CAL POLY ENGINEERING

PHOTOBOT

# Final Design Review

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Preparation date: December 12, 2016

## Statement of Disclaimer

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# 1.0 Introduction

The purpose of this project is to create a remotely controlled camera device; the PhotoBot will capture images and videos of various plants and perhaps animals for biological analysis. The features for such a device will allow a user to capture images and videos from various angles and heights with minimal outside assistance. Furthermore, the device will be designed for users that do not wish to spend an extensive amount of time and effort taking pictures and videos in the rainforest. The key constraints of the device will include safety, versatility, ease of use, and durability. Ultimately, this project will be completed for Dr. Cris Cristoffer as a senior project through the Mechanical Engineering Department at Cal Poly.

During the second phase of the PhotoBot project, the team produced a number of ideas with respect to the basic functions. The functions defined for the PhotoBot include: positioning the bot, setting up the cable system, taking repeated pictures, powering the systems, and rotating the camera. The basic functions help produce a number of design possibilities, which then enabled the team to use weighted design charts. The charts were useful to narrow down the range of selections and quantify how well each design fulfilled the sponsor's criteria. However, deciding on the weights of the decision matrix and figuring out the most important requirements turned out to be a difficult task; the large scope and broad specifications of the PhotoBot project created substantial design challenges. Nevertheless, based on the results from the charts the team was able to select a design concept. This detailed design report will reflect the analysis made on this particular design and list its advantages and disadvantages.

# 2.0 Background

## *2.1 Existing Cable Camera System*

As a result of conducting a patent search, there are no existing products that meet Dr. Cristoffer's criteria. However, it appears that there are many existing products which are similar to what Dr. Cristoffer desires. The existing products researched that are on the market include the following: LineCam-Flow X1, Speed Line, and FlyLine. Of the listed models, the FlyLine seems is the only patented design. The specifications of these individual products and links to homemade cable cams can be found in Appendix A. Although there are some differences in the products above, each has the same wheel design and has some feature, such as a slot, which can secure a gimbal or mounting frame in place.

Essentially, all of these models travel along a wire that is tied between two points and films what is in sight. All of the models are controlled remotely including the shuttle itself and the positioning of the camera. However, depending on the complexity of the cable cam, they can weigh anywhere from five to sixteen pounds (excluding the weight of the camera) and range from $4,000 to $12,000.

While these existing products have some features that Dr. Cristoffer wishes to implement in his product, they do not meet all of his requirements. Even though a video feed would be ideal, Dr. Cristoffer prioritizes taking pictures of a particular substance (i.e. plants) at the same angle in a given period of time. Dr. Cristoffer would also like the camera to move along a polygon shape instead of just a straight path so that the camera can encompass a wider range of perspectives.

## *2.2 Electronics and Software*

Another important aspect of this project concerns the electronics and software needed to implement Dr. Cristoffer's requirements. First, there are several devices on the market that can be remotely controlled while simultaneously transmitting live video back to the user. For instance, the DJI Phantom Aerial UAV Drone Quadcopter for GoPro, can be remote controlled and stream live video back to some kind of device; currently, the drone is priced at $500 on Amazon [1]. There are also other electronic devices which can be modified to produce an interface that provides remote control and live video feedback; Android smartphones currently have many useful features like video recording and streaming, GPS, application programming, low power requirements, the ability to change pins on microcontrollers, and other many potentially valuable options [2].

This device will also need take the same pictures at precisely the same location each time in order to track certain plants. As a result, some type of electronic device or software code will be needed to handle this data manipulation and storage. Thus, the bot will need to keep a record of its positions, store camera angles, and be able to move back to those locations. An advanced microelectronic device, programmable gate array, or smartphone may be capable of handling the necessary data storage, data transfer, and timing needed to move the camera to a specified location at a predetermined date and time.

Finally, since the device has to last approximately six months, all electronic components and microcontrollers will need to be able to run at very low power while still ensuring operating reliability. Furthermore, the software will need to be optimized on an operating system level in order to send the device into standby or low power mode when not in use and when power becomes low.

## *2.3 Camera Options*

As for the camera itself, most GoPro models are compatible with the GoPro mobile device app. The user is able to set the camera settings, switch between video and camera mode, take pictures, start and stop recording, view and delete content, power off, and more. In addition, the GoPro is small, lightweight (under 0.5 lbs.), waterproof, and can wirelessly transmit up to 600 feet. However, the video feed has about a four second delay, and the application cannot disable the camera's Wi-Fi. Depending on the model, the battery lasts between 1 to 3.5 hours; they can cost anywhere from $200-$500 [3].

Another alternative is the SPYPOINT camera, which is a wireless trail camera that is priced at $550. The SPYPOINT is powered by six AA batteries, can take 8MP photos (color by day, black and white by night), has motion sensing capabilities, is able to take up to six pictures per detection, and can record video as well as sound. It also comes with a black box, which can wirelessly receive photos taken within 250 feet of the camera. Other notable features include motion triggering and taking pictures at preset intervals. The user can also set the camera on and off at a specific time [4]. However, the scheduler is limited since it can only be set for one day

The final option is using a smartphone with a high quality camera to take the pictures. Many smartphones today have the ability to take pictures that are basically on par with professional cameras. A 16-megapixel camera with a 1.5-inch aperture, for instance, has superb quality and would be more than sufficient for the sponsor. Two possible options the team researched include the Verykool s505 12-megapixel camera for $59.99 and the Cubot X1 16-megapixel camera for $162 that has a 1.5-inch aperture. Both of these cameras offer quality pictures for a low price [16,17].

## *2.4 Track Materials*

Another important consideration is that most wheels on existing cable cameras are designed to be in contact with five to eight-millimeter-thick rope or cable – the brand and type of rope used is based on the weight of the device and on personal preference. Some people use climbing-rope while others use coated steel cable; refer to Table 1 in Appendix B for a list common ropes/cables used, as well as their specifications and cost. In addition to the rope, different equipment – such as ratchet straps, carabineers, and pulleys are used in securing the rope/cable in place.

## *2.5 Cable System Technology*

The main inspiration for the PhotoBot was ski lift technology. The idea was simple: instead of having the bot traverse the wire, simply move the bot similar to how a ski lift allows riders to move to the top of the hill. Figure 1 below shows two examples of typical ski lift designs that might be implemented.

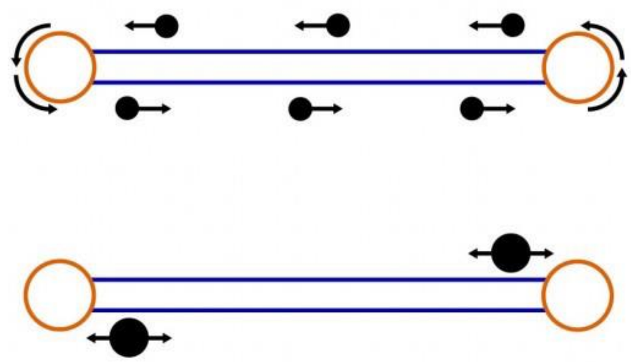


Figure 1. Qualitative drawing of modern ski lift technology [18]

In the top diagram of the figure, a device moves in one direction in a single loop. The bottom diagram shows a system that operates similarly, but can reverse the direction of a device.

## *2.6 Control System with Android Phone*

By using an Android phone with the Android Development Kit (ADK) to take pictures and control the bot, the PhotoBot will have access to a wide range of functionality. Not only does this functionality include complete operating system control, but it also includes the ability, for example, to completely utilize all features of the onboard camera. Furthermore, there is already a significant amount of Android application code on the internet. This code is open source and thus can be used for free without worrying about copyright or infringement on intellectual property. Furthermore, this code is thoroughly tested and used by thousands of other developers which suggests its high reliability. As a result, software testing will find fewer bugs, and even fewer will end up in the final product [15].

There are two examples in the appendix which describe the free source code. Code Snippet #1 allows the developer to set various camera parameters like zoom and exposure time. This gives the user more control over picture quality. In addition, Code Snippet #2 allows software to automatically take a picture. In this code example, the camera establishes the preview of the shot and then takes the picture once the preview has been verified by the sponsor. The code also contains error handling which will be useful in case the program runs into a fatal error; the PhotoBot operating system will be able to restart and recover, which means that the bot will not just shut down in the middle of the rainforest.

## 3.0 Specifications and Requirements

The team's main focus will be to successfully design and engineer a product as specified by Dr. Cristoffer. The product, given the name PhotoBot, will be designed as a remotely operated mobile-camera system to be used for observing plant and animal life in remote forests. Dr. Cristoffer mentioned that the device should comply with the following design requirements:

1. *Size and Weight:* The device must meet typical travel requirements for fitting in carry-on with a passenger on a plane.
2. *Battery Life:* The desired unattended operation time for the device is six months. As a result, the battery or power source should be capable of delivering enough power to last under moderate usage.
3. *Camera Viewing Angles:* The camera system should be capable of rotating about at least one axis. Another requirement is that the camera system should be able to operate at various heights.
4. *Camera Specifications:* The quality/specifications of the camera should be high resolution/quality.
5. *Connectivity:* Another requirement for the camera system is that it should have the capability to be remote controlled via a laptop interface. A method for controlling the camera as well as the spatial position of the system should be incorporated.
6. *Water-Resistance:* The environment in which the device may be used will vary. The device must be water-resistant with respect to the IP rating of a typical trail camera.
7. *Automation:* This camera system should include some type of automation that would allow the camera to take pictures at various locations/positions and on a daily/weekly basis.

8. *Low-Cost:* This project cannot exceed the maximum budget of $2,000 for parts and materials.

In order to ensure that the engineering team will effectively accommodate Dr. Cristoffer's requirements, the measurable engineering specifications were derived from a Quality Function Deployment (QFD) chart which can be found in Appendix C. This chart was used to define what the sponsor would like to have accomplished through this project and identify measureable and verifiable boundaries for the solution. This chart includes different sections. The "WHAT" sections lays out the customer requirements and their corresponding importance. The "HOW" sections lays out the engineering specifications that are related to the requirements. The "NOW" sections lists what products currently exist that are similar to the PhotoBot. These products are all rated based on how well they can satisfy the customer requirements. Near the end of the chart, the "HOW MUCH" section lists more specific requirements and rates how well each of the existing products and the PhotoBot can accomplish them.

The QFD chart was able to help formulate the goals for the project are by finding correlations amongst the engineering specifications. An explanation for the selection of the engineering specifications is detailed below and summarized in Table 2. Under the Risk column, the letters L, M, and H identify a Low, Medium, and High risk. Under the Compliance column, the letters T, I, A, and S identify Testing, Inspection, Analysis, and Similarity to existing designs. This column establishes how each design requirement is to be verified.

Table 2: Engineering Specifications

| Spec # | Parameter Description | Requirement or Target | Tolerance | Risk | Compliance |
|---|---|---|---|---|---|
| 1 | Weight | Less than 4 lb | Max. | M | T |
| 2 | Power Supply | Power supply is at least 10,000mAH | Min. | M | T |
| 3 | Camera Rotation | Camera has at least 180° viewing angle | Min. | L | I |
| 4 | Height of Operation | Operation height between 1 and 15 meters | N/A | L | T,I |
| 5 | Size | Device fit within a 22" X 14" X 9" space | N/A | L | I |
| 6 | Live Feedback | Does it have this function? (Yes/No) | N/A | M | I |
| 7 | Wireless Picture Transfer | Does it have this function? (Yes/No) | N/A | M | I |
| 8 | Automatic Camera Control | Does it have this function? (Yes/No) | N/A | H | I |
| 9 | IP54 Compliant | Does it meet this requirement? (Yes/No) | N/A | M | A,T,S |
| 10 | Cost of Final Assembly | Is the total cost less than $2000? (Yes/No) | N/A | L | A |
| 11 | Manual Remote Camera Control | Does it have this function? (Yes/No) | N/A | M | I |
| 12 | Camera Specifications | Meet or Exceed Canon SX170 IS Specifications? (Yes/No) | N/A | H | A,I |

Size and weight requirements were based on information from American Airlines; the maximum size for a carry on is 22" x 14" x 9". There is no weight limit, but the passenger must be able to lift the bag onto the overhead bin [5]. Dr. Cristoffer has requested that the complete device weigh no more than 10 pounds. The power supply for this system will need to supply enough power for the device to last 6 months. For an initial estimate the specifications from an existing product's battery were used as a starting point. LineCam is a powerful camera-cable system that can last up to 8 hours of continuous operation at speeds of 45mph. LineCam's power source is a 2-cell 10,900 mAh battery [8].

Water-resistance will be specified to match or exceed the typical rating for trail cameras. From initial research, typical trial cameras are IP 54 rated, which specifies that "water splashing against the enclosure from any direction shall have no harmful effect" [6]. Camera specifications need to match or exceed the specifications of Dr. Cristoffer's Canon SX170 IS. Relevant camera

specifications for the Canon SX170 IS include a 16MP sensor, 16X Zoom, 8.9 oz. camera weight, has autofocus, and image stabilization [7].

The PhotoBot also needs a scheduling system in order to automatically position itself to previous photo locations. This feature is necessary so that pictures can be captured even when the user is not there to manually operate the bot. Furthermore, the sponsor needs to be able to manually override the PhotoBot in order to make adjustments or take an arbitrary shot. Given all of these requirements, the PhotoBot needs an easy control interface which can both control the device and receive image data. Next, the PhotoBot requires the ability to move around a location on an X-Y plane and also possibly move on the Z-axis. Given the difficulties of setting up a system that can operate on an X-Y plane, the Z-axis control may not be feasible.

Based on how the team weighed the customer requirements and established the relationships among the engineering specifications, important aspects of the project were determined. Out of all the customer requirements, the ability to remotely take images and video is the most crucial requirement at 14% importance. The ability to take images and video from multiple perspectives is the second most crucial at 13% importance. Low cost, carry-on dimensions, and waterproofing all come in rated at 12% importance. Based on the engineering specifications stated in the QFD chart, the most important aspect of the project is attaining automatic control of the camera. The engineering specifications of lesser importance are manual camera control, the ability for the system to operate at the largest possible height, and designing the entire system to weigh less than 10 pounds.

# 4.0 Design Development

## *4.1 Foundational Phases*

In order to achieve the best design possible, a specific engineering design approach will be followed. As specified in Figure 2, the product design process will include three main stages: specification development and planning, conceptual design, and product design.

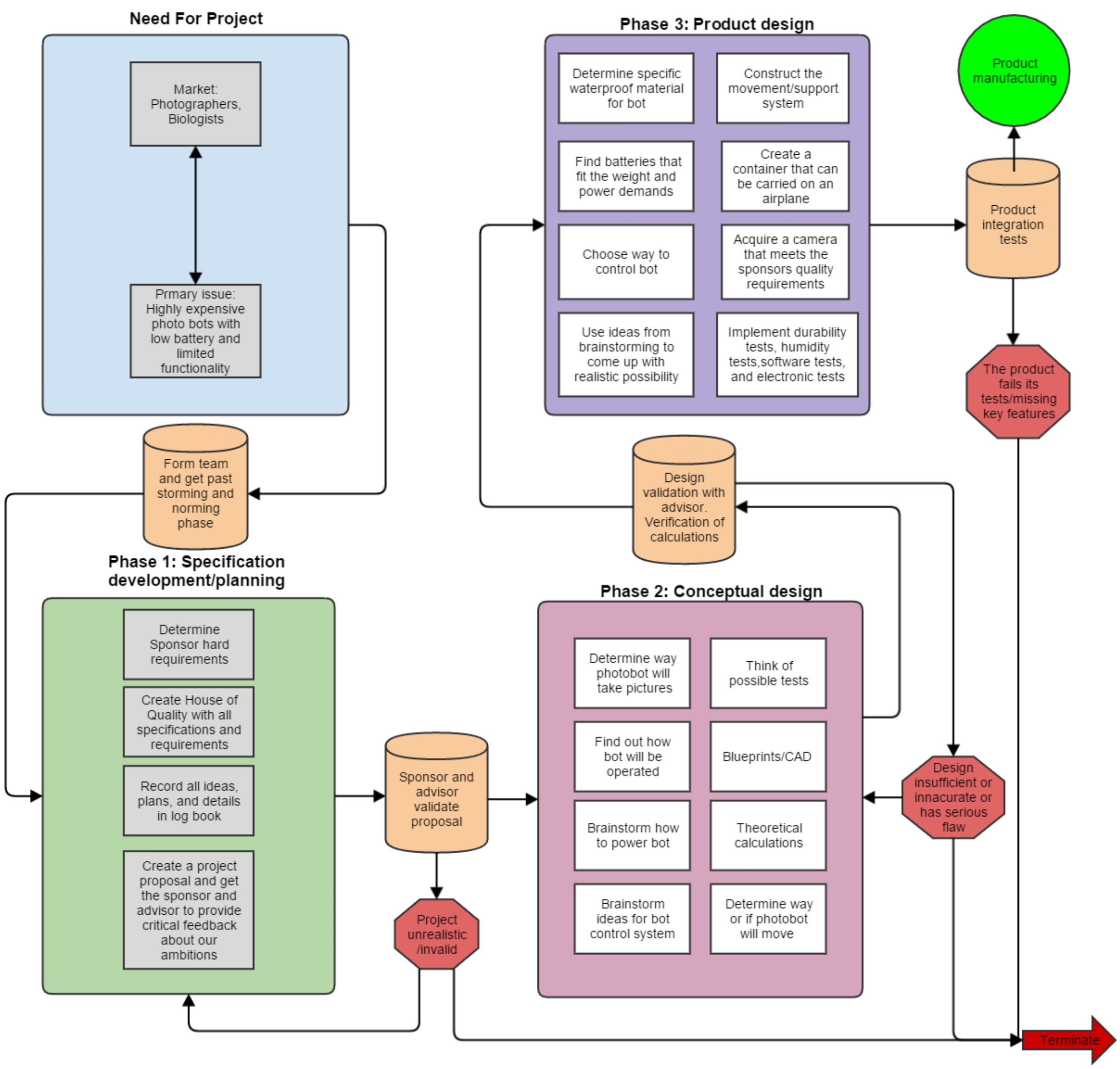



Figure 2. Project Design Flow Chart

*Specification development and planning*: Here the team will determine the requirements for the design. Each customer requirement is matched with a measurable engineering specification to

ensure that the requirement is satisfied. Team planning and organization is also laid out in this stage to meet the project milestones.

*Conceptual design:* In this phase, the engineering team will produce as many solutions as possible for each basic function. Prototyping will be an important component of this stage in order to provide proof of concept. During this process, ideas will be combined, modified, and refined in order to select an ideal design.

*Product design:* In this stage of the process, the engineering team will begin detailing all the specifics of the chosen design. Specific parts, materials, and components are described with detailed drawings. In the second half of this process, the device will be built and tested to ensure that the product complies with the sponsor's requirements.

## *4.2 Concept Generation*

In the concept generation phase, each concept was critically reviewed by the engineering team based on customer requirements, feasibility, and overall functionality. Presented below are the top concepts for the supporting functions of the PhotoBot System.

### 4.2.1 Positioning System

A. **Adjustable Bracket/Rails for a Polygon Cable System**

*Description:* The first concept would use a cable system capable of being suspended in a polygon shape. At each turn in the line, a custom bracket/rail would allow the PhotoBot to change directions. The brackets would be supported and installed using a single tension line for each turning point. Figure 3 illustrates the concept for the bracket system using three brackets.

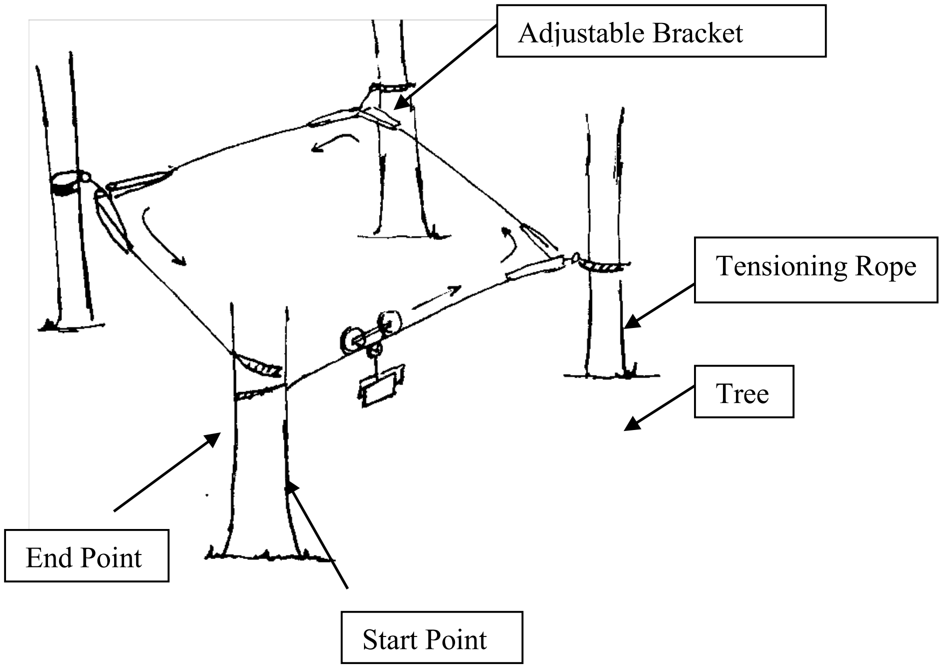



Figure 3. Bracket Polygon System Concept

*Benefits:* This system allows for maximum flexibility when building a cable path. Installation is straight forward and requires minimal tools.

