
HPMI Safety Meeting	09/16/14	09/16/14	100%	All
Needs Assessment Report Meeting	09/17/14	09/17/14	100%	All
Group Meeting	09/18/14	09/18/14	100%	All
Brainstorm Ideas	09/19/14	09/25/14	100%	All
Assembled Last Year Project	09/26/14	09/26/14	100%	All
Group Meeting	09/29/14	09/29/14	100%	All
Assign Define phase report sections	09/29/14	09/29/14	100%	All
Design Website	09/30/14	10/07/14	100%	Amber
Group Meeting	10/08/14	10/08/14	100%	All
Analyze Feasible Designs	10/08/14	10/10/14	100%	Talya & Thomas
Analyze Design Components	10/08/14	10/10/14	100%	Talya
Group Meeting	10/13/14	10/13/14	100%	All
Get material pricing	10/13/14	10/13/14	100%	Talya
Solidworks Design	10/13/14	10/13/14	100%	Thomas



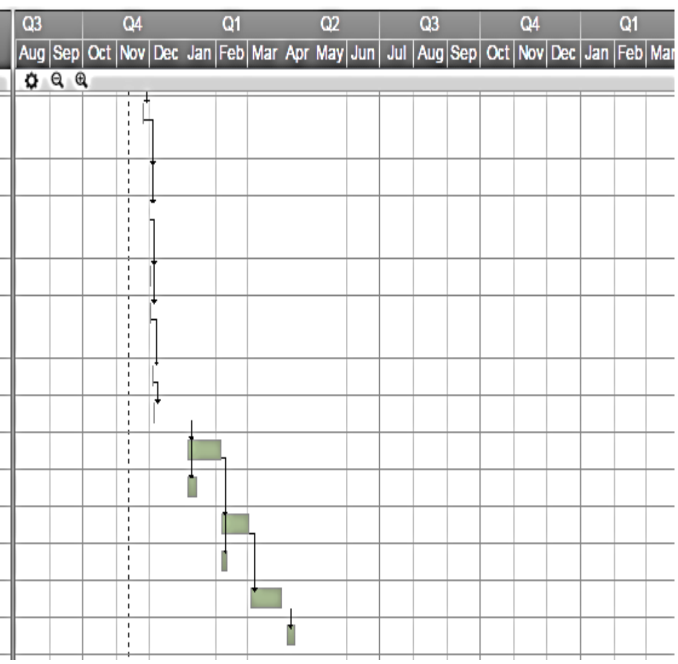
Task Name	Start Date	End Date	% Complete	Assigned To
Put together Define Phase report	10/14/14	10/14/14	100%	All
Get report reviewed by advisor	10/15/14	10/15/14	100%	Dr. Chuy
Group Meeting	10/16/14	10/16/14	100%	All
Make Define Phase presentation	10/16/14	10/16/14	100%	All
Revise Define Phase report	10/17/14	10/17/14	100%	All
Practice Define Phase presentation	10/17/14	10/17/14	100%	All
Practice Define Phase presentation (with audience)	10/20/14	10/20/14	100%	All
Needs Analysis Report/Presentation	10/21/14	10/21/14	100%	All
~~Group Meeting(Tentative)~~	~~10/21/14~~	~~10/21/14~~	100%	
Group Meeting	10/22/14	10/22/14	100%	All
Choose Feasible Design	10/22/14	10/22/14	100%	All
Measure Phase	10/22/14	12/03/14		
Update Website	10/22/14	10/22/14	50%	Amber
Group Meeting	10/23/14	10/23/14	100%	All
Draw Scaled Model	10/23/14	10/28/14	100%	Thomas & Talya
Get advisor input	10/29/14	10/29/14	100%	Dr. Okoli
Group Meeting	10/30/14	10/30/14	100%	All
Group Meeting	11/04/14	11/04/14	100%	All
Assign Revisions Parts for Define	11/04/14	11/04/14	100%	All



Task Name	Start Date	End Date	% Complete	Assigned To
Build Scaled Model	11/04/14	11/04/14	100%	Thomas & Talya
Group Meeting	11/06/14	11/06/14	100%	All
Revise Define Phase Report	11/06/14	11/07/14	100%	All
Meet with Teacher Assitants	11/10/14	11/10/14		All
Group Meeting	11/10/14	11/10/14	100%	All
Revise Define Phase Report	11/10/14	11/10/14	100%	All
Put together last year's mechanism	11/13/14	11/13/14		All
Group Meeting	11/13/14	11/13/14		All
Present product order to advisor	11/13/14	11/13/14		Thomas
Incorporate automation	11/13/14	11/13/14		Shaneatha
Group Meeting	11/18/14	11/18/14		All
Order parts	11/18/14	11/18/14		Amber & Chris
Discuss Measure Phase report	11/18/14	11/18/14		All
Assign Measure Phase report parts	11/18/14	11/18/14		All
Group Meeting	11/20/14	11/20/14		All
Put together measure phase report	11/20/14	11/20/14		All
Get Measure phase report assessed	11/21/14	11/21/14		All
Group Meeting	11/25/14	11/25/14		All
Revise Measure Phase Report	11/25/14	11/25/14		All