*Potential Issues:* Cable alignment will be a major concern for this design which will increase bracket complexity. Package size and portability may also be compromised if the bracket design becomes large.

*Prototype:* An early prototype for this device was made to assess the feasibility of installing the bracket rail system. Figure 4 shows the first prototype being tested using a simple setup.

Figure 4. Bracket Polygon Initial Prototype Test

**B. Circular Rail Junction**

*Description:* In this design, a suspended cable system would be routed through a central, circular junction. The PhotoBot can travel in a loop as shown by the directional arrows in Figure 5. A rail-switching mechanism would allow the bot to travel in a closed loop.

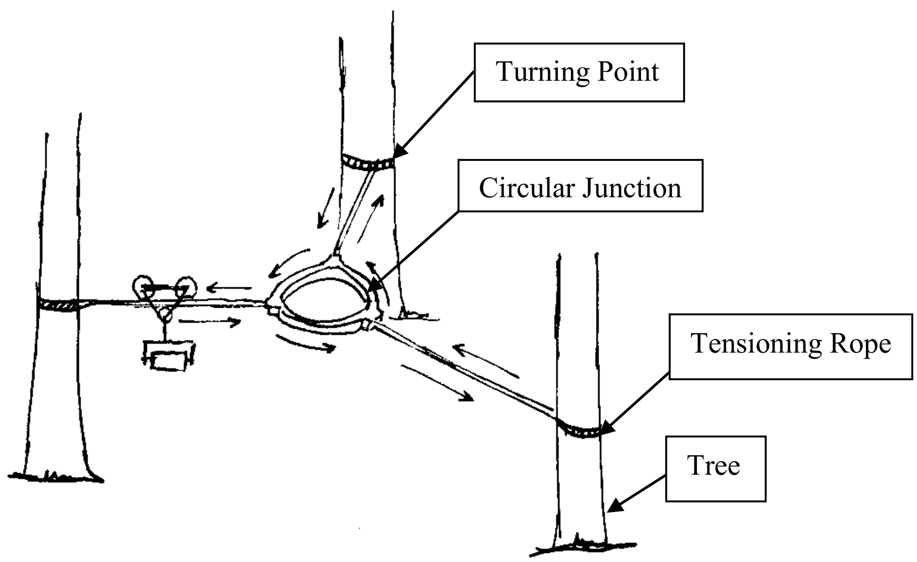



Figure 5. Bracket/Rail Polygon System Concept

*Benefits:* The installation procedure would be simple since there are only three connections that need to be tensioned and tied-off. The cable system would allow the PhotoBot to cover a large XY plane and many viewing angles.

*Potential Issues:* The design of the circular junction may be too complex and involve small moving parts; This may make manufacturing unfeasible.

**C. SkyCam Cable System**

*Description:* This concept is similar to the cable-cam systems used in stadiums. Each cable attached to the PhotoBot would be independently controlled by a motor. As a result, the bot can easily move to many X, Y, and Z positions. Figure 6 shows a conceptual drawing for the SkyCam system.

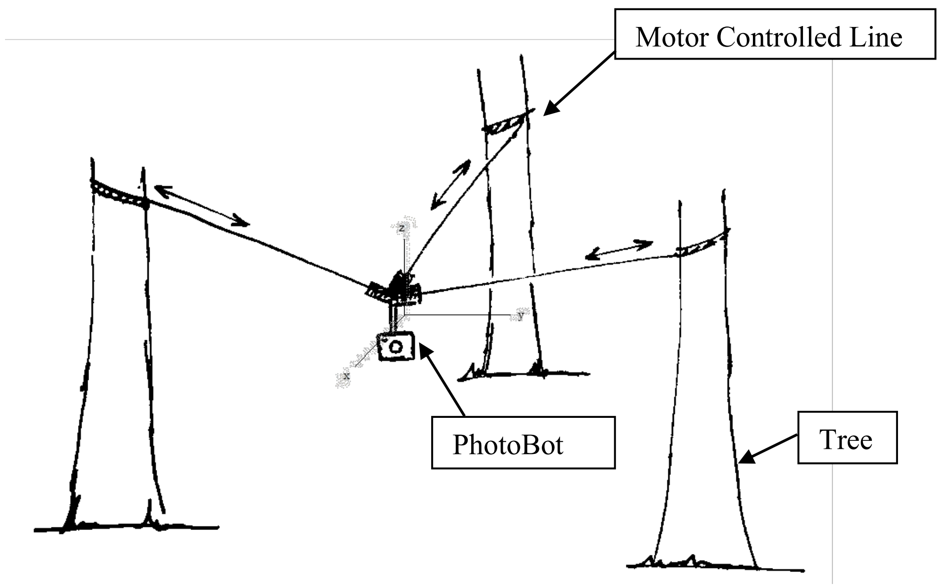



Figure 6. SkyCam Cable System

*Benefits:* This system would provide inherent z-axis movement for the PhotoBot and more spatial freedom.

*Potential Issues:* Major concerns for this design include the complexity for the simultaneous control of all three motors, difficulty in installing the motor supports, power consumption, and weight.

**D. Mobile-Line/ Pulley System**

*Description:* Inspired by ski-lift cable designs, this system would use a motor to move a cable. The PhotoBot is clamped onto a point in the cable and can turn by using horizontal pulleys. Figure 7 shows a conceptual sketch for this concepts.

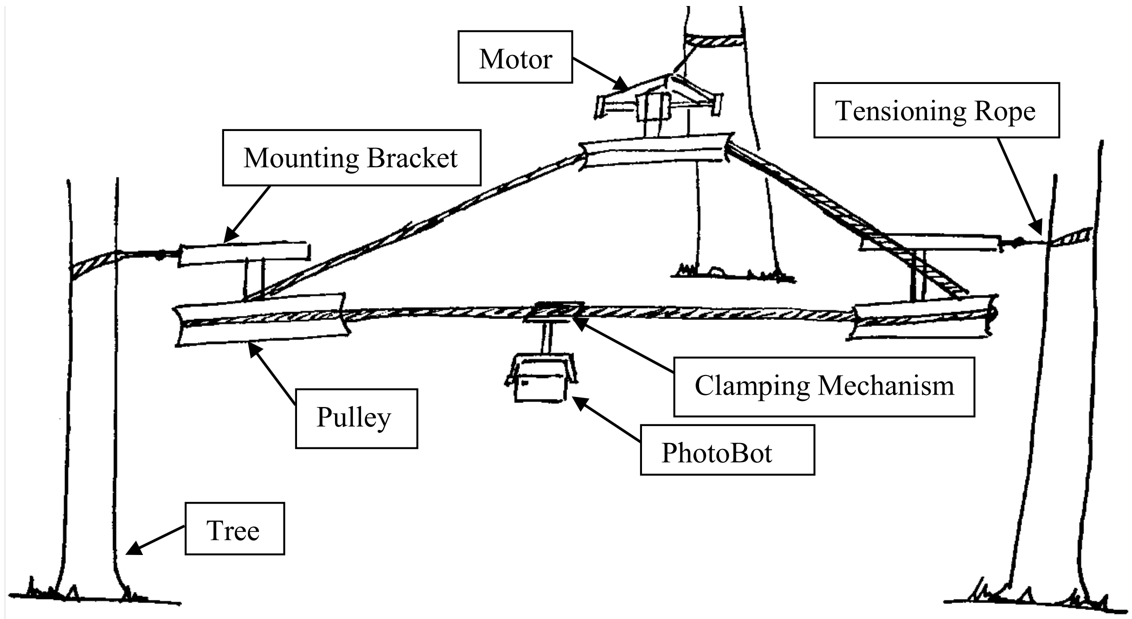



Figure 7. Mobile-Line/ Pulley System Concept

*Benefits:* Switching cable directions is easy. It also minimizes the weight of the PhotoBot since the motor is attached to the bracket. It also allows power sources to be on the ground.

*Potential Issues:* A concern might be that the power requirements might be higher for this system. Another concern is the complexity required for the bot communicate wirelessly to the motor.

4.2.2 Cable Setup

**A. Weighted Line Throw or Assisted Launcher Throw**

Throwing the weight over the branch is a simple approach to install the cable system. The expected height range is 25 to 30 feet but can be higher if using a projectile launcher. The rope will go over a branch and then the user can tie down the line at the base of the tree. The sling shot method is shown in Figure 8.

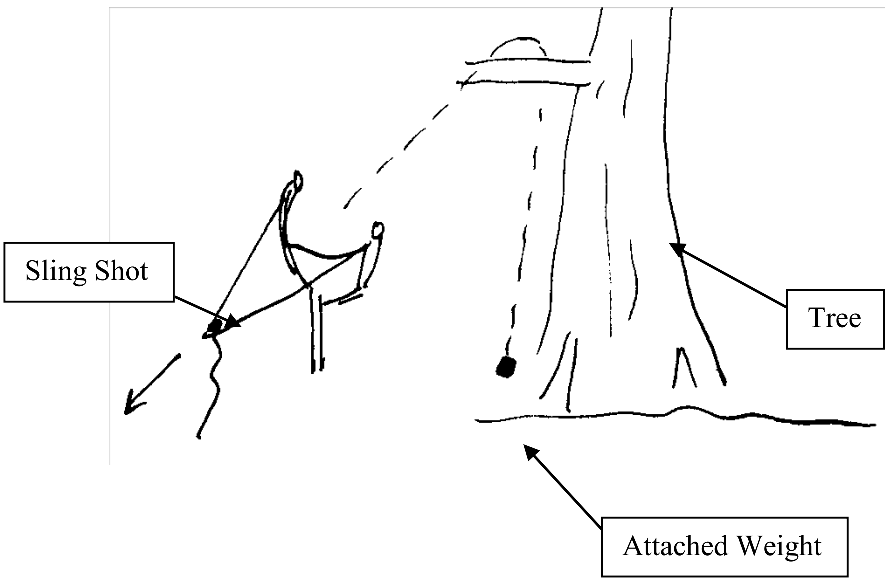



Figure 8. A Launcher Used to Install Cable Lines

**B. Extension Arm to Install rope**

Use an extension arm to loop the rope over the branch as illustrated in Figure 9. There are existing products on the market which can already accomplish this. The span of the arm is expected to be about 25 ft.

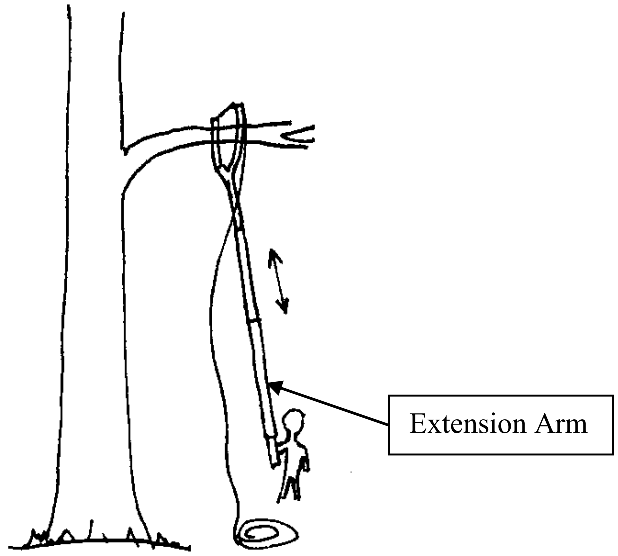



Figure 9. Extended Arm for Installing Cables

4.2.3 Camera System

**A. GoPro Camera**

*Benefits:* GoPro cameras are small, lightweight, waterproof, and the newest versions have wireless control capabilities.

*Potential Issues:* Although the wireless controls are already integrated, the GoPro alone cannot perform the automated tasks required by the sponsor.

**B. Android Phone Camera**

*Benefits:* Android camera phones can rival the picture quality of many compact cameras while providing a cheap, customizable platform to create user-defined programs.

*Potential Issues:* There might be some difficulty in developing the Android application.

**C. Trail Camera**

*Benefits:* Trail cameras are fully weatherproof, have a long battery life, and some have night vison photography options. Most have some type of scheduling integrated into the camera and motion triggered photography.

*Potential Issues:* It may be a challenge will be to modify any pre-programmed scheduling tasks so that the camera could take pictures at a specific location not time interval.

**D. Canon SX170 IS**

*Benefits:* The Canon has high resolution, image stabilization, zoom, and flash capabilities. *Potential Issues:* It will be very challenging to develop a mechanical control system to automate the camera functions. Waterproofing the camera may be expensive and/or unfeasible. It will also be challenging to modify the power source such that it could last 6 months.

4.2.4 Power Delivery

**A. Ground to Cable Delivery**

This idea uses a large power source and keeps it on the ground while a cable would supply the power to the PhotoBot's electrical systems above. In Figure 10, this concept is shown in two potential configurations depending on where the main electronics are located. On the left, the power is shown connected to the mobile PhotoBot. On the right, the power source is connected to a stationary motor.

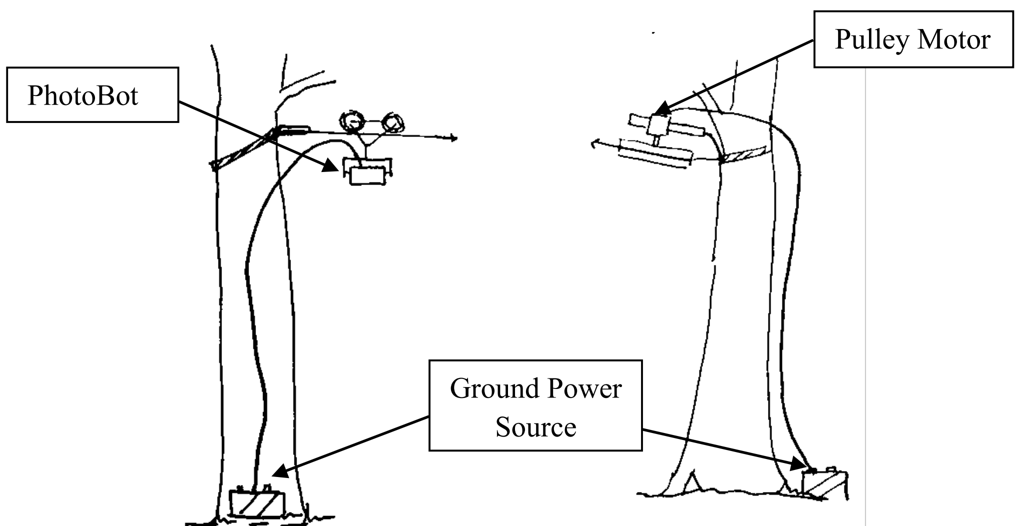


Figure 10. Ground to Cable Power Delivery Concept

**B. Onboard Battery Power**

Another concept for powering the PhotoBot is to mount a battery pack directly on the PhotoBot. This would only be used when all the electronic systems are mounted on the PhotoBot.

4.2.5 Optional Charging Systems

**A. Solar Panel Trickle Charging**

A separate solar panel system may be used to provide a minimal power source for the PhotoBot's battery source. This charging system provides trickle charge that extends the operational duration.

**B. Water Generation Power**

Rainfall might be an option to generate power by collecting rainfall and funneling it through a generator wheel. The compact housing, as shown in Figure 11, is attached to the camera's support frame-adding minimal weight to the PhotoBot.

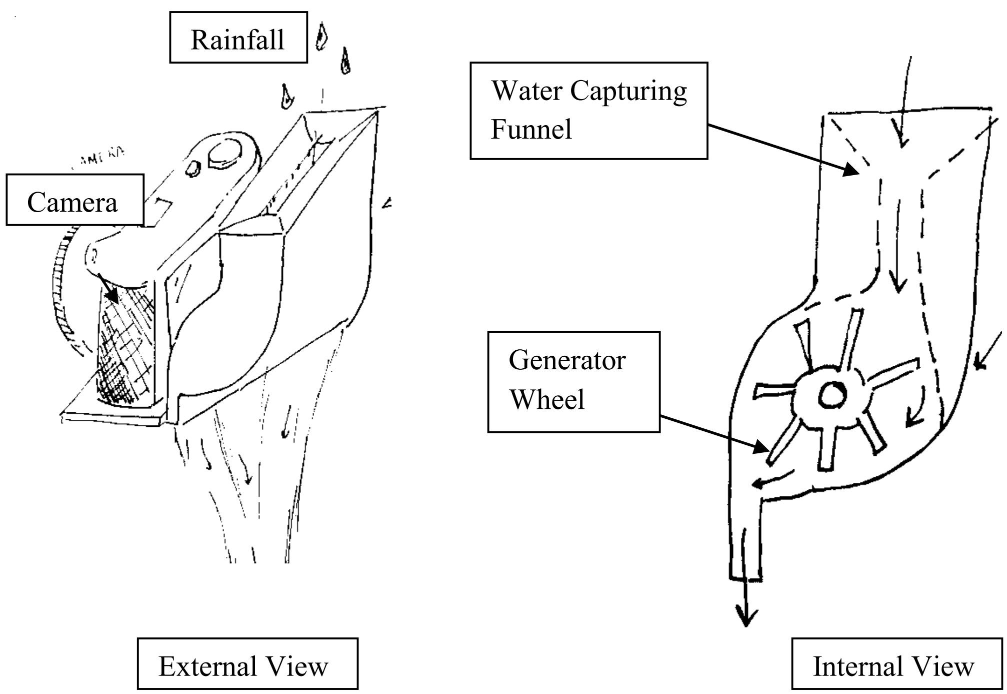



Figure 11. Rain Powered Water Generation

4.2.6 Camera Support and Rotation System

**A. Automatic Two-Axis Rotational Support**

An optional second axis design for the PhotoBot's camera rotation would allow the camera to rotate about the Z and X-axis as shown in Figure 12. This design would require two servo motors to control both of the angular positions. The drawback is an increase in power consumption, weight, and complexity for the support design.

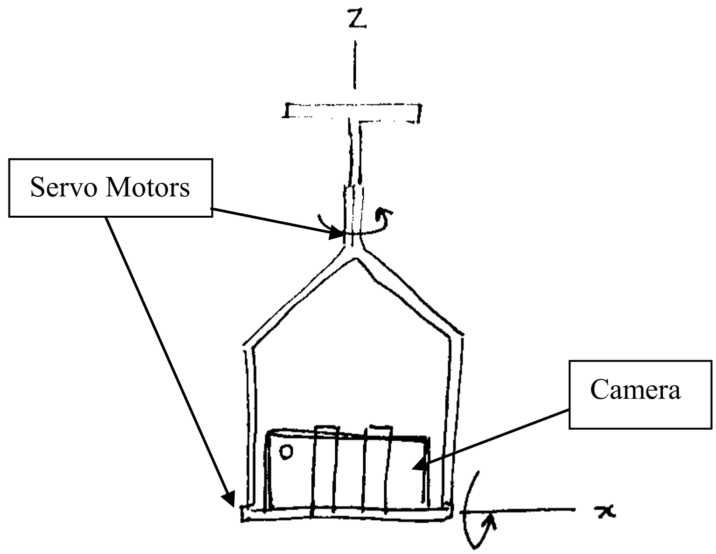



Figure 12. Two-Axis Rotation Support Concept

**B. Automatic One-Axis Rotational Support**

A single rotation axis could be implemented to allow rotation about the x-axis. This is an easier design and has a lower power consumption, and lower weight compared to the design in Figure 12.

**C. Manual One-Axis Rotational Support**

A manual-single axis rotation support for the camera would be inexpensive and simple to implement. As shown in Figure 13, the position about the x-axis will be set by manually tightening a screw to secure the camera in the desired position.

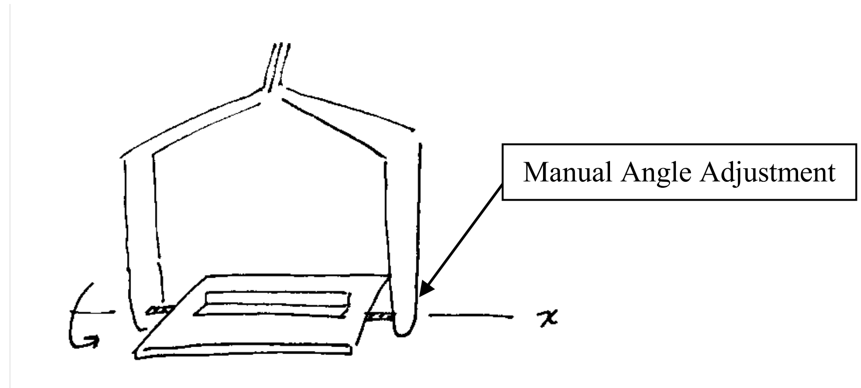



Figure 13. One-Axis Manual Rotation Support Concept

### *4.3 Idea Selection*

The functions defined for the PhotoBot include the following: position the camera, set up the cable system, take repeated pictures, power the systems, and rotate the camera. The team used final decision matrices for all functions except powering the system and rotating the camera. The final decision matrices are shown and explained in *Section 4.3.1, 4.3.2,* and *4.3.3*.

For the preliminary concept selection, Pugh matrices were completed for each function of the PhotoBot. These simple matrices provided a good initial understanding of the advantages and disadvantages of all the generated concepts compared to a baseline design: a single axis camera system which would not include rotation of the camera or automatic scheduling. Each concept was rated with either a plus (+) or minus (-) to represent a concept which was more or less advantageous than the baseline. These Pugh matrices can be seen in Appendix D.

To power the camera and positioning system, the team will use a rechargeable battery stationed on the ground which is then connected to the PhotoBot system.

In addition, a motor will be used on the camera to rotate it around an axis parallel to the cable that the bot is running on. Also, the cable system is designed to adjust the camera image in order to straighten out if the cables are sloping. A uniaxial hinge at the clamp on the cable will keep the cable taut. Furthermore, the bot will be able to rotate around an axis that is perpendicular to the cable and Gravity will keep the bot parallel with the ground. If the first motor can successfully rotate the PhotoBot horizontally, the team will attempt to add a second motor to rotate the camera about the vertical Z-axis. If the camera can rotate around two axes, this will allow for an optimum range of picture. The PhotoBot design drawings include its overall dimensions that can be seen below in Figure 14. Although the design in the figure is not a true representation of the PhotoBot, it captures the general idea of the final design.

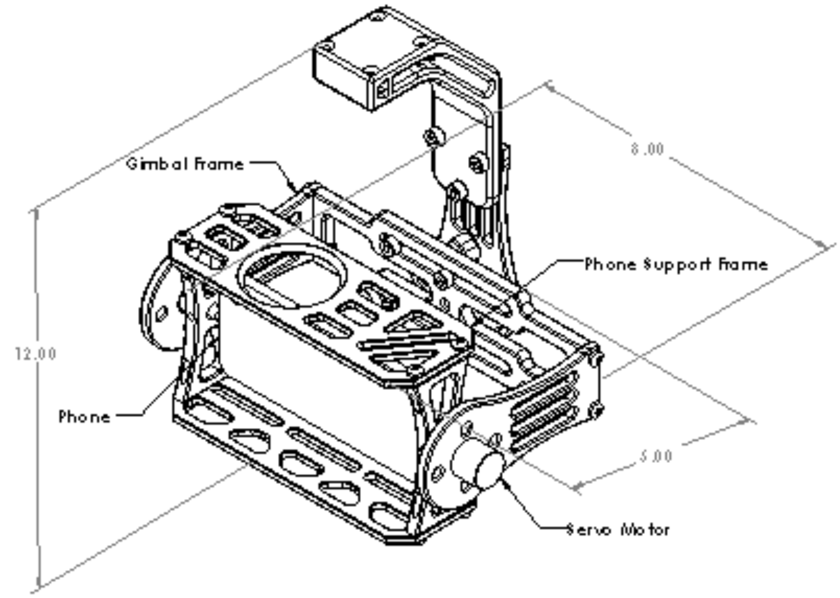



Figure 14. Isometric Drawing of PhotoBot

4.3.1 Positioning System

The pulley line is the final cable system design that will position the PhotoBot. As seen in Table 3, the pulley line is the superior based on the design criteria. Furthermore, the second best alternative is the polygon brackets. These top two ideas both have the same picture coverage. Likewise, neither of these ideas are able to move the camera up and down; however, this will be overcome by the rotation of the camera. Although these two ideas both have strong advantages, the main reason behind choosing the pulley line comes from feasibility requirement.

Table 3. Final Decision Matrix for Positioning PhotoBot

| Design Criteria | Weighting Factor | Single Line | Polygon Brackets | Circle Track | Tri-Wire | Pulley Line |
|---|---|---|---|---|---|---|
| Weight | 5 | 100 | 70 | 80 | 50 | 65 |
| Size | 7 | 100 | 70 | 70 | 80 | 75 |
| Cost | 5 | 100 | 60 | 50 | 45 | 50 |
| Set-up Ease | 20 | 100 | 75 | 85 | 70 | 80 |
| Ease of use | 10 | 100 | 100 | 100 | 60 | 100 |
| Position XY | 25 | 15 | 100 | 85 | 100 | 100 |
| Position Z | 5 | 0 | 0 | 0 | 100 | 0 |
| Waterproof | 3 | 100 | 100 | 95 | 75 | 90 |
| Feasibility | 20 | 100 | 75 | 70 | 40 | 90 |
| TOTAL | 100 | 73.75 | 79.4 | 76.5 | 70.6 | 82.7 |

A major complication with the polygon brackets is the slipping of the PhotoBot as it traverses the cable. The orientation of the cables will never be perfectly horizontal; therefore, there will always be some vertical slope between the between the brackets. Also, the bracket system requires significant tension in order to eliminate as much slack as possible. In addition, depending the PhotoBot weight, the cable will be further weighed down even more especially considering that some type of plastic-coated metal cable would be used; the wheel system that moves the PhotoBot will have difficulty holding onto the cable if there is any incline. Also, since rain and humidity are constant factors in the rainforest, the cable could occasionally be lubricated. The pulley line, however, will avoid all of these issues since the PhotoBot will be rigidly clipped onto the moving cable. Nonetheless, there are a couple of drawbacks with the pulley line system. It may require a larger battery to move the tensioned cable, which would increase the cost and weight of this design. Regardless, compared to slippage, this issue is relatively insignificant. Second, a stronger fixture is required to support each of the pulleys; this affects the cost and how easily the system can be transported.

Another major reason why the pulley line is the better choice is due to cornering capabilities. Moving the cable between horizontally-spinning wheels allows the PhotoBot to complete a turn of any angle, which is very similarly to how a ski lift operates. Furthermore, cornering is much more difficult by simply using the brackets. The brackets are problematic because the ends of the rails are rigid, and so they are not able to compensate for deflection of the cable. Also, it would be difficult for the PhotoBot to travel over a sharp corner, which may jeopardize the PhotoBot’s stability.

The pulley line probably has more complicated electronics, and waterproofing all of the components will be slightly more difficult. However, nothing needs to be adjusted or calibrated with the pulley line design. In contrast, the bracket design includes adjustable brackets and rails. For this reason, the pulley line will be easier to set-up.

The drawing below shows one of the wheel brackets for the pulley line the bracket will be a square shape that will hold the wheel. The shaft on the motor will be inserted in the wheel and attached with a washer and nut on the bottom side of the wheel while a rotating rod will hold the motor. The ends of the rod will be held with bearings. Thus, this rod was designed to rotate to compensate for differences in height of the other wheel brackets. Basic dimensions are also shown on Figure 15. Additionally, Figure 16 shows the layout of a pulley line.

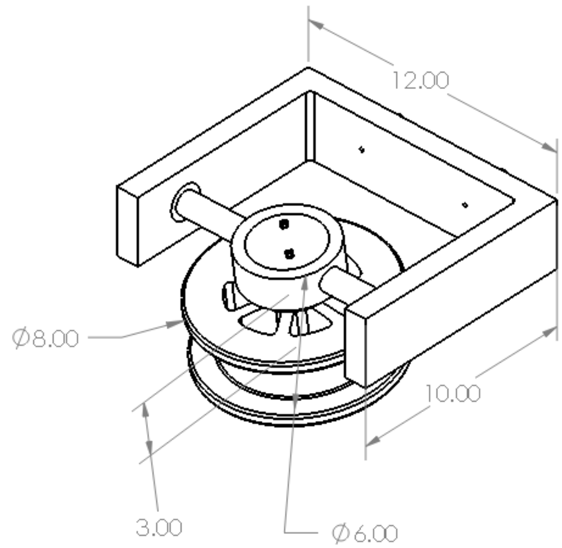



Figure 15. Isometric Drawing of Pulley Wheel and Bracket

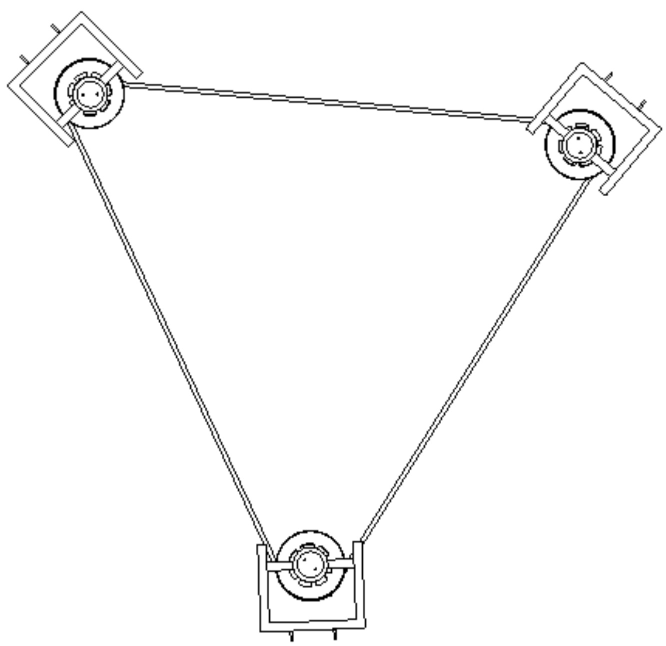


Figure 16. Full Assembly of Pulley Line

4.3.2 Cable Setup

The best method for setting up the cable will be by throwing a weight according to Table 4. This approach is simpler and easier than tying down a cable. In order to assist Dr. Cristopher with getting the rope high enough, a small weight will be clipped onto the end of a cable and be thrown over a branch. The cable will then be used to attach the mounting bracket for each wheel to the tree. The end of the cable will be secured around the base of the tree or in the ground or on a branch. This method is the most feasible since it only requires a minimal amount of money, weight, strength, and skill. However, it may take several tries to get the cable set up this way. Depending on how much brush is in the way, it could be difficult to throw a weight around a branch; the weight may also be stuck on something once it's thrown up and then may be impossible to retrieve.

Table 4. Final Decision Matrix for Setting up Cable

| Design Criteria | Weighting Factor | Throwing a Weight | Grabber Arm | Launcher | Step Ladder in Tree |
|---|---|---|---|---|---|
| Weight | 8 | 90 | 75 | 65 | 80 |
| Size | 10 | 90 | 60 | 70 | 90 |
| Cost | 10 | 95 | 50 | 50 | 85 |
| Set-up Ease | 2 | 100 | 80 | 85 | 70 |
| Ease of use | 20 | 100 | 100 | 100 | 60 |
| Position Z | 10 | 80 | 70 | 90 | 65 |
| Feasibility | 20 | 95 | 90 | 75 | 30 |
| Safety | 20 | 75 | 100 | 65 | 20 |
| TOTAL | 100 | 89.7 | 83.6 | 75.9 | 53.8 |

In the case where throwing a weight is too cumbersome, the second best alternative would be to use a grabber arm. From previous research, a grabber arm can be purchased that is specifically designed to attach a cable or rope around a branch that is up to 20 feet high. This device would be very easy to use and safer than throwing a weight around. Unfortunately, this grabber arm can only collapse to a few feet in length and would be heavier to transport. However, since this reliable, well tested device can be purchased online, which means this method might be a better choice in certain situations.

4.3.3 Camera System

The team decided on an Android phone as Table 5 indicates. This Android phone has a high-pixel camera, a wireless communication system, and customizable software that can satisfy many requirements. An Android application written in Java can control the capture function for the camera and also schedule taking pictures automatically. Furthermore, the Android application will interface with an Arduino to control the positioning of the PhotoBot and the camera rotation.

Table 5. Final Decision Matrix for Camera System

| Design Criteria | Weighting Factor | GoPro | Android Phone | Trail Camera | Canon DSLR |
|---|---|---|---|---|---|
| Weight | 12 | 100 | 100 | 70 | 50 |
| Size | 8 | 100 | 100 | 70 | 65 |
| Cost | 20 | 70 | 85 | 65 | 80 |
| Picture Quality | 20 | 80 | 70 | 70 | 100 |
| Waterproof | 10 | 100 | 90 | 100 | 50 |
| Power Integration | 10 | 100 | 100 | 100 | 50 |
| Control Implementation | 20 | 70 | 85 | 60 | 40 |
| TOTAL | 100 | 84 | 87 | 73 | 65.2 |

One advantage of using an Android is that it can easily interface with an Arduino. There is already plenty of existing instructions and free code that will make it easy to create reliable software for this system. In contrast, software control with the GoPro is much more difficult. The GoPro uses its own proprietary software to control the camera. Although the GoPro remote control is excellent, it doesn’t have the capability to execute a picture taking schedule, which is a major requirement for Dr. Cristoffer. Also, the GoPro is significantly more expensive than buying an Android phone and electrical components and also doesn’t offer superior quality images. Finally, with either the GoPro or Android phone the user will be able to see where the camera is aimed and thus be able to position the camera for a desired frame.

## 5.0 Management Plan

The management plan for the PhotoBot senior project consists of assigning individual responsibilities and splitting the team into subsystems; the goal is to focus the team's efforts and further organize the project in order to produce the most efficient distribution of work. The next step is to create a detailed timeline with specific goals and deadlines for the duration of the project. Table 6 below lists the general milestones to be completed for this project that are also relevant to the sponsor.

Table 6. Summary of Senior Project Milestones

| Milestone | Date |
|---|---|
| Project Proposal | 2/2/2016 |
| Preliminary Design Review and Report | 2/29/2016 |
| Critical Design Review and Final Design Report | 4/26/2016 |
| End of Quarter Status Report | 6/2/2016 |
| Project Update Memo to Sponsor | 9/27/2016 |
| Manufacturing and Test Review | 10/18/2016 |
| Project Expo | 11/14/2016 |
| Final Project Report | 12/1/2016 |

The Gantt chart shown below in Table 7 gives an overview of how long each set task can be focused on in order to complete each milestone, which is highlighted in the chart. With that, the chart gives a rough estimate of the amount of time that should be spent on each task. The Gantt chart is a great tool because it provides a visual schedule to see if the team is on track. To explain the chart further, the Work Breakdown Structure (WBS), called out in column one, consists of four milestones including: the project proposal, the preliminary design review, the critical design review, and the expo presentation.

Each milestone contains the necessary tasks that have to be finished before meeting the criteria of the corresponding deliverable. Moreover, some of the preliminary tasks are not dependent on one another, thus allowing the team to work on multiple tasks at a time. To get a better, more generalized visual of the different paths that can be taken, refer to the Pert chart in Appendix F.

| WBS | Tasks | Start | End | Duration (Days) | % Complete | Days Complete | Days Remaining |
|---|---|---|---|---|---|---|---|
| 1 | **Project Proposal** | 1/4/16 | 2/2/16 | 30 | 100% | 30 | 0 |
| 2 | **Preliminary Design Review** | 2/2/16 | 2/29/16 | 28 | 100% | 28 | 0 |
| 2.1A | Design Cable System | 2/2/16 | 2/16/16 | 15 | 100% | 15 | 0 |
| 2.1B | Select a Camera | 2/2/16 | 2/16/16 | 15 | 100% | 15 | 0 |
| 2.2A | Determine How to Install Cable System | 2/16/16 | 2/23/16 | 8 | 100% | 8 | 0 |
| 2.2B | Layout Program Design and Components | 2/16/16 | 2/23/16 | 8 | 100% | 8 | 0 |
| 2.3 | Conceptual Design for Photo Bot | 2/23/16 | 2/27/16 | 5 | 100% | 5 | 0 |
| 3 | **Critical Design Review** | 2/29/16 | 5/5/16 | 67 | 0% | 0 | 67 |
| 3.1A | Detailed Drawings for Mechanical Components | 3/1/16 | 3/15/16 | 15 | 0% | 0 | 15 |
| 3.1B | Stress Analysis for Mechanical Components | 3/1/16 | 3/15/16 | 15 | 0% | 0 | 15 |
| 3.1C | Power Calculations | 3/1/16 | 3/15/16 | 15 | 0% | 0 | 15 |
| 3.1D | Encapsulated Programming | 3/1/16 | 3/15/16 | 15 | 0% | 0 | 15 |
| 3.1E | Complete Bill of Materials | 3/1/16 | 3/15/16 | 15 | 0% | 0 | 15 |
| 3.2 | Complete Final Design Report | 3/15/16 | 5/3/16 | 50 | 0% | 0 | 50 |
| 4 | **Expo Presentation** | 5/5/16 | 11/14/16 | 194 | 0% | 0 | 194 |
| 4.1A | Order parts and Materials for Cable System | 5/5/16 | 5/19/16 | 15 | 0% | 0 | 15 |
| 4.1B | Order parts and Materials for Photo Bot | 5/5/16 | 5/19/16 | 15 | 0% | 0 | 15 |
| 4.1C | Order Hardware/Components for Communication and Automation | 5/5/16 | 5/19/16 | 15 | 0% | 0 | 15 |
| 4.1D | Design Controls/Communication Software/PC Application | 5/5/16 | 6/5/16 | 32 | 0% | 0 | 32 |
| 4.2A | Build Cable System Components | 5/19/16 | 6/3/16 | 16 | 0% | 0 | 16 |
| 4.2B | Build Photo Bot Main Device | 5/19/16 | 6/3/16 | 16 | 0% | 0 | 16 |
| 4.2A | Build Cable System Components | 9/25/16 | 10/8/16 | 14 | 0% | 0 | 14 |
| 4.2B | Build Photo Bot Main Device | 9/25/16 | 10/8/16 | 14 | 0% | 0 | 14 |
| 4.2CD | Testing and Refinement of Controls/Communications System | 9/25/16 | 10/8/16 | 14 | 0% | 0 | 14 |
| 4.3AB | Test Photo Bot and Cable System Together | 9/25/16 | 10/8/16 | 14 | 0% | 0 | 14 |
| 4.4 | Implement Control/Communication System | 10/8/16 | 10/17/16 | 10 | 0% | 0 | 10 |
| 4.5 | Test and Refine Complete System | 10/17/16 | 10/30/16 | 14 | 0% | 0 | 14 |
| 4.6 | Project Hardware/Safety Demo | 10/30/16 | 11/3/16 | 5 | 0% | 0 | 5 |

Timeline columns: 01 - Feb - 16 | 08 - Feb - 16 | 15 - Feb - 16 | 22 - Feb - 16 | 29 - Feb - 16 | 07 - Mar - 16 | 14 - Mar - 16 | 21 - Mar - 16 | 28 - Mar - 16 | 04 - Apr - 16 | 11 - Apr - 16 | 18 - Apr - 16 | 25 - Apr - 16 | 02 - May - 16 | 09 - May - 16 | 16 - May - 16 | 23 - May - 16 | 30 - May - 16 | 06 - Jun - 16 | Summer | 25 - Sep - 16 | 02 - Oct - 16 | 09 - Oct - 16 | 16 - Oct - 16 | 23 - Oct - 16 | 30 - Oct - 16 | 06 - Nov - 16 | 13 - Nov - 16 | 20 - Nov - 16

Table 7. Gantt chart

## *5.1 Administrative Roles*

Each team member will hold specific positions for the length of this project. First, Samantha Clements is assigned as the communications officer. She will be the main point of contact with the sponsor. Furthermore, she will be responsible for facilitating team meetings and making sure that the team discussion stays focused. Samantha will also be in charge of meetings with the advisor. Next, Carlos Esquivel has been assigned as the team treasurer. Carlos will be responsible for presiding over the team's overall budget with respect to the PhotoBot hardware and materials. He will also analyze the project and determine whether the proposal is economically viable. Kassandra Rodriguez has been assigned as the team secretary; her primary role consists of updating the team binder and Google drive, creating an online summary addressing weekly meetings, and producing the planned agenda for the next week. Kassandra will also be the main editor for the weekly status reports. Finally, Aubrey Russell is assigned to quality assurance. Although this position will be more important during prototyping and testing phases for the project, Aubrey will ensure that correct operation and safety procedures are being followed when building and testing is conducted. Aubrey will be responsible for leading and organizing the testing plans to ensure project quality.

### *5.2 Subsystems*

The team has decided that it would be beneficial to divide the group into subsystems to particularly focus the team's efforts as the project is very broad. These subsystems are as follows: power supply, mechanical support system, system control and software control.

The power supply subsystem will be centered around choosing how the entire system will receive power over the time period in which the PhotoBot will be operating without a user. Aubrey Russell and Samantha Clements will lead this subsystem. The main component that will need to be powered is the camera. Another possible component that is considered to be powered is a motor transmission that will move the camera system. Whether by some means of a direct power supply or alternative energy, this subsystem team will choose the most efficient option for prolonged life.

The mechanical support system will be responsible for designing how the camera will be spatially supported. Kassandra Rodriguez and Carlos Esquivel will be in charge of this subsystem. There are two aspects to this task: determining how the camera will move and how the camera will be mounted to the moving system. The mechanical support team will decide how to design and set-up the hardware for positioning system for the camera. This subsystem team will need to investigate manual and automatic options.

The PhotoBot is heavily reliant on what software and electronics are to be used. To make the project more manageable, it has been decided to split this aspect into two different sections. System control will be in charge of deciding how the previously described mechanical support system will be controlled. Kassandra Rodriguez and Samantha Clements will be on this subsystem. This subsystem will have to work closely with the mechanical support system for certain aspects. If the mechanical support system is to be moved, perhaps a pulley system or a motor and gear transmission will need to be considered to move the camera axially and rotationally.

Software control will be responsible for determining what software system will be used to remotely control all functions of the camera. Aubrey Russell and Carlos Esquivel will be in charge of this subsystem. The functions of the camera that are to be considered are photo capture, video recording, zoom, autofocus and possible file download to a separate interface. This aspect of the project may be completed by several different possible methods. For example, the team may choose to purchase an existing camera system that uses its own application to retrieve photos and videos via computer or smartphone.