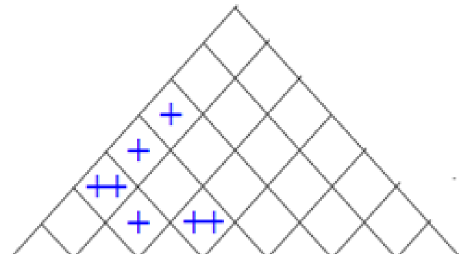


Task Name	Start Date	End Date	% Complete	Assigned To
Create Measure Phase Report presentation	11/25/14	11/25/14		All
Group Meeting	12/01/14	12/01/14		All
Practice Measure Phase report presentation	12/01/14	12/01/14		All
Group Meeting	12/02/14	12/02/14		All
Measure Phase Report/Presentation Practice	12/02/14	12/02/14		All
Measure Phase Presentation	12/04/14	12/04/14		All
Peer Evaluation	12/05/14	12/05/14		All
Analyze Phase	01/05/15	02/04/15		All
Test Mechanism	01/05/15	01/13/15		All
Improve Phase	02/05/15	03/02/15		All
Add housing (if time allots)	02/05/15	02/10/15		All
Control Phase	03/04/15	04/01/15		All
Final Presentation	04/06/15	04/13/15		All



7.2 House of Quality

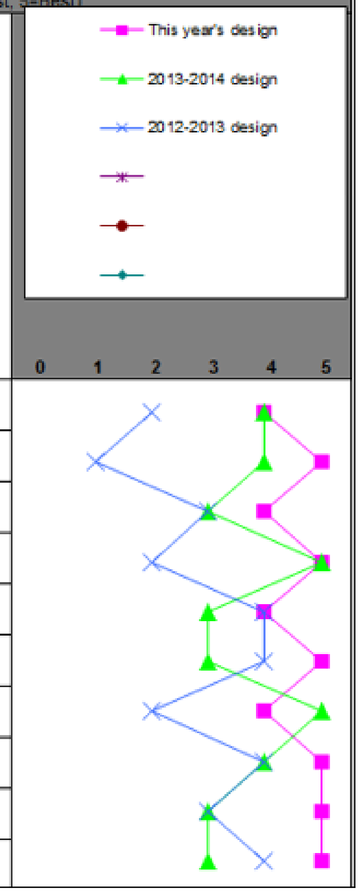
Legend		
Θ	Strong Relationship	9
○	Moderate Relationship	3
▲	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
—	Negative Correlation	
▼	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
X	Objective Is To Hit Target	



				Column #	1	2	3	4	5	6	7
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▼	▲	▲	▲	▼	▼	▼
Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	Weight of materials	Quality of materials	Speed of pole extension	Battery capacity/Durability	Size of cart	Size of wheels	Complexity of design
1	3	7.3	6.0	Water proof		○					○
2	3	8.5	7.0	Environmentally friendly	○	▲					▲
3	9	8.5	7.0	Fast	○	○	Θ	○			○
4	9	9.8	8.0	Cost effective		Θ		○	○	○	▲
5	3	9.8	8.0	Safe	▲	○			▲	▲	▲
6	3	9.8	8.0	Easy to use	▲	○	▲	▲	○	○	○
7	3	11.0	9.0	Durable		○		○	▲	○	○
8	9	11.0	9.0	Light Weight/Portable	Θ	○	▲	▲	○	○	▲
9	9	12.2	10.0	Power efficient	○	○	○	Θ	○	○	○
10	9	12.2	10.0	Automated			Θ	Θ		○	○
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	4	6	5	6	4	4	4
				Max Relationship Value in Column	9	9	9	9	3	3	3
				Weight / Importance	206.1	304.9	243.9	328.0	148.8	207.3	222.0
				Relative Weight	12.4	18.4	14.7	19.8	9.0	12.5	13.4

Competitive Analysis
(0=Worst, 5=Best)

					This year's design	2013-2014 design	2012-2013 design			
1	3	7.3	6.0	Water proof	4	4	2			
2	3	8.5	7.0	Environmentally friendly	5	4	1			
3	9	8.5	7.0	Fast	4	3	3			
4	9	9.8	8.0	Cost effective	5	5	2			
5	3	9.8	8.0	Safe	4	3	4			
6	3	9.8	8.0	Easy to use	5	3	4			
7	3	11.0	9.0	Durable	4	5	2			
8	9	11.0	9.0	Light Weight/Portable	5	4	4			
9	9	12.2	10.0	Power efficient	5	3	3			
10	9	12.2	10.0	Automated	5	3	4			



7.3 Motor Torque Calculations

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

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

Weight of the tope three poles (with the cutting mechanism)

$Wc := 109.28 lbf$

$Wc = 486.102 N$

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

$F := 500N$

The radius of rotation

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

Maximum torque required for the motor

$T := F \cdot r$

$T = 38.1 \cdot N \cdot m$

7.4 Force Calculations

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

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

Weight of the tope three poles (with the cutting mechanism)

$Wc := 109.28\,lbf$

$Wc = 486.102\,N$

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

$F := 500N$

The radius of rotation

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

Maximum torque required for the motor

$T := F \cdot r$

$T = 38.1 \cdot N \cdot m$