## *5.3 Construction*

### 5.3.1 Mechanical

Although the team does not have detailed design for each individual function, there is a general understanding of the necessary products and materials that the PhotoBot requires. Table 8, 9, and 10 lists the first draft of the components that will likely make up the cable system, support bracket, and actual PhotoBot. This list also inherently includes a rough cost approximation.

Table 8. Rough estimate of Cable System

| Product | Qty | Rough Estimate |
|---|---|---|
| 500’ Climbing Rope | 1 | $40.00 |
| 250’ Coated wire rope | 1 | $50.00 |
| Pinch Bolt | 2 | $5.00 |
| Screw Lock Carabiner | 3 | $10.00 |
| Tree Rigging Sling | 3 | $20.00 |
| Total | | $190.00 |

Table 9. Rough estimate of support bracket

| Product | Qty | Rough Estimate |
|---|---|---|
| Ball Bearing | 6 | $7.00 |
| Battery to power wheel | 1 | $200.00 |
| Eye bolts | 6 | $4.00 |
| Material for brackets | 3 | $200.00 total |
| Motor | 1 | $100.00 |
| Nut | 3 | $5.00 |
| Shaft | 3 | $7.00 |
| Washer | 3 | $5.00 |
| Wheel | 3 | $100.00 total |
| Total | | $717.00 |

Table 10. Rough estimate of PhotoBot

| Product | Rough Estimate |
|---|---|
| Battery for servo motor | $100.00 |
| Miscellaneous (nuts, bolts, electrical components, etc.) | $100.00 |
| Material for Body of Bot/Mounting Gimbal | $100.00 |
| Servo Motor | $5.00 |
| Total | $305.00 |

Based on the cost analysis from the tables above it will cost the team about $1300 to build the entire PhotoBot system. This total is just an estimation, but it gives the team an idea how much needs to be spent in order to build a system that meets the majority of the sponsor's requirements. Additionally, the listed prices represent the average cost for each of the listed products. As a final note, shipping, taxes, and labor were excluded from the total cost.

5.3.2 Electrical

In Figure 17 below is a likely circuit layout for the PhotoBot. Instead of using complex models of rechargeable lithium ion batteries, large capacitors are used to store an equivalent amount

of power and thus simulate the result of using a rechargeable battery. A large battery is used next to the solar power voltage source so that the solar panel is always trickle charging it.

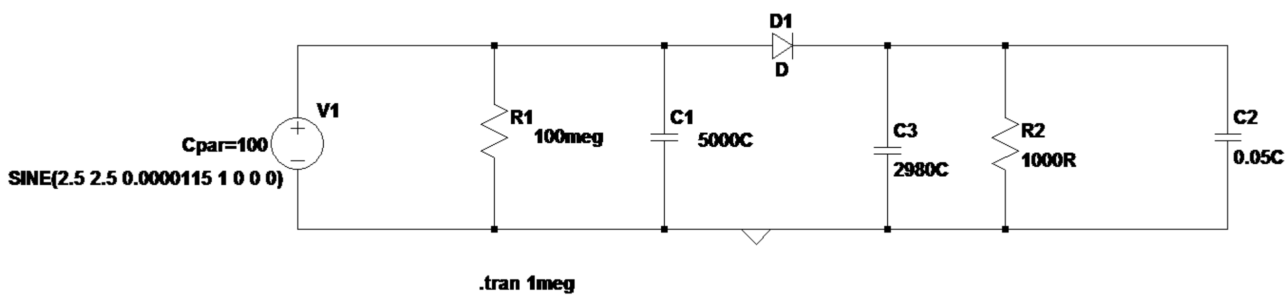



Figure 17. PhotoBot preliminary electrical power circuit

Figure 18 is the output from the circuit above where green measures voltage at the sinusoidal voltage source, and represents the possible power supply over the course of a day resulting from a solar panel, which has peaks and valleys corresponding to the time of day. There are approximately 84,600 seconds per day and so this shows approximately six days in the form of 0.5 mega seconds. The blue measures the voltage of the node to the right of the diode and represents a rechargeable battery which is discharged and charged as the PhotoBot solar panel. Eventually, once this circuit becomes more sophisticated and realistic, the team will be able to predict the power characteristics of the bot over the course of six months.

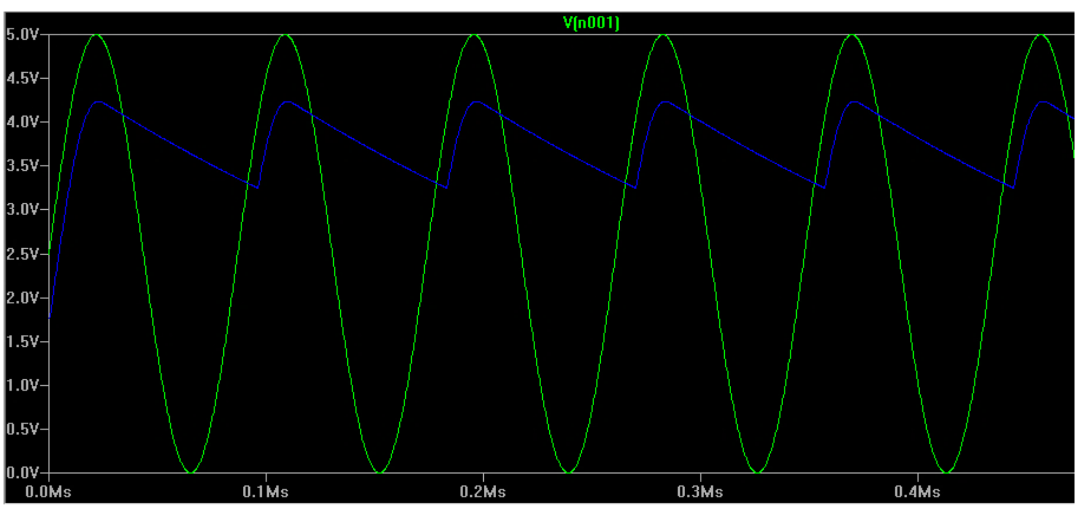



Figure 18. Sinusoidal solar power input and battery output for the PhotoBot

<u>5.3.3 Software</u>

Figure 19 is a depiction of the software flow diagram that describes the system architecture as well as the logic used to direct the behavior of the PhotoBot. The flowchart indicates that the bot first

goes through an initialization and then calibration phase when the bot is first turned on. Then the bot gets the user input and saves the corresponding data to a memory device so the bot can move to the correct location when it's time to take a picture. Once Dr. Cristoffer finishes setting the initial locations, picture frequency, and camera orientations, the bot computer will create a queue of all the required pictures. The bot will get the next picture location and time from the queue and then wait until it is time to move the bot and take the picture. It iterates through this process until it has taken all the pictures. Finally, the bot also checks the current power level at the end of each stage and then either continues to the next stage or enters low power mode and waits for enough power to continue.

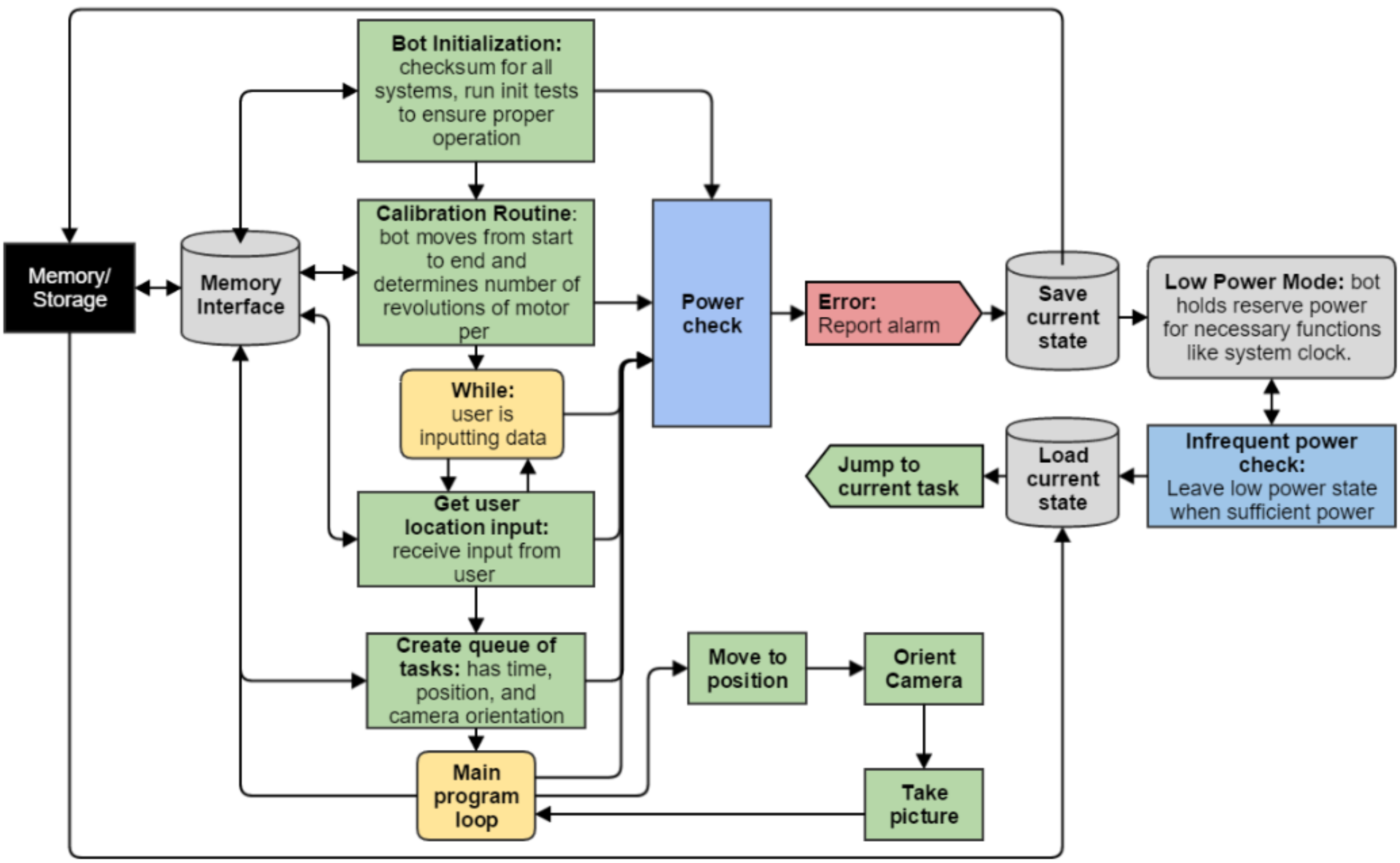



Figure 19. Preliminary software flowchart

## *5.4 Preliminary Testing Plans*

5.4.1 Mechanical

After the SolidWorks design for the wheels and brackets have been finalized, Finite Element Analysis (FEA) will be used to test the stress points on the system depending on various X and Z forces. This method will provide a good understanding of how heavy the PhotoBot should be and how much tension can be applied in the cable. The deflection of the cable was analyzed based on the length of the cable and the load applied to the cable. These calculations were used to determine the amount of resting tensions required for the pulley line, which yielded a value of 60 lbf. Also, initial strength calculations were performed for the driving pulley to determine which points on the pulley would experience high stress. These stresses were based on the resting tension in the line. Refer to Appendix E for the cable tension and bracket strength calculations. The team also plans on building a very rough small-scale prototype to physically test the strength of the design.

### 5.4.2 Electrical

The team will use LT Spice simulations of electrical circuits in order to predict power consumption, circuit reliability, and circuit functionality. Furthermore, when the circuit is constructed, a multi-meter will be used to confirm that the voltage and current values are within tolerances and that simulations predictions match the measured values. If the measured values do not match the predicted values, something is wrong with one of the components or the circuit was constructed incorrectly. The circuit simulations will also help debug any problems with the real circuit since the team can see which part of the circuit deviates from the predictions and then focus on that element of the circuit.

### 5.4.3 Software

In order to test the software, the team will use the personal software process as well as unit tests and integration tests. First of all, the team will generate the code design and write all the necessary documentation for all parts of the code. When the design is finished, the team will come together and verify that the complete design makes sense and will most likely work. After the design phase, the team will move onto the coding phase and construct each individual module. As each function and code module is completed, tests will be written to make sure that the function produces the expected outputs based on various inputs. These unit tests will try to trigger all possible error cases and explore all the possible inputs that could happen. With the coding complete, the team will move onto a code review and check that all the software is logical and contains no obvious errors.

## 6.0 Preliminary Design

The final design for the PhotoBot system consists of a driving pulley connected to a servo motor and two idler pulleys. Galvanized steel cable wire will be used as the connector between the pulleys. An acrylic frame will be mounted to the cable wire, which will support the PhotoBot camera – a 20.7MP Sony Xperia Z1 smart phone. The motor systems on the PhotoBot and pulley will be controlled by use of an Arduino and IOIO module. The Android will control the camera rotation about a single axis. Through use of a PC application, the movement of the PhotoBot can be manually controlled. The total estimated operational duration of the final design is 80 days with a current draw of 5A from the motor, a 60 ft cable length, while the PhotoBot is moving at 9.82 ft/min. Refer to Appendix N for a sample calculation of the power requirements and life estimate. Figure 20 below displays the final layout of the PhotoBot system.

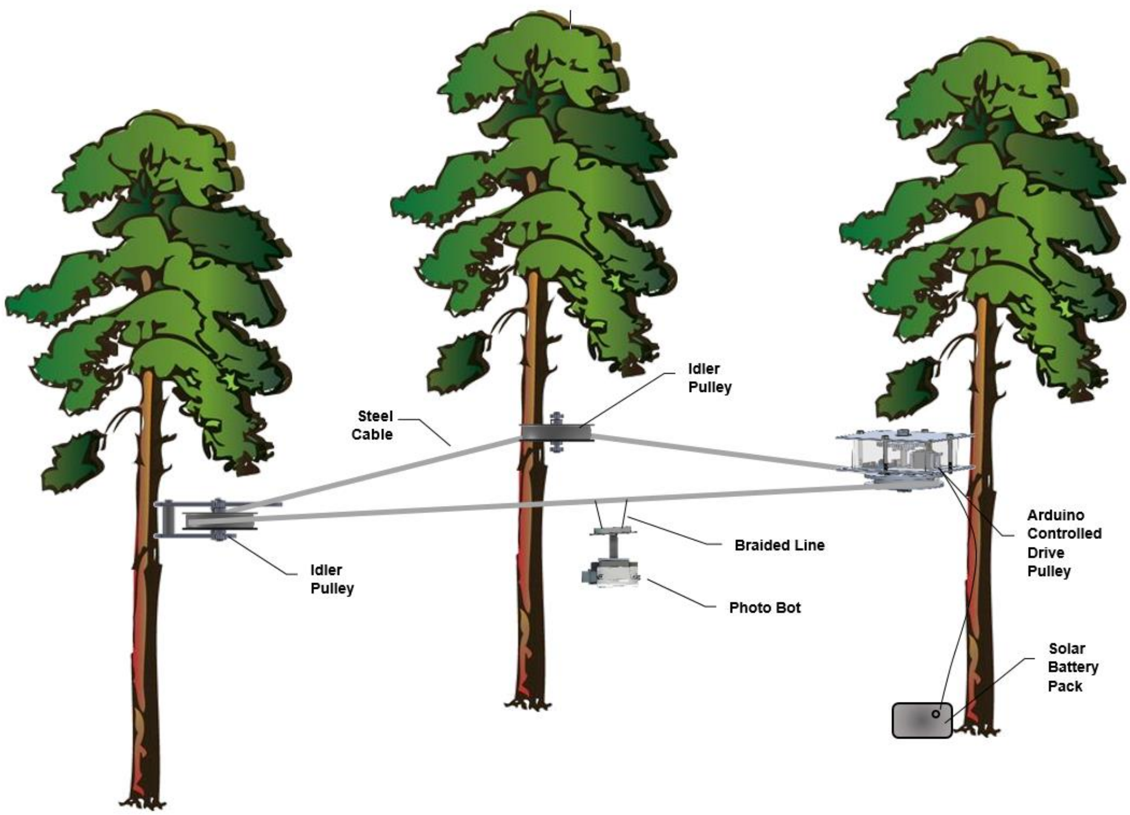



Figure 20. Final PhotoBot system layout

### *6.1 Driving Pulley*

The driving pulley in the PhotoBot system, seen in Figure 21, will be the only pulley connected to a motor. The servo motor used for this pulley will supply a maximum torque of 31.5 ft-

lbf to move the PhotoBot around the cable loop at an average speed of 10 ft/min. An Arduino will be used to remotely control the motor speed. The servo motor and gears, Arduino, and electrical wires will be enclosed in the bracket housing. The total weight of the driving pulley assembly is approximately 4 lbf. The following sections explain the detailed operation of the driving pulley system, showing supporting calculations, and describe its manufacturing plans.

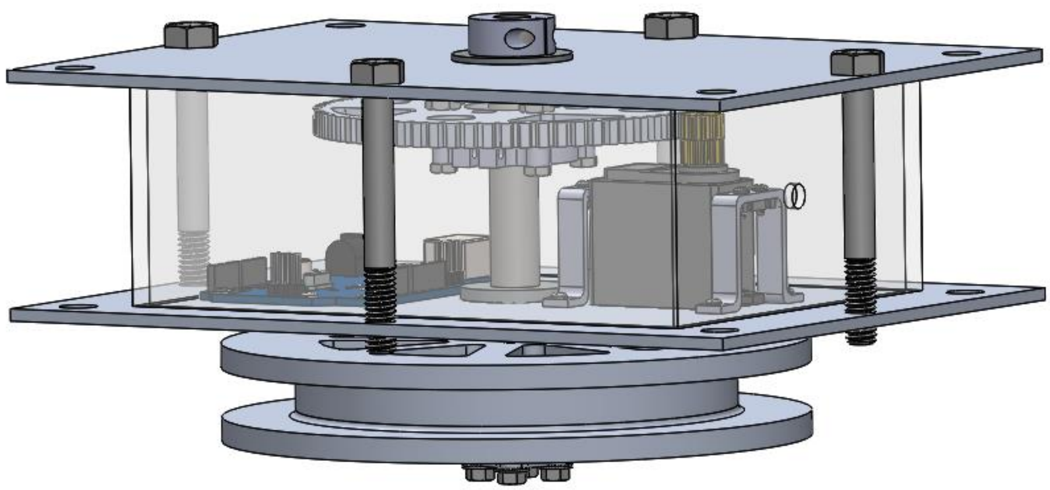
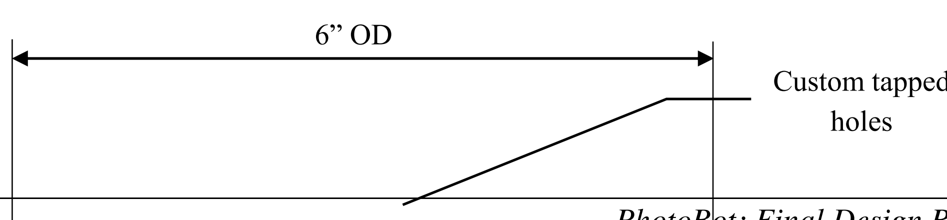


Figure 21. Driving pulley assembly of PhotoBot system

6.1.1 Overview

A 6” OD, 1” thick aluminum pulley will be machined by the team for this assembly. Machining a custom pulley will be advantageous for three important reasons. First, the wide flange of the pulley (measuring ¾” deep) will act as a guide to prevent the cable wire from slipping off the pulley. This flange depth was not found for existing pulleys that could have been purchased. Second, the pulley will have a ½” bore for the shaft. The combination of this bore diameter and the pulley outer diameter was also not found for existing pulleys. Although this machining process will be more expensive and timely, it will greatly increase the successful function of the system. Third, custom tapped holes will be placed near the bore of the pulley to fit an existing set screw hub which will mount the pulley to the shaft. Figure 22 below displays each of these three important components.



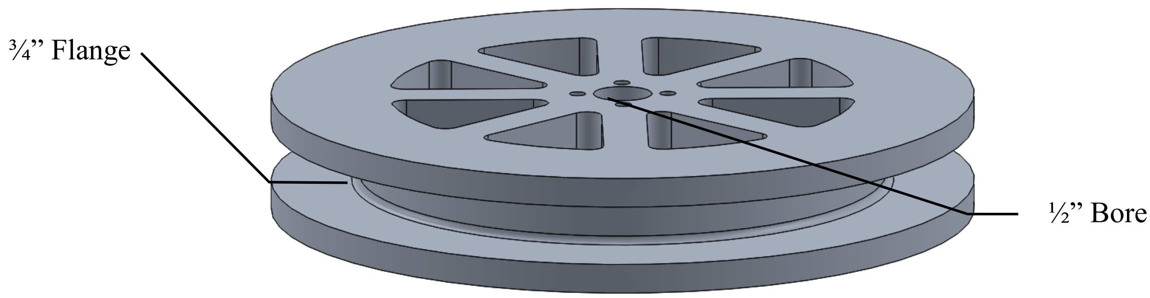



Figure 22. Machine aluminum pulley with important aspects labeled

The chosen motor for the driving pulley is a 6V High Torque Servo Motor. The maximum torque output for this motor is around 3 ft-lbf. Unfortunately, this servo motor will have to be modified to be continuous; a stop tab on the internal shaft that is present in this motor will have to be removed. Four solar-powered 20,00mah mobile charging batteries will be used for the motor. To increase the torque output for the PhotoBot system, a gear ratio of 1:10.7 will be used to achieve a torque of 31.5 ft-lbf. This servo motor is rated at a maximum of 40 ft-lbf with a certain gear ratio. However, there are currently no gears available for stock purchase to achieve that ratio. The gears will initially be lubricated. As seen in Figure 20 above, a second pinion will be welded to the existing pinion on the servo motor. The existing pinion on the servo motor has a different pitch and pressure angle than the chosen 128 tooth aluminum gear, so a 12 tooth pinion with the same pitch and pressure angle will be used instead. The electrical wiring coming from the back of the servo motor, as shown in Figure 23 below, will be connected to the Arduino on the other side of the pulley shaft.

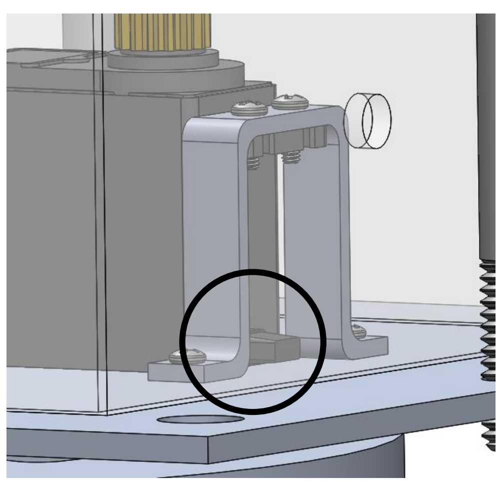


Figure 23. Location of servo motor electrical wires that will connect to the Arduino

The housing for the motor, gears, and Arduino will consist of two aluminum bracket plates and acrylic housing. The purpose of this housing is to protect all inside components from environmental interference. It will also protect the user from possible injuries from the rotating shaft or gears.

6.1.2 Mounting

The pulley will be mounted to the shaft with four cap screws and one set screw hub. The set screw hub has a ½” ID that will slide over the shaft. The four holes in the set screw hub are not tapped. The cap screws will slide into the hub and thread into the pulley. Figure 24 below shows the depth of the screws in the tapped holes of the pulley. The screws will end shortly before the surface of the pulley. The set screw in the hub will ensure that the pulley is fit firmly against the shaft.

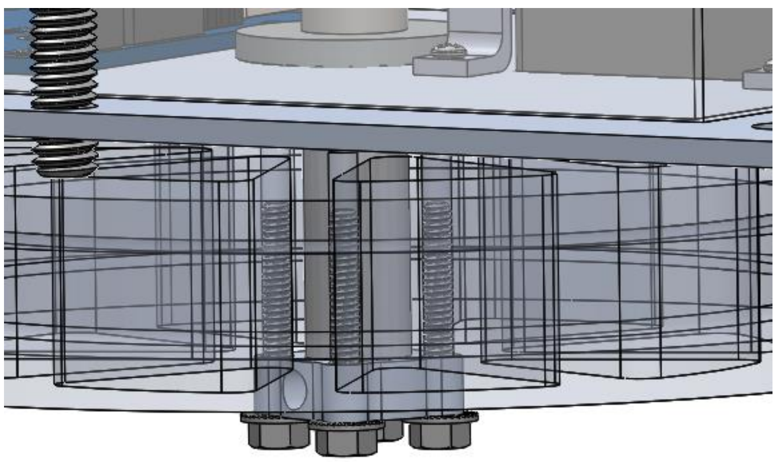


Figure 24. Depth of screws shown in tapped holes of transparent aluminum pulley

The 128 tooth gear will be mounted to the shaft with a 1” bore clamping hub, hub adapter, cap screws and hex nuts, as displayed in Figure 25 below. The hub adapter (1”OD, ½” ID) will be compressed inside of the clamping hub. The cap screws will thread through the tapped holes in the clamping hub, run through the untapped holes in the gear, and be secured on the surface of the gear with hex nuts. Figure 26 shows a top section view of how these parts are assembled.

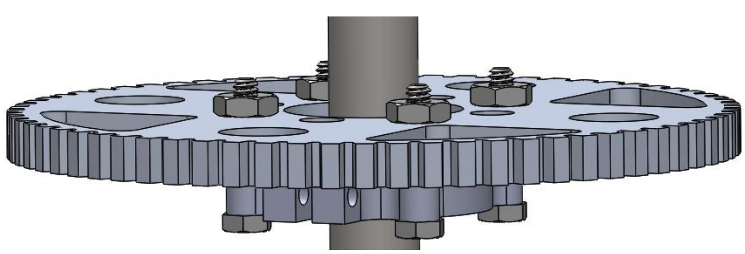


Figure 25. Assembly of clamping hub, hub adapter (not seen) and cap screws to mount gear

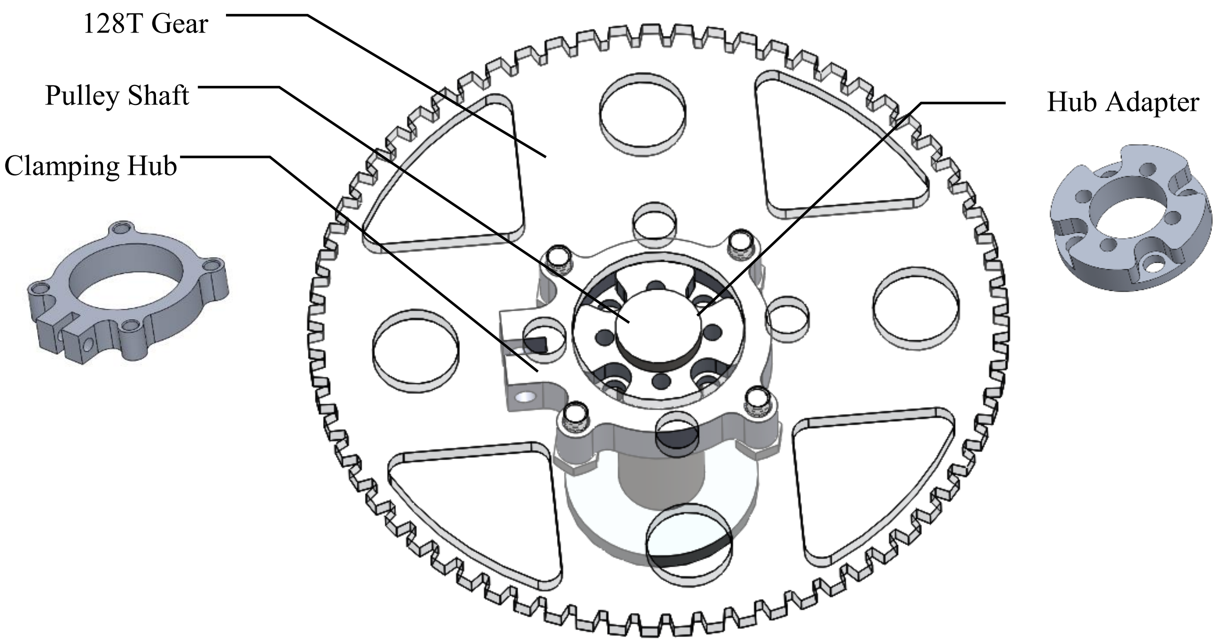



Figure 26. Top section view of transparent gear, displaying assembly of clamping hub and adapter

The two bracket plates will be connected together by four cap screws, as seen in the figure below. The top plate will have a hole for the unthreaded portion of the cap screw. The bottom plate will have a tapped hole for the threaded portion.

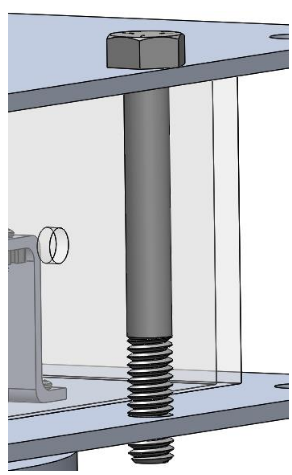


Figure 27. One of four cap screws used to secure the two bracket plates together

The motor will be supported by two U-shaped brackets on either side of the motor. The servo motor has two shoulders that extend out from the sides, each with two holes. The U-shaped brackets will be screw into the shoulders and the bracket plates with a total of eight screws, as shown in the figure below. The Arduino will also be mounted to the bottom plate with its existing tapped holes and screws that come as a package.

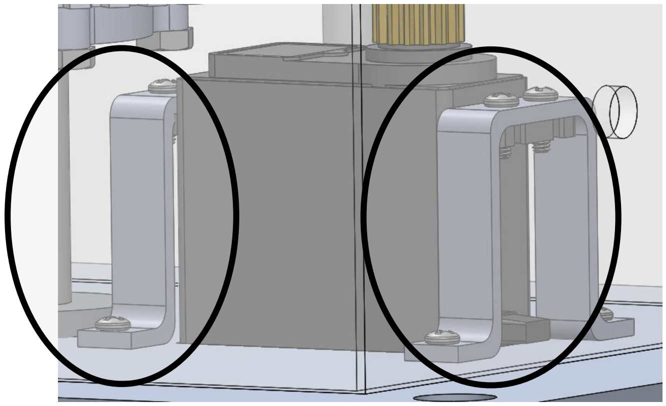


Figure 28. Location of U-shaped brackets to mount servo motor

In addition to U-shaped brackets supporting the motor, there will also be a pocket in the bottom bracket plate for the motor to sit in. This pocket is essential for the design because the motor needs to be in a specific position in order for the pinion to mesh correctly with the gear. This pocket will ensure that the motor remains stable while locating its correct position.

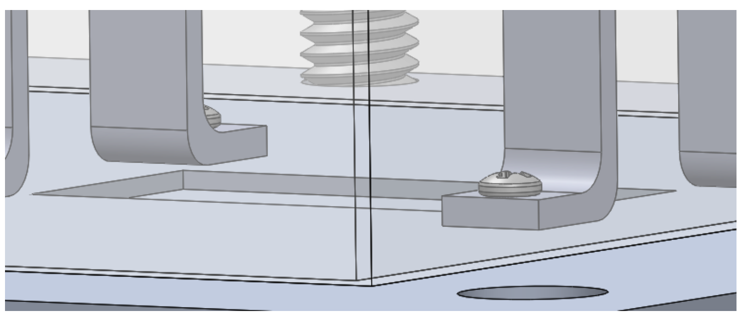


Figure 29. Bracket plate pocket for servo motor to be seated

The pulley shaft will be mounted to both of the bracket plates with two press-fit ½” bore flanged ball bearings. The flange of the bearings will sit on the outside of either bracket plates. The top end of the pulley shaft will also be mounted with a set screw collar. This ½” ID collar will slide over the shaft and will be compressed onto the shaft. This feature was added into the design to make sure that the shaft will not be pulled through the bracket plates if too much additional tension or weight is applied to the pulley. Unfortunately, this component will introduce friction to the shaft and will have to be initially lubricated. However, this friction could be avoided by allowing a small space between the bearing and the collar.

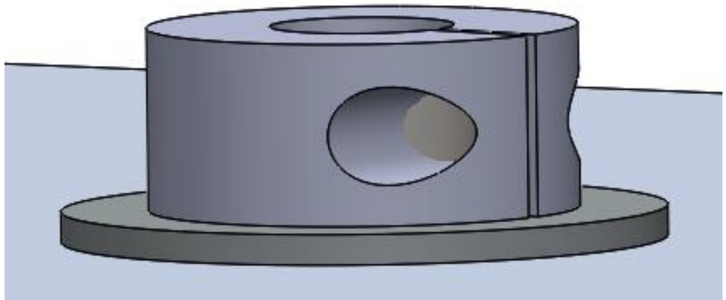


Figure 30. Set screw collar to secure top of shaft in bracket plate

A small hole will be drilled into the back acrylic wall closest to the motor to allow for a connection of the motor to the batteries. The batteries will either be mounted to the top of the aluminum bracket plate or stationary on the ground. The total weight of these batteries is 2.5 lbf. Placing this weight onto the pulley assembly may be too heavy to easily support. Either mounting method will be later verified when testing begins.

6.1.3 Torque Requirements

To determine the amount of required torque to move the cable on the pulleys, a dynamic model of the three pulleys and the cable wire on a single plane was modeled using the diagram below. For this analysis, several assumptions were made: 1) the average weight of one pulley was 3 lbf, 2) the station tension was set to 60lbf, 3) the coefficient of friction between the vinyl-coated cable and rubber-coated pulley, $\mu$, was 0.6, 4) the desired speed of the PhotoBot was 0.5 ft/s, 5) the time to accelerate to the desired speed was 5 seconds and 6) the diameter of the pulley on which the cable was rotating was 2.25in. Each pulley was labeled as *1*, *2*, and *3*. The distances between the centers of the pulleys were labeled as *a*, *b*, and *c*. The angles between the pulleys were labeled as $\alpha$, $\beta$, and $\gamma$. The tension in the cables between each pulley was labeled as *A*, *B*, and *C*. The angle of wrap that the cable makes around each cable was labeled as $\alpha'$, $\beta'$, and $\gamma'$ which were calculated based on geometry. The independent variables in this analysis were set to be the angle $\gamma$ and the distances *a* and *b*.

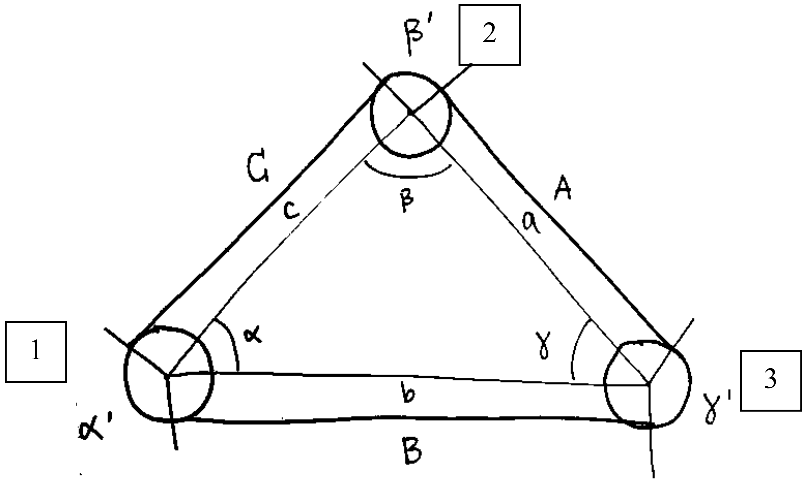



Figure 31. Diagram of pulley and cable system analysis to determine required torque

Pulley *1* was assumed as the driving pulley. Therefore, it was determined that tension *B* > *C* > *A*. A basic dynamic equilibrium analysis was performed on this system using the below equations, where *o* represents the center of the pulley and *α* represents the angular acceleration of a pulley.

$$\sum M_o = I\alpha_o \quad [1]$$

This equation was applied to each of the three pulleys. For example, this equation applied to pulley *1* becomes the following, where *R* represents the radius of the pulley and *M* represents the applied torque from the motor:

$$T_B R - T_C R - M = -I\alpha_o \quad [2]$$

To find a relationship between the two different tensions and incorporate the friction factor acting on any of the three pulleys, the below equation was used. In this equation, *θ* represents the angle of wrap around a pulley. $T_1$ represents the greater of the two tensions acting on a single pulley. This equation would yield the maximum possible value for $T_1$ before slippage would occur.

$$\frac{T_1}{T_2} = e^{\mu\theta} \quad [3]$$

Therefore, substituting Equation 3 into Equation 2 yields the following for tension *B*:

$$T_B = \frac{-I\alpha_o + M}{R\left(1 - {}^{1}/_{e^{\mu\alpha'}}\right)} \quad [4]$$

Equations 2, 3, and 4 were applied to each of the three pulleys. This yielded a set of equations with four unknown variables: the three tensions values and the torque input. In order to solve this set of equations, the torque input $M$ was set as an independent variable ranging from 0-30 ft-lbf.

Depending on a wide varied range for the angle $\gamma$ and the distances $a$ and $b$, this analysis yield a torque input range of 2-20 ft-lbf. Refer to Appendix K for an example of the results for one iteration of these calculations. Therefore, it was decided to choose a motor that could provide the maximum required torque for the system. As the chosen motor can provide up to 31.5 ft-lbf of torque, this allows for the ability to decrease the amount of power supplied to the motor and extend the operation life of the motor.

However, this analysis could have been more accurate due to a few errors. First, it was assumed that each of the three pulleys were operating on the same plane, i.e. all pulleys were perfectly level. In reality, this would be impossible. When the PhotoBot is installed in the rainforest, it will be very difficult to set the pulleys up on the same plane. Unleveled pulleys will most likely result in a higher amount of required torque to move the system. Second, this analysis did not factor in the weight of the PhotoBot on the cable. Although this weight will be a small value (around 1.5lbf), it will have an effect on the require torque. This is also most likely results in an increase in the amount of required torque.

### 6.1.4 Materials and Manufacturing

Many of the parts for the driving pulley assembly will be bought from distributors such as McMaster-Carr, ServoCity, Home Depot, Amazon, and SainSmart. However, some parts will be machined by the team from stock materials. Refer to Appendix P for a complete list of materials to be purchased for the driving pulley assembly. This section will provide information on which materials and manufacturing methods will be used for the machined parts. Refer to Appendix G for all dimensioned drawings of parts to be machined for the driving pulley.

The pulley shaft will be cut from a ½" diameter hardened precision steel rod from McMaster Carr. This shaft will be cut at 4.5" and deburred and chamfered around the end diameters.

The driving pulley will be machined from a 7"x7" 1.5" thick 6060-T651 Aluminum plate from DiscountSteel.com. The pulley will first be milled on a CNC machine to mill out the outer diameter, pockets and tapped holes. It will then be turned on a lathe to cut out the flange. Next, the

surface of the pulley will be faced to turn the thickness down to 1”. Last, the groove of the pulley will be coated in a rubber dip to create traction for the cable.

The motor housing will be machined by the team from ⅛” thick 12”x12”stock 6061-T6 Aluminum sheets and ⅛” thick 12”x24” stock Clear Cast Acrylic sheets from Amazon and McMaster-Carr, respectively. The bracket plates will be cut down on a band saw to the correct size of 8.5”x 6.25”. It will then be milled on a CNC machine to create the pocket for the servo motor, the holes for the cap screws, the holes for the shaft, and the mounting holes for the servo brackets and Arduino. A drill press will be used to make the 0.4” diameter rope holes. A hand tap will be used to tap the bottom bracket pla505te 5/16”-18 screw holes for the cap screws and 2-56 screw holes for the Arduino and servo motor. The acrylic housing will be made from four separate laser-cut plates. These plates will be cut to size and epoxied together by the edges. The top and bottom surfaces will be sanded for flatness.

The U-shaped brackets will be made from .032” thick stock 5052 Aluminum sheets. The plates will be cut down to strips on a band saw and a drill press will be used to create the holes for the screws. Last, the U-shape will be made with a sheet metal bending machine.

### *6.2 Idler Pulleys*

The PhotoBot system will use a minimum of two idler pulleys to direct the moving cable and camera in a closed loop path. The pulley design provides a stiff frame to mount the idler pulley. The aluminum plate design ensures that the frame will endure the required tension loads, yet minimize deadweight. The simplicity in the design minimizes parts, cost, and assembly time. Figure 32 shows the conceptual assembly for the idler pulley design.

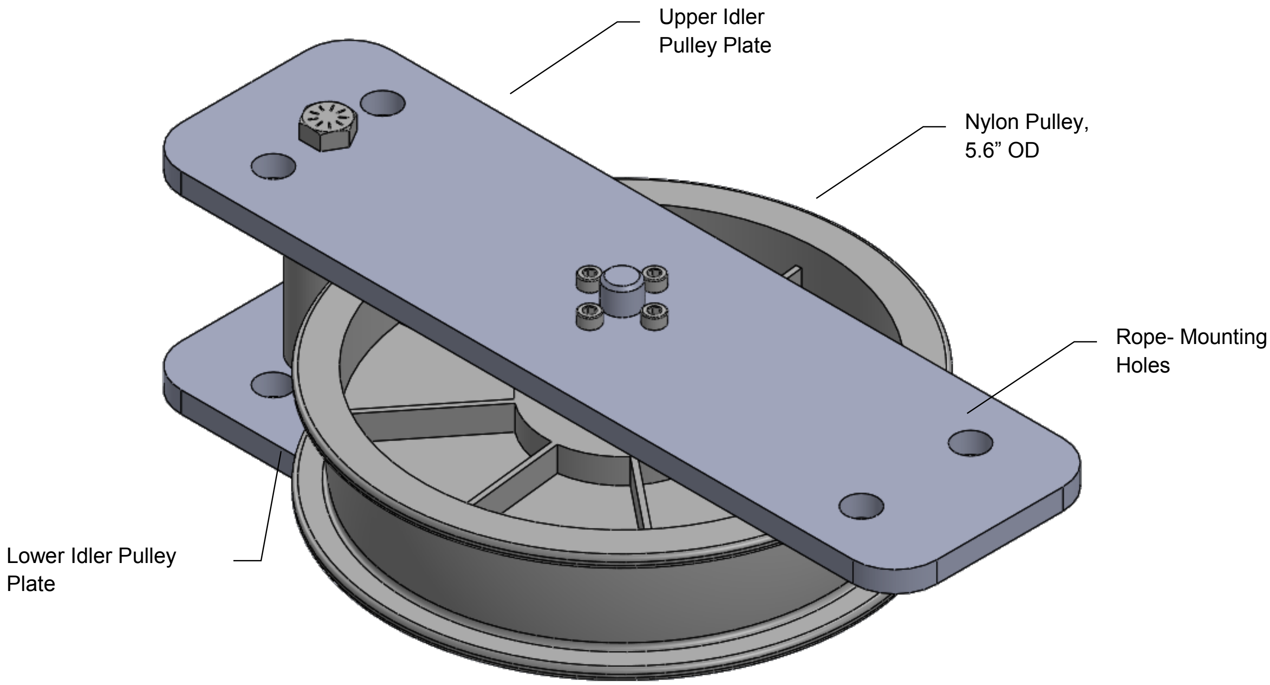



Figure 32. Conceptual Design for Idler Pulley

6.2.1 Overview

The idler pulley will have a fixed shaft supported between two aluminum plates. In addition, an aluminum spacer and screw compresses the plates on the opposite side of the pulley shaft. Two aluminum setscrew hubs, one mounted at each end, secure the shaft onto the plates. Figure 33 shows the idler pulley’s frame design without the pulley mounted.

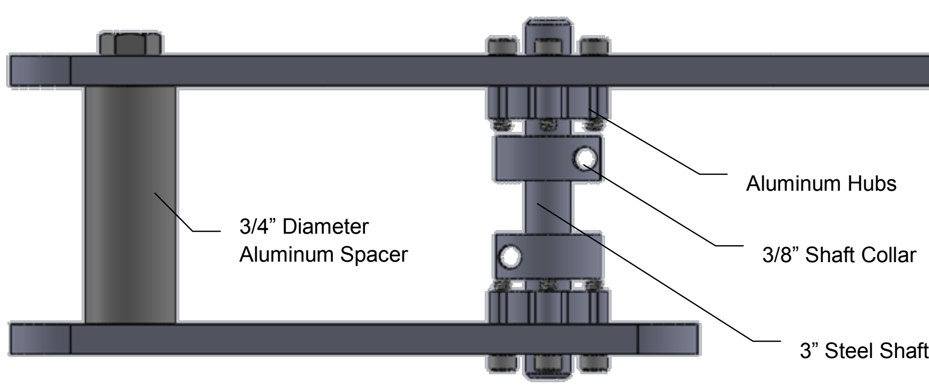



Figure 33. Conceptual Design for Idler Pulley

The pulley's bearings will allow the for free rotate freely about the shaft. To keep the pulley from sliding in the direction of the shaft's axis, two collars on each side of the pulley. The collars used will have a setscrew, which will allow them to attach rigidly onto the shaft diameter. The assembly of the shaft and collars are shown in Figure 33 and 34.

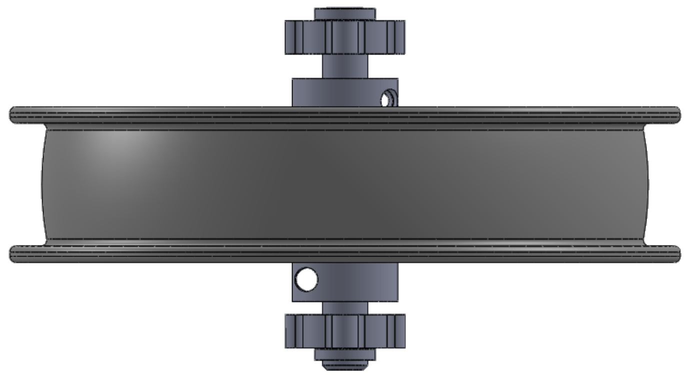


Figure 34. Idler Pulley and Shaft Support Design

6.2.2 Strength Calculations

The maximum allowable tensile load is determined from the maximum allowable tensile stress in the weakest part of the aluminum plates or the allowable shear stresses in the clamping bolt and pulley shaft. Analysis was performed to evaluate all three locations to determine the safe working cable tensions with this bracket design. It was found that the weakest part in the design is the pulley shaft.

Beam deflection analysis was used since it was found to yield more conservative stresses in the shaft. The assumptions made in the analysis assumed that the cable tension was setup in the worst possible orientation. The analysis also assumed that the shear force is shared equally by the pulley shaft and steel bolt. Finally, it was assumed that the material properties of the hardened shaft were assumed to be similar to A36 steel. Using a factor of safety of 3, the allowable cable tension was determined to be 140 lbf. Refer to Appendix L for the detailed strength calculations of the plate, bolt, and shaft.

6.2.3 Materials and Manufacturing

For the idler pulley assembly, there are only two plates that need to be machined, all the rest of the components will be purchased. The upper and lower pulley plates will be made from 6061-T6

aluminum since aluminum is easy to machine and the strength is sufficient for our application. There are two options for manufacturing the plates: CNC machining or conventional milling. Since our team has experience working with CNC programming and the parts are not very complex, the CNC machining could be done in as few operations as possible. A custom fixture will not be necessary, a vise and parallels will be enough. If time does not permit for CNC machining, it will be feasible to machine the plates using a milling machine. The tolerances for our parts are not very tight, so a CNC does not have to be used.

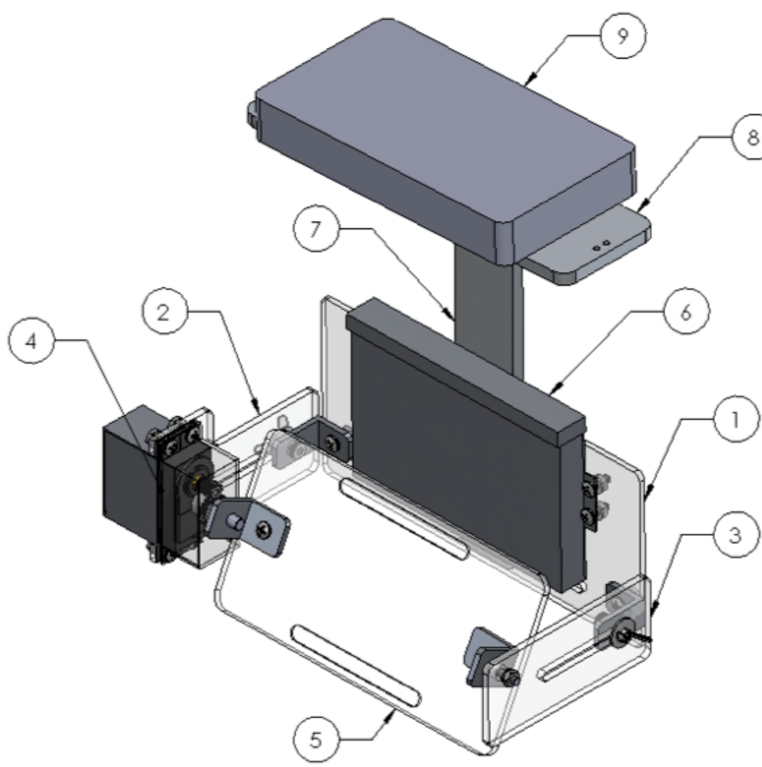
The pulley shaft material was chosen as hardened steel since it will mitigate shaft deflection. There is no significant cyclic loading on the shaft; this will reduce or eliminate the possibility of fatigue failures. A lighter pulley will require less energy to rotate, so a nylon pulley was chosen to minimize the mass moment of inertia of the pulley.

## *6.3 PhotoBot*

The PhotoBot, seen in Figure 35, is the main device that will be holding the camera. The system will be hanging from a moving cable wire that will allow it to travel along a polygon shape and capture a wide range of views. The PhotoBot contains a servo motor that allows the camera to tilt forward or backwards 180 degrees. Including its sub components, such as the phone, battery, servo motor, electrical components and its housing, the PhotoBot weighs about 1.6 lbf and is about 8.6x5.1x8.4 in. The section below will describe in detail the main components of the PhotoBot and describe how the model will be manufactured.

### 6.3.1 Overview

The main frame of the design can be seen in Figure 35, which assigns each main component with a number. The PhotoBot's frame is made up of three parts, which includes a back side ①, and two side arms labeled ② and ③. Mounted to a side arm ② is a servo motor ④ and a 1:2 gear stage that will provide 76 oz.-in of torque, which is a sufficient amount to allow a plate ⑤ that the phone will be secured tightly on, to tilt 180 degrees. See Appendix M for the required torque and gear ratio calculations. Mounted to the supporting back end of the frame ① is an aluminum box ⑥ that contains all of the necessary electric components for the bot, such as an IOIO module and a transistor. To get a full analysis of the software that allows the user to remotely capture a photo or control the angle of tilt, see Section 6.5




| ITEM NO. | DESCRIPTION |
|---|---|
| 1 | Back Frame |
| 2 | Side Arm 1 |
| 3 | Side Arm 2 |
| 4 | Servomotor |
| 5 | Plate for Phone |
| 6 | Housing for Electronics |
| 7 | Supporting Arm |
| 8 | Top Plate |
| 9 | Battery |

Figure 35. PhotoBot assembly with labeled main components.

To get a closer look of the assembly that supports the frame of the PhotoBot, see Figure 35. Attached to the back frame of the bot is a supporting arm ⑦, which holds the weight of the system and allows it to hang down from the cable wire. To add, the supporting arm ⑦ is mounted to a L-bracket with a shoulder screw, which will allow it to freely swing along the Y axis. Such a feature is necessary because if there is a slope in the line, it will correct itself to allow the weight of the PhotoBot to always be normal to the ground. In addition, the top plate ⑧, which is also mounted to the same L bracket that the supporting arm ⑦ is secured to, is used to hold a solar-powered 20,000 mah 5 volt mobile charging battery ⑨ that will be used to power the phone, servo motor, and all of the necessary electrical components. The battery will be secured using zip ties and to ensure that the ties will not slip, they will be fed through small holes located under the battery on the top plate⑧. Also, 65 lbf braided SpiderWire will be tied off to the top plate ⑧ by feeding it through small holes, which are located at each end of the plate, and will then be directly tied to the steel cable line.

Figure 36. Closer view of assembly that will be supporting the frame of the PhotoBot.

6.3.2 Assembly

The PhotoBot is designed for easy assembly. The whole design is assembled using 6-32 thread size screws and nuts, and .1in thick 5052 aluminum L brackets. As seen in Figure 36, the main frame of the bot is linked together with the use of small L brackets. On each side arm of the frame, a shoulder screw with a 6-32 thread is not only used to secure it to the back piece, but if need be, it allows the user to slide the back frame along the length of the slot. Similarly, shoulder screws are used to assemble the back supporting arm to the back frame, and it allows the back frame to slide along the y axis. The use of flange hinges allows it to be relatively easy to adjust the position of the back frame of the bot as well as the supporting arm. Looking at the supporting arm and top plate, they are bolted together using a relatively large .1-inch-thick 50552 aluminum bracket. As stated before, the supporting arm is linked to the L bracket with a shoulder screw, which acts like a hinge and assures that that the weight of the bot is always normal to the ground.

As for the housing of the servo motor and the extra electrical components, they are directly screwed into the acrylic frame. In addition, looking at the configuration of the servo motor and how it allows the plate that will be secured to rotate (see Figure 37 for the close up view), the pinion will be pressed fit into the shaft of the motor and will be mated with a gear. Holding the gear is a small custom steel shaft that is press fit into its hole and that is attached to the frame of the plate using a small L bracket. To account for the space between the face of the gear and the face of the L bracket, a steel spacer is put in place. Similarly, on the other end of the plate, a small custom steel shaft and a steel spacer is used to secure it to the frame of the bot while still allowing it to freely rotate. The slots on the plate where the phone will be secured to allow an armband that will be holding the phone to be fed through and secured on. See Appendix I for the engineering drawings of each custom piece and for an exploded view of the whole system and how each component will be attached.

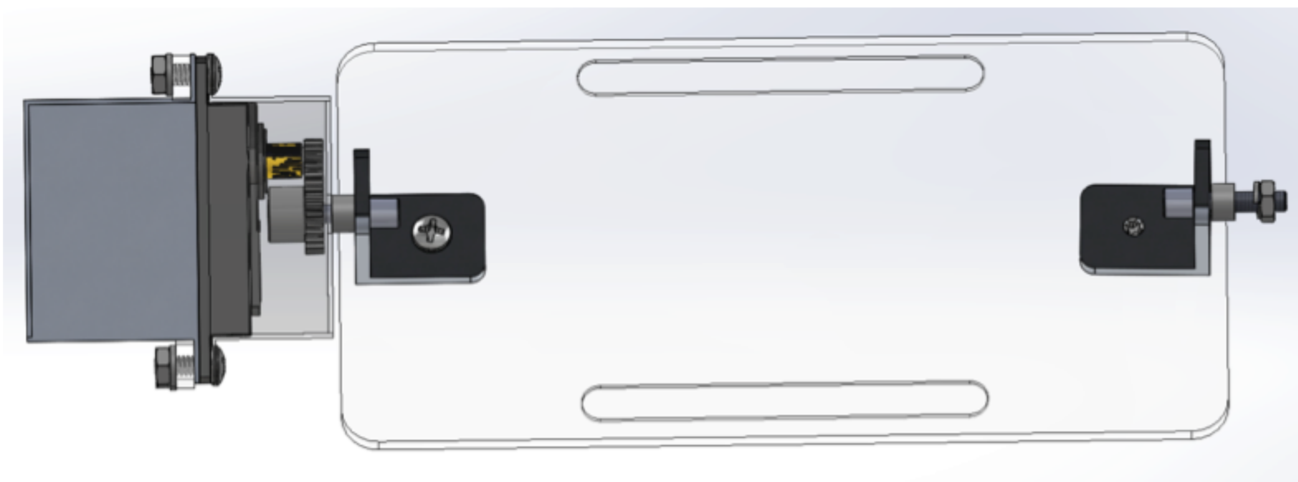


Figure 37. Configuration of servo motor and gear stage.

6.3.3 Material Choice and Machining

The team decided to make the body of the PhotoBot with cast acrylic sheets because it's cheaper than any other metal sheets, easier to manufacture, lightweight, and strong enough to withstand the load being placed on the material. In addition, this specific acrylic have a temperature range of -40 to 170°F, have a large tensile strength that ranges from 8,000 to 11,250 psi, and can be used outdoors. In machining this material, the laser cutter located at Mustang 60, Cal Poly's machine

shop, will be used to cut the acrylic to size. In addition, aluminum sheets was chosen to make the L brackets and the housing for the servo motor and electrical components because it is strong enough to withstand the weight of the bot and is easy to manufacture. 5052 aluminum was specifically chosen because it is easy to weld, is corrosion resistant, has a yield strength of 28,000 psi, and has a temperature range from -300 to 300°F. The team will use the sheet metal shear machine in the Hangar, one of Cal Poly's machine shop, to cut the material to size and the sheet metal brake to bend the material. A rotex punch machine will be used to make holes in the aluminum sheet. Also, TIG welding will be done to enclose the aluminum housing for the servo motor and for the electrical components to prevent any water from leaking through. To make the custom shafts that are attached at each end of the plate for the phone, a quarter inch diameter 12L14 steel shaft will be turned and faced down to size using a lathe machine that is located in the Hangar. In addition, a dye will be used to create an external thread on one of the parts that requires that feature. Also, 65 pound braided fishing line was chosen to hang the bot from the cable wire because it is designed to be in tension, is strong, lightweight, cheap, and will not interfere with the pulleys as it passes by. To note, all of the materials that make up the PhotoBot (excluding the fishing line, servo motor, phone, battery and electrical components) will be purchased from McMaster-Carr.

## *6.4 Mounting and Cables*

### 6.4.1 Cable System

The cable, which will run between each of the three pulleys, will be 3/32" diameter galvanized steel vinyl-coated wire rope. A large available length of the cable will be provided. The user will determine the length of the cable; the cable can be cut by use of a cable cutter, as seen in the figure below. This economy size cable cutter has the ability to cut cable up to 1/8" diameter.

Figure 38. Economy size cable wire cutter

After the cable is cut, the PhotoBot will be connected to the cable and four stops will be installed to ensure that the PhotoBot does not slide on the cable. The stops will slide along the cable and be crimped with a swaging tool, as seen in the figure below. After the stops have been installed, braided fishing line will be knotted around the cable between the stops to be tied to the connecting link on PhotoBot.

Figure 39. 3/32" Aluminum stops and swaging tool

After the stops have been installed, the free ends will be secured together with a ferrule and swaging tool shown in the figure below. One free end of the cable will slide through the ferrule and the other free end of the cable will slide through the opposite end of the ferrule. Then the ferrule will be crimped with the swaging tool. Figure 41 displays the configuration of the stops and ferrule on the cable.

Figure 40. 3/32" Aluminum ferrule to connect free ends of cable wire

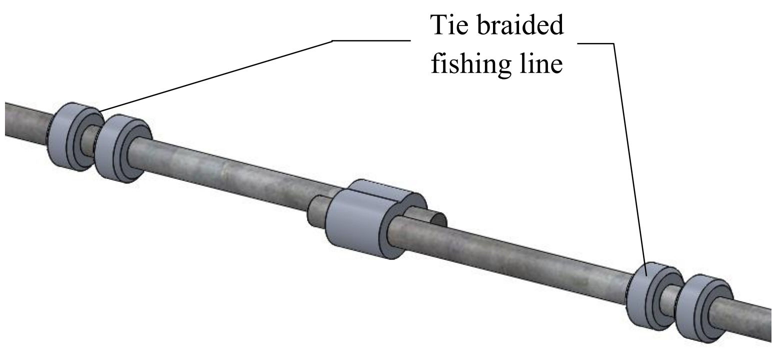



Figure 41. Assembly of ferrule and stops on cable wire

Finally, after the cable has been secured together and the PhotoBot has been connected, the cable can be set between each pulley flange and mounted to the trees.

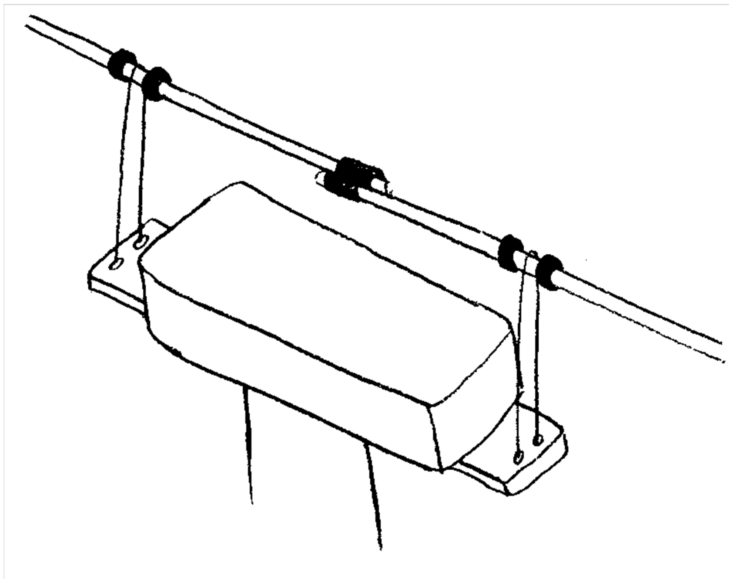


Figure 42. Assembly of PhotoBot connected to the cable wire

6.4.2 Mounting the Driving Pulley

The entire pulley assembly will be secured to a surrounding tree by means of rope rated at a tensile strength of 250 lbf. The front ends of the rope will loop through the front four holes on both bracket plates. Under the bottom bracket plates, the ropes will be knotted off so that they may not slip back through the holes when being tensions. The free ends of the rope will be thrown over a branch, and will loop through the back four holes on the bracket plates. The free ends will then be tied around a tree at the place and secured with a stake. The diagram in Figure 43 lays out the steps to complete this set up.

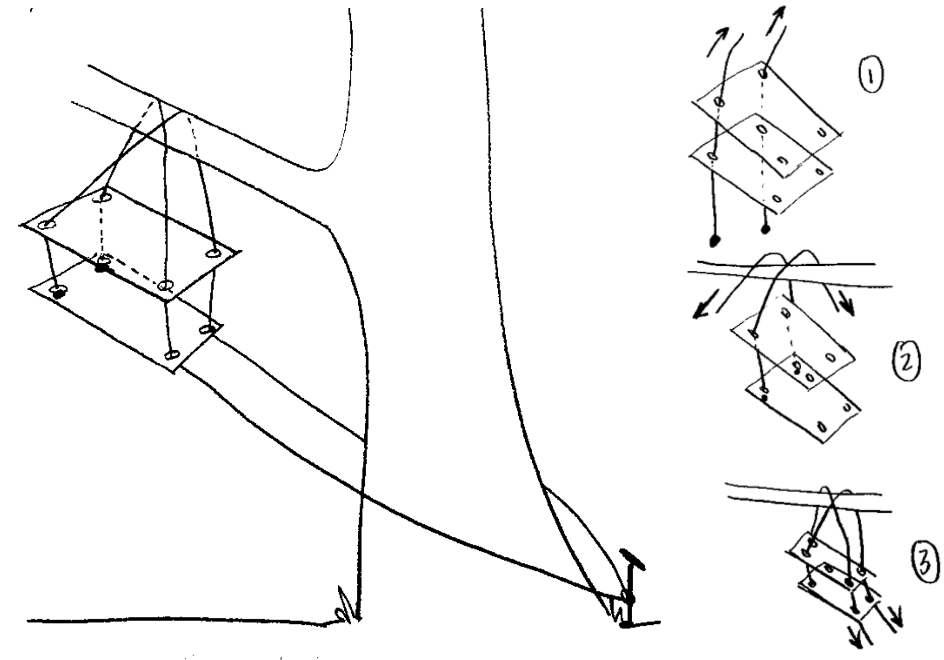



Figure 43. Steps for mounting the driving pulley assembly to a tree branch

*6.5 Software and Electrical*

The PhotoBot will use an Android phone connected with an IOIO module in order to control the camera rotation and take pictures. The android will be connected through a USB connection to the IOIO module; the android will send signals over the USB serial connection. These signals will then activate certain GPIO pins on the IOIO module, which can be used to control the servo that determines the rotation of the camera. Moreover, the IOIO module will not only control the servo's encoder, but it will also control the gate voltage of a Darlington transistor that allows power to flow to the servo motor. This transistor is required because the IOIO module GPIO pins cannot supply enough current on their own to activate the servo motor. Finally, a 20,000 milliamp hour battery will supply 5V to the IOIO module, which will in turn provide power to the android over the USB connection; the transistor will also receive its power from this 5V source. The schematic below in Figure 44 shows the electrical connections.

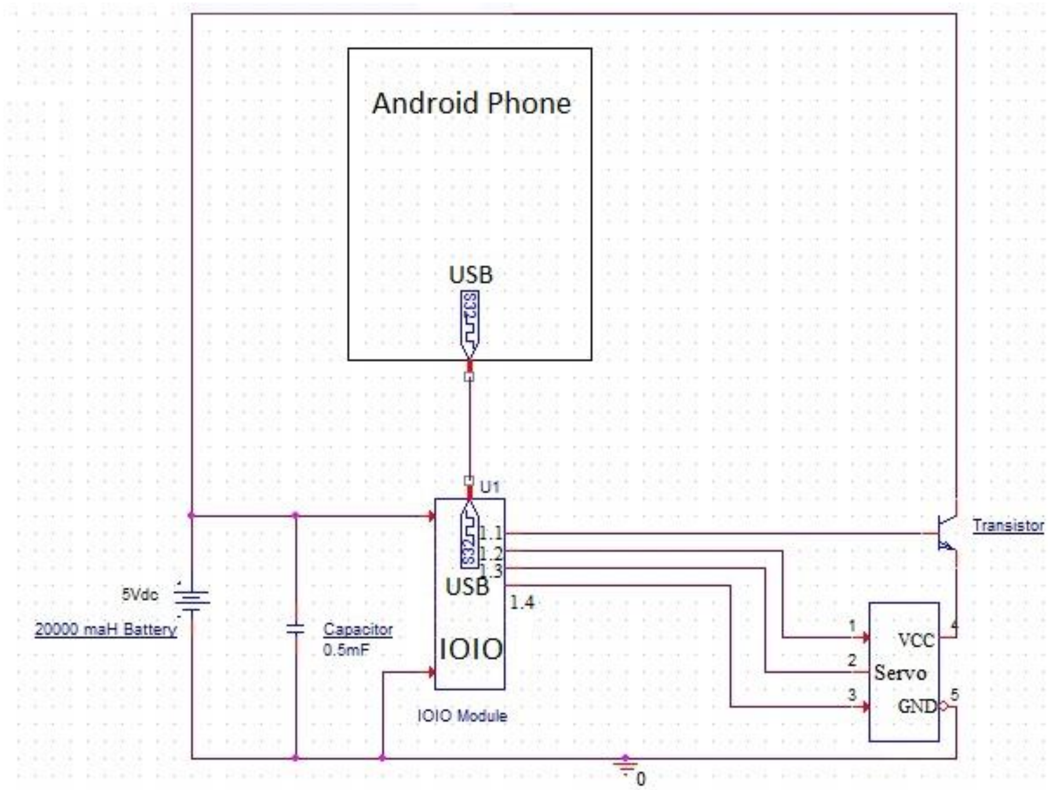



Figure 44. Android and IOIO electrical diagram

Another similar circuit is used to connect the Arduino to the servo motor that drives the pulley. The Arduino replaces both the android and IOIO module; the Arduino uses simple software that supplies power to the servo whenever enough time has passed. The novel feature of this circuit is the four separate power sources. Two batteries are added in series to meet the voltage requirements of the circuit, and another two batteries are added in parallel in order to extend the operational period of the PhotoBot. The schematic below, Figure 45, shows the electrical configuration for the pulley and the Arduino.

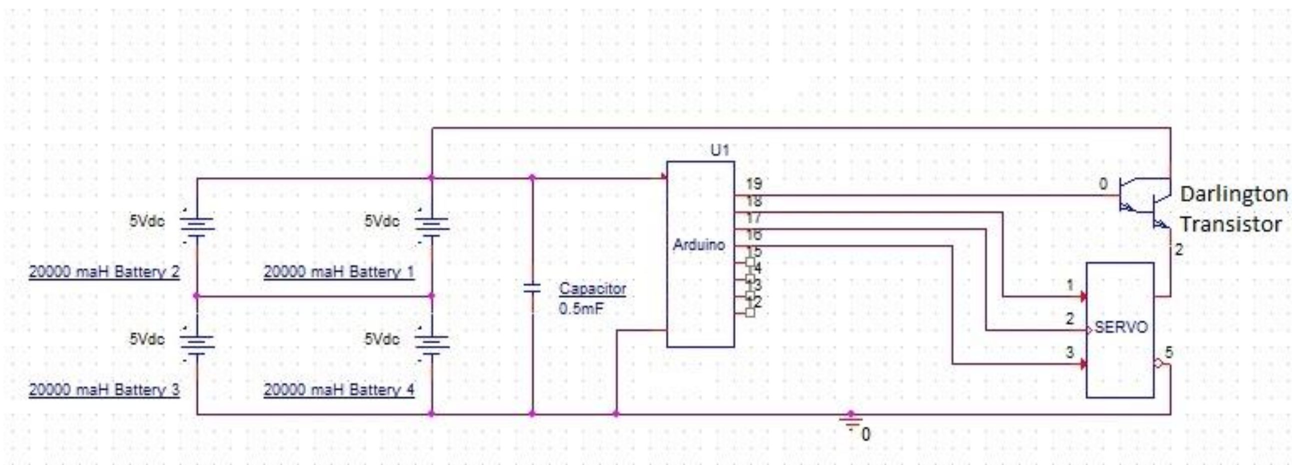



Figure 45. Arduino and Servo wiring diagram

In addition, a PC application will interface with the Android phone over wireless. The Android phone will create a wireless hotspot that creates a connection with the PC software. After a connection is established, the user will pair the PC and the Android by launching the PC application and the Android app. Then, the programs will initialize both a TCP client and server; the TCP client and server will establish a socket connection where commands and data can be exchanged over the wireless networks with 100% reliability. In order to facilitate the simultaneous exchange of commands and data, the PC program and the Android app will create a thread for sending and receiving data. When the appropriate command is received, the android app will respond with an acknowledgement and either carry out the requested functionality or respond with some important data.

There are also several commands that the user can send to the Android phone; these commands include "take_photo", "rotate_camera_down", "rotate_camera_up", "begin_auto_mode", "begin_manual_mode", "set_camera_parameters", and "exit". Most of these commands are self-explanatory except for "begin_auto_mode" and "begin_manual_mode", which make the bot begin taking pictures automatically or manually respectively. However, the user will be unaware of these specific commands; these commands will be abstracted behind a user interface that will convey status information and control camera parameters. The camera parameters include camera rotation, camera contrast, camera zoom, and camera flash settings. Furthermore, the status messages will convey things like the total number of pictures the bot can take, the predicted amount of time the bot can run for before it runs out of power, and any possible error messages regarding connection failure or low power. Finally, the user interface will also have access to a live video stream so that the user can see

exactly what the bot sees. The software flow diagram below, Figure 46, gives an idea of how the PC application and the android will exchange data.

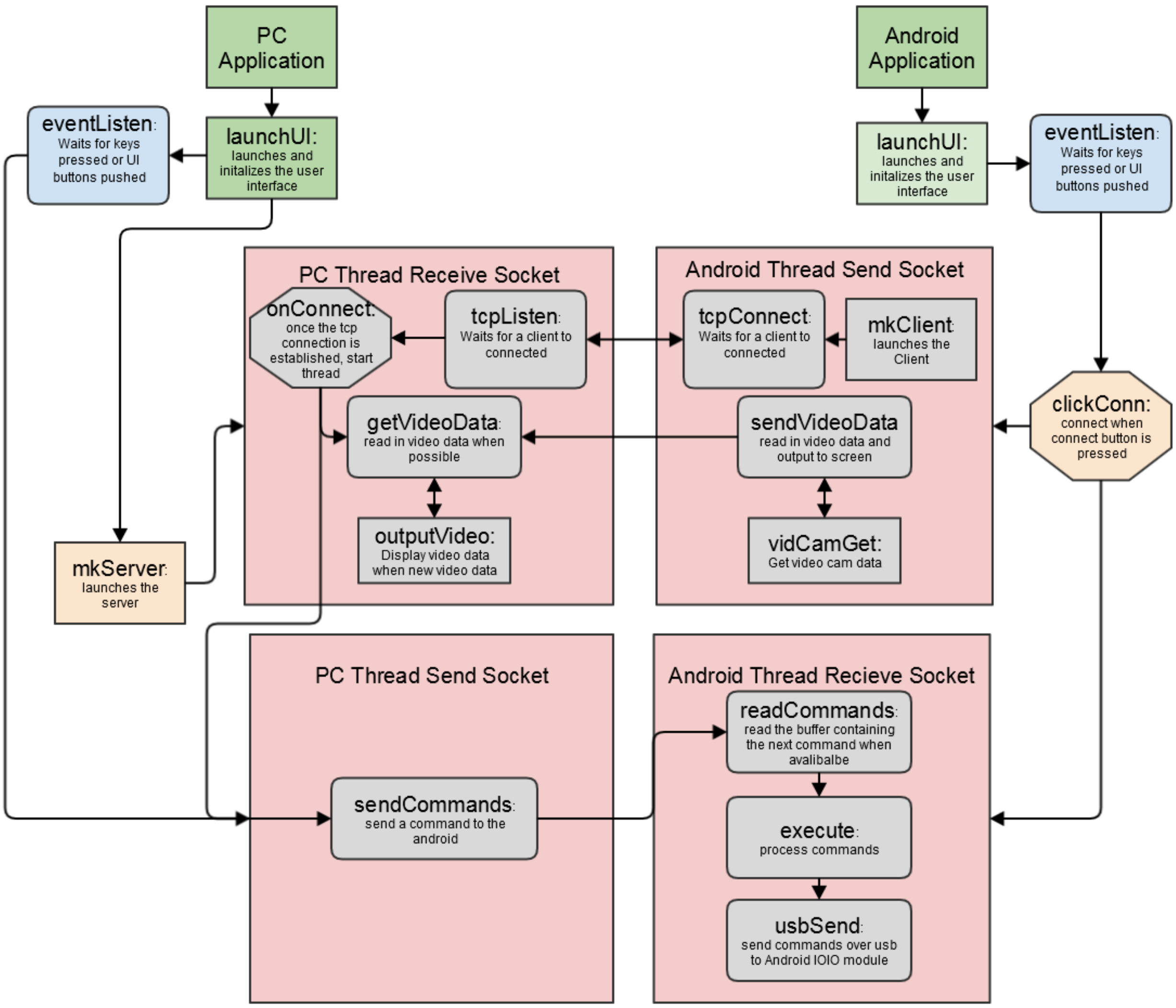



Figure 46. Android and PC application wireless communication layout

Last, the PhotoBot project can also be improved if time allows; the android phone can control both the camera rotation and the servo motor for the pulley. The Android could connect to a microcontroller with a Wifi module, like the Rasberry PI, and control the microcontroller using the same code that enables the PC application to communicate with the Android app. This would give the user maximum control over the PhotoBot and let the user create a fully customizable schedule. However, this would add significant complexity and increase power consumption.

## *6.6 Cost Analysis*

Based on the preliminary design, it was estimated that the PhotoBot would cost about $1,300 to manufacture. The cost of final design is below the initial cost estimates. The projected cost will be about $1,000 for all parts. Cost savings were made by using cheaper acrylic where possible, minimizing hardware, and decreasing the complexity where possible. Although cost-cutting decisions were made, it was decided that more should be allocated towards the purchase of a better camera phone. The cost to move from a 16MP sensor to a top of the line 20.7 MP sensor was an additional $120. Considering that the camera is the centerpiece of the system it is a justified increase in costs. All other material costs are detailed in the Bill of Materials in Appendix P.

## *6.7 Design Verification*

Verification and testing will be important to ensure that the PhotoBot system will work as designed. Extensive prototype testing has been done to improve the initial design concept and more tests are planned throughout the production lifecycle of the PhotoBot. In addition to testing, FMEA (Failure Modes and Effects Analysis) was evaluated for each of the sub-systems for the PhotoBot. Tests and actions have been created to evaluate and reduce the risk for critical failures in the PhotoBot design. The FMEA results is documented in Appendix O. A design verification plan report was created to outline all the tests required to verify components of the PhotoBot design such as the IP54 rating, motor torque requirements, and cable tension requirement. This document can also be found in Appendix O. Lastly, a safety checklist highlighting any potential hazards during testing is included in Appendix Q.

### 6.7.1 Prototype Tests and Results

To verify the PhotoBot's cable system design, several prototypes were built and tested. Figure 47 was the first prototype built. The results proved that the brackets could be suspended above ground without being attached to the tree for support.

Figure 47. Prototyping the hanging tension bracket design.

In the second prototype, three pulley brackets were made and tested in a small-scale mockup of the proposed system. From this test, it was realized that more grip was needed for the pulleys and that a special tool would be needed to crimp the cable line together. Figure 48 shows the test setup.

Figure 48. First prototype with working pulleys.

The drive pulley was prototyped using LEGO gears to transmit torque from a small DC motor. For this setup, 4V were supplied to the motor and a speed reduction of 75:1 was provided by a 3-stage gear system. The new drive pulley prototype was used with the previous pulley concepts to model a complete system with a drive motor. The torque output from the gearbox was calculated to be about 0.7 ft-lbf, however, it was found that the DC motor did not have enough torque to drive the cable. Instead, the results from this test provided an estimate for how much torque should be anticipated in the final system. The setup drive pulley prototype is shown in Figure 48 and the new setup is shown in Figure 50.

Figure 49. Drive pulley prototype with LEGO gears and shafts.

Figure 50. Second system prototype with drive pulley.

The Android to laptop application was also prototyped to provide a proof of concept. Although there were some difficulties in the process, Figure 51 shows the first working iteration of the application.

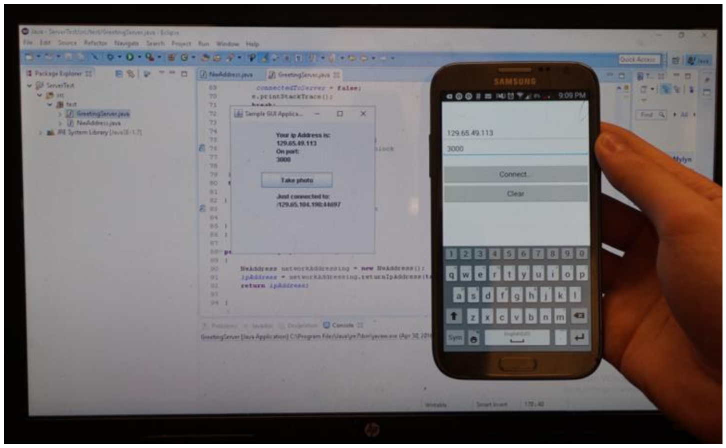



Figure 51. First working prototype for android laptop communication. The laptop was capable of activating the Android's camera and remotely take a picture.

# 7.0 Product Realization

## 7.1 Final Design Modifications

In this section the final design is discussed in detail and any modifications that were not in the critical design are documented here. The total cost for the final system can be seen in the Bill of Materials in Appendix P.

### 7.1.1 Drive Pulley

A number of major and minor changes were made to the drive pulley assembly. Most of these changes were realized necessary to make as the manufacturing process progressed. The major changes made to the pulley were the following: changing the design and material of the custom pulley, changing the height of the housing panels, changing the orientation of the motor and removing the motor brackets. An overall view of the final design for the drive pulley assembly can be seen in the figure below.

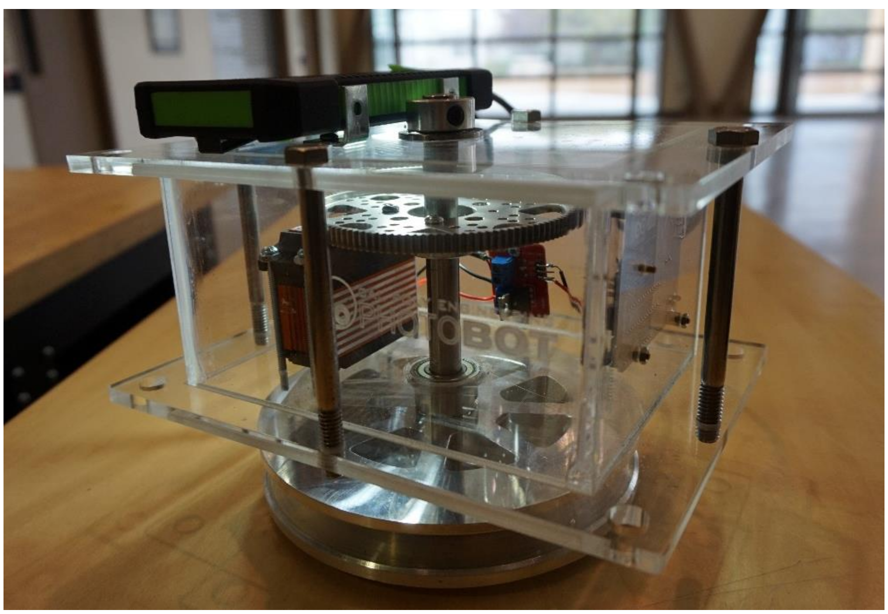


Figure 52. Overall new design for drive pulley assembly

The design of the pulley was changed to more securely fix the pulley to the drive shaft. This new design includes two pockets on either side of the pulley for which a set-screw hub will freely lay inside. The set-screw hubs are fixed to the drive shaft. These pockets were designed to closely fit the profile of the set-screw hub so that when the shaft turns, the pulley and hubs will interlock and the pulley will also turn. The use of screws through the pulley was also eliminated this way and allowed for easier manufacturing. These pockets can be seen in Figure 53 below. A long pocket was also

included so that a wrench could fit in the pulley to secure the set-screw. The assembly of the hubs and pulley with the pulley transparent can be seen in Figure 54.

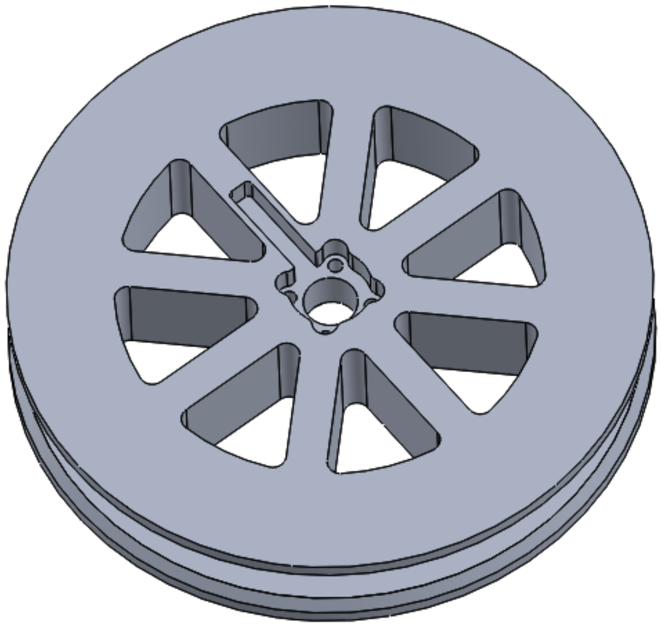


Figure 53. New pulley design with set-screw hub pockets

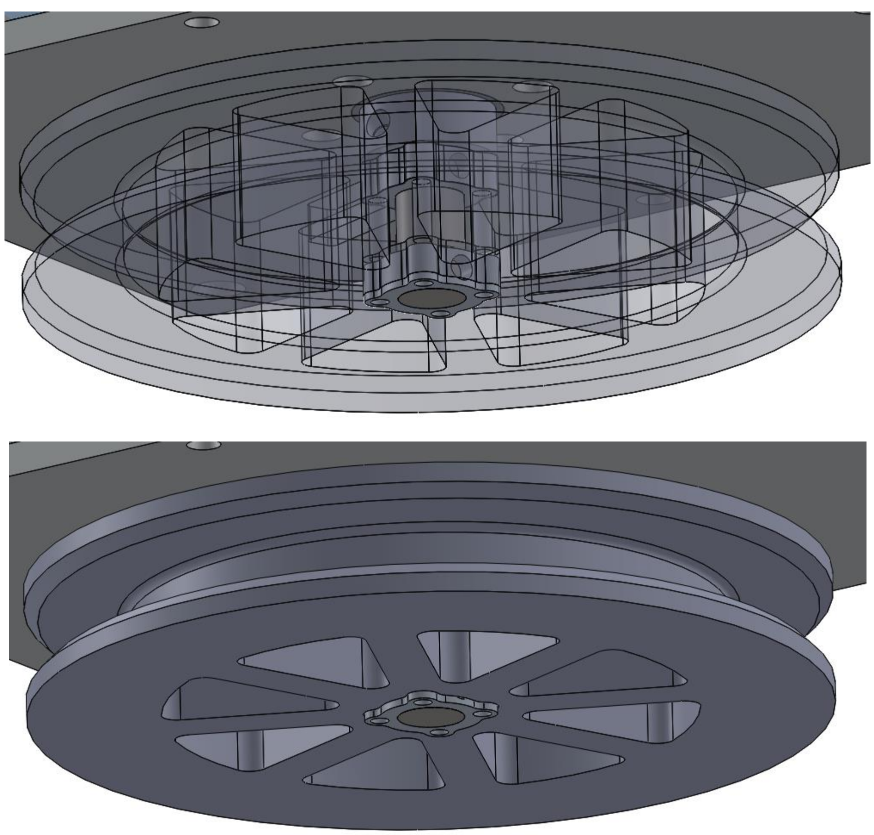


Figure 54. Views of pulley and set-screw hub assembly

Originally, the pulley was to be prototyped by being 3D printed from ABS and later on the final model of the pulley would be CNC'd from aluminum. However, it was decided that the ABS pulley would work best because it is much more lightweight and had proven to be durable. This virtually eliminated all manufacturing for the pulley by 3D printing it.

The height of the housing panels was increased by 2.5 inches. This is because the size of the servo motor was not available before purchase and was underestimated in the design. The servo motor was much larger than expected. Increasing the height of the housing panels allowed for more space inside the housing. It was decided to place the Arduino on one of the side panels to allow room for a motor controller. A cutout for the Arduino USB connection was also cut out of the housing panel. This motor controller would help in programming the cycles of the motor.

As the size of the servo motor was actually larger than expected, this created a space issue between the motor and the housing panel it was closest too. Originally, the length of the motor would have run into a housing panel if the gears were still to mesh. Instead of changing the length of the acrylic housing which would only create more issue, it was decided to simply rotate the servomotor by 90 degrees. Also, the brackets which were manufactured to hold the motor in place were not sufficient enough to properly secure the motor and the motor would vibrate too much. Using long screws, which connected the top of the motor directly to the bottom plate, helped keep the motor much more stable. This assembly is shown in the figure below.

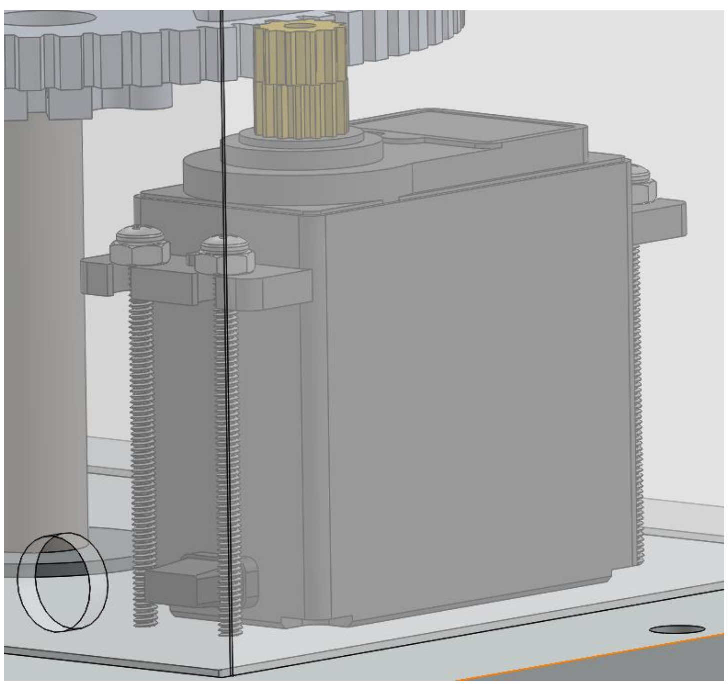


Figure 55. Servo motor mounted to bottom plate with long screws

Other minor changes that were made to the drive pulley include the following: replacing the adapter hub on the pulley for a set screw collar, adding brackets to the top plate for the battery, drilling condensation holes in the bottom plate, cutting a space in the housing panels for the Arduino USB connection, and gluing the bearings in place. It is also important to note that many of the holes for the screws were hand drilled.

7.1.2 Idler Pulley

There were two main changes to the idler pulleys: The material of the body was changed to .25” acrylic instead of aluminum. This was done to save on material and manufacturing costs and it had the added benefit of being lighter. Another change was that the purchased pulley was replaced with a 3D-printed pulley. The original pulley was not suitable because the groove depth was too shallow. As a result, it was difficult to keep the cable in place during operation because the cable would slip off the edge. The printed pulley has both deeper grooves and is lighter than the previous pulleys. The final assembly of the idler pulley is shown in Figure 56 below.

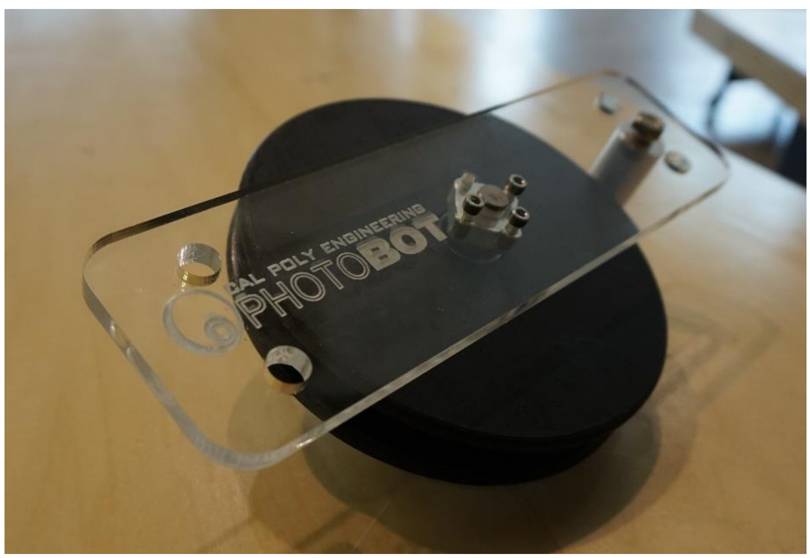



Figure 56. Final assembly of idler pulley

7.1.3 PhotoBot

In comparing the design of the PhotoBot before the building stage of the project to the final product, there were a minimal amount of changes that were made. Essentially the structure of the PhotoBot remained the same; a few implications were made to simplify the preliminary design. For instance, as seen in Figure 37 under the Preliminary Design section, the PhotoBot had a gear system

at the servo motor. Upon implementing this design, we realized that the gear system was not necessary. After doing some simple torque calculations with the actual weight of the phone and the plate that it would be secured to, we determined that the torque provided by the servo motor would be sufficient to hold the load and to rotate the phone along its horizontal axis. In needing to translate the torque provided by the servo motor to the plate for the phone, we fixed a circular acrylic plate to both the propeller of the servo motor and to the L bracket that is rigidly attached to the plate. Refer to Figure 57 for the configuration of the servomotor that is attached to the plate for the phone.

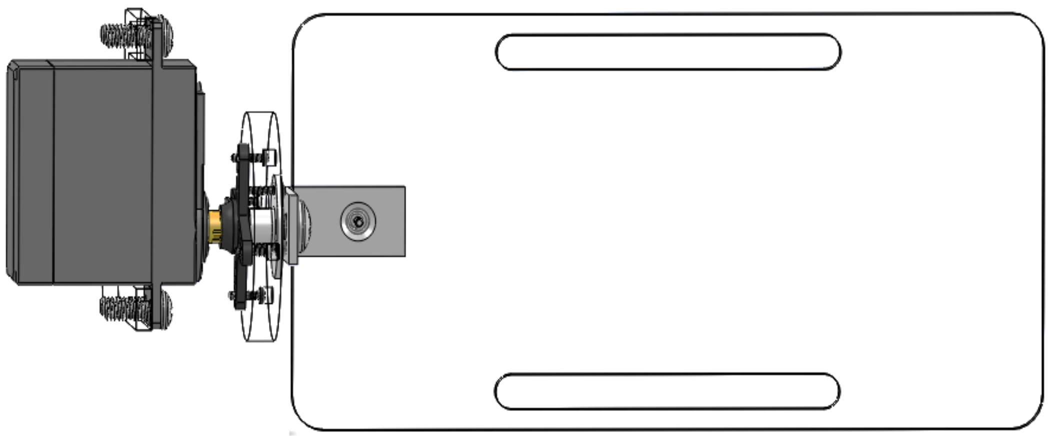
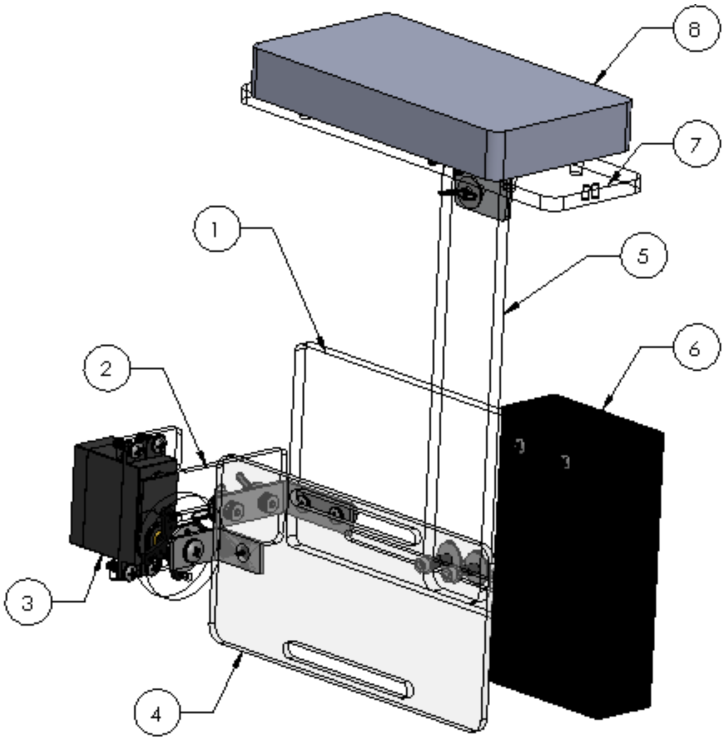


Figure 57. Configuration of the servo motor that is attached to the plate for the phone.

Another modification that was made was eliminating one of the side arms of the PhotoBot, item number 3 in Figure 35. The decision to eliminate the side arm was due to the fact that the group agreed that the PhotoBot would look more aesthetically appealing without it. Although the phone is prone to bend down without the side arm intact, the load of the phone and its frame is small enough to where the bend that occurs is not critical and is not of concern.  Other small changes of the design included substituting the custom made housing for the electronics and the custom L brackets with similar existing products. Also, since there is no longer a gear system, a housing for the servo motor is no longer needed. As a substitute, the servomotor will be sprayed with waterproofing spray. To add, no changes were made in the choosing the material of the body of the PhotoBot, it is still cast acrylic. Shown below in Figure 58 is the SolidWorks' final assembly of the PhotoBot with its main components labeled. Figure 59 shows an actual image of the PhotoBot. See Appendix I for the final engineering drawings of each custom piece and for the exploded view of the whole system and how each piece mates with one another.




| ITEM NO. | DESCRIPTION |
|---|---|
| 1 | BACK FRAME |
| 2 | SIDE ARM |
| 3 | SERVOMOTOR |
| 4 | PLATE FOR PHONE |
| 5 | BACK SUPPORTING ARM |
| 6 | ELECTRONICS BOX |
| 7 | TOP PLATE |
| 8 | SOLAR BATTERY |

Figure 58. Final SolidWorks PhotoBot assembly with its main components labeled.

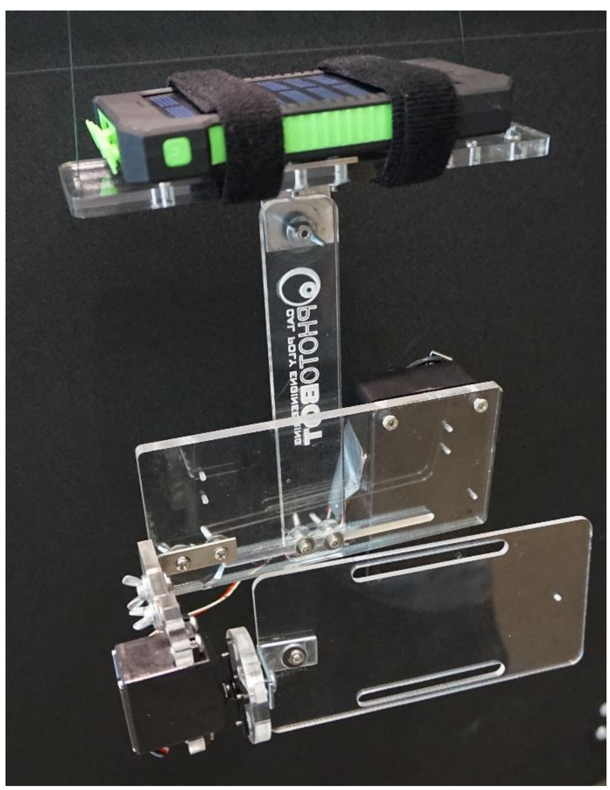


Figure 59. Actual image of the PhotoBot.

### 7.1.4 Installation

Among implementing the plan described in the preliminary design which discusses how the entire PhotoBot system would be installed, the team came soon to find out that some modifications would have to be made in order to ensure that the system would be stably secured. Initially we thought that we could successfully install the system by raising it up with rope rated at a minimum tensile strength of 250 lbs and tying it off around a tree. However, the major downfall of that design was that tying off the ropes to the trees did not provide a sufficient amount of tension. Hence, we resulted this issue by using ratchets to provide the necessary tension. In tying off the idler pulleys, a piece of rope (its length depends on the size of the desired perimeter of the cable) will be used to feed through the holes located on its top plate, which will then be tied to the hooks of a ratchet. A closer look in how the idler pulleys will be attached to the ratchets can be seen below in Figure 60.

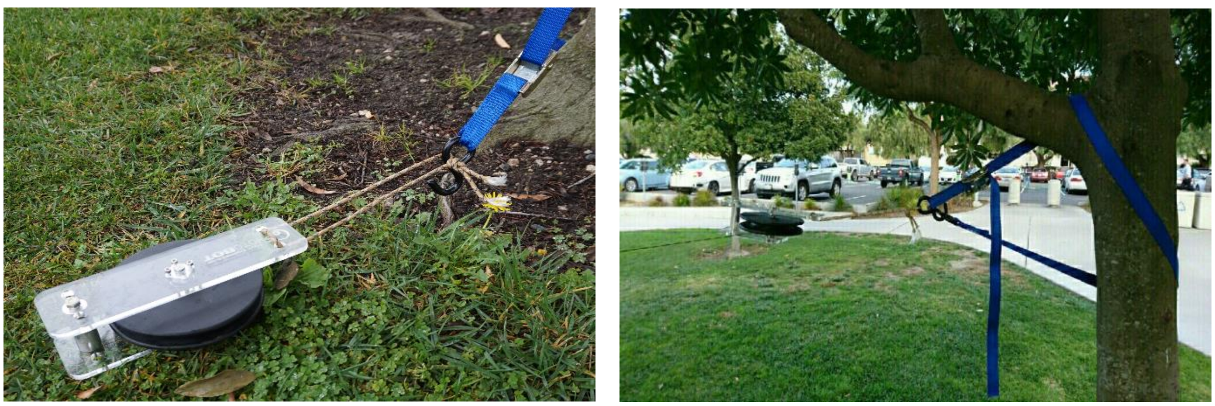


Figure 60. Images showing how the idler pulleys would be attached to the ratchets.

As for the driving pulley, we implemented the same idea described above but discovered that the combination of the tension from the cable around the pulley and the weight of the pulley's housing caused it to flip upside down. To solve this problem, we secured the driving pulley at more than one location. In doing so we looped a rope through a hole located on the corner of the top plate of the pulley and continued to feed it directly down into a hole located on the corner of the bottom plate and then tied it off. The same procedure was done at the other corner of the housing of the driving pulley with a separate rope. An image of this configuration can be seen in Figure 61.

Figure 61. Image showing how the driving pulley is tied off at two different locations.

Since a ratchet will be used at each idler pulley, one is not necessary at the driving pulley. The two ropes that are tied to the driving pulley will wrap over a branch and will then be tied off to the trunk of the tree. If need be, the ropes can be staked to the ground for extra security. Also as a way to direct the position of the pulleys and to minimize the chance of them tilting in an upward direction, one end of a long rope can be tied to one of the holes located on the plates of each pulley and the other end can be staked to the ground at a location that best positions each pulley. An image of the driving pulley hoisted in a tree with an added rope at the front of the system to direct the position of the pulley can be seen below in Figure 62.

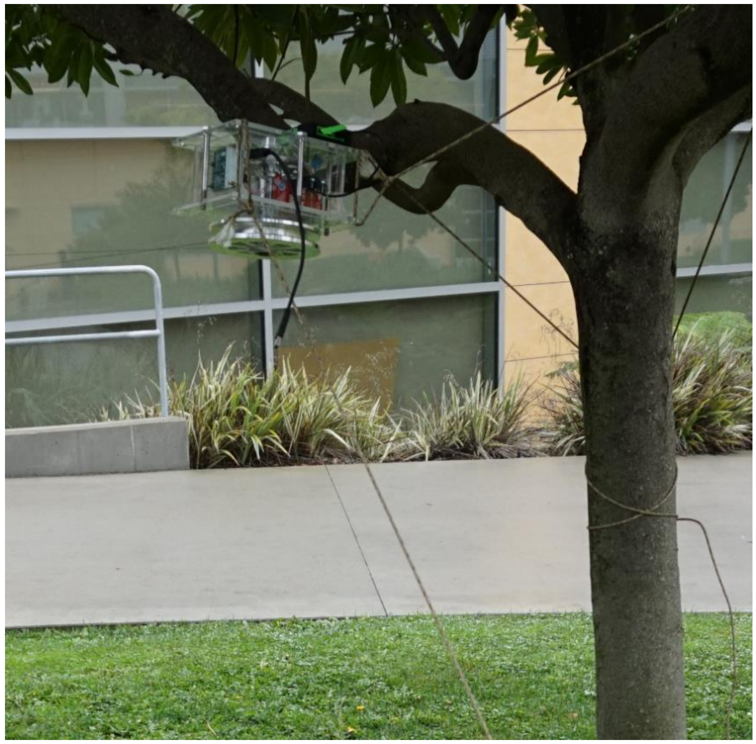


Figure 62. Image of the driving pulley hoisted in a tree.

After installing the entire system using many different ways, we found that the most effective way to do so is to first lay out the pulleys on the ground to the approximate desired shape and size. Thereafter, the cable could be cut to size, crimped together, and then wrapped around each pulley. The next step would be to tie the two ropes to the driving pulley. Also, a long piece of rope (about the length of the height at which the system will be raised at) should be tied to the driving pulley and to the idler pulleys if desired. The ropes tied at the back of the driving pulley will then be thrown over branches of a tree. Once the rope goes over the branch, the ratchets used for the idler pulleys should be thrown over the branches of a tree. Thereafter, the idler pulleys can be tied to the hooks of the ratchets using pieces of rope. At this point one should make sure that that the cable is still wrapped around the pulleys. Once everything is set, the driving pulley can be raised up by pulling on both ropes until the desired height is reached, and then it can be tied off to the tree and or ground. To raise the pulleys, the straps of the ratchets need to be pulled. As a warning, the user might have to alternate raising the pulleys. For instance, each pulley may have to be raised a few feet at a time in order to prevent the cable from slipping off.  Refer to Appendix R for an informative user's manual showing how to install the entire system.

### 7.1.5 Electronics

There were some major changes to the circuitry of the PhotoBot, which had several significant advantages and solved some major problems. The most significant change was the addition of a Wifi module that was connected over UART to the MSP430 microcontroller; the original plan involved the use of a usb cable, which connected the phone to the microcontroller. The Wifi module now sets up an access point that both the PC laptop and android phone connect to. This makes it so that the android phone can connect to the battery over usb; if we had continued to use of the usb cable to connect to the microcontroller, not only would we have had to do some soldering on the usb cable power wire, but we also would have had to make some kernel modifications on the android to enable it to charge and connect to the MSP430 simultaneously.

The main problem is that the android feature, which enables the phone to other devices over usb, called Android On The Go, is meant to supply power to a device like a keyboard or mouse. It could potentially break the phone or be completely ineffective to connect a battery to the android usb cable when its supplying power. Furthermore, using the Wifi module means that the user no longer has to setup a Wifi hotspot on either his laptop or phone—the pc and laptop will connect automatically to the Wifi device. The Wifi module is also extremely power efficient and would enable future development by enabling another Wifi module connected to the Arduino to communicate with the Android phone, which would enable full control of the PhotoBot and not just the rotation of the camera.

## *7.2 Manufacturing Processes*

Most of the manufactured parts for the PhotoBot were either done on a laser cutting machine or 3D printer. All plate components for the drive pulley assembly, idler pulley assemblies, and PhotoBot assembly were main from ⅛” or ¼” acrylic and were cut on a laser-cutting machine. The parts were designed in SolidWorks and the profiles were transferred to an appropriate program for the machine. All logos were etched on the laser-cutting machine as well. Shown below is an example of one the laser-cut parts.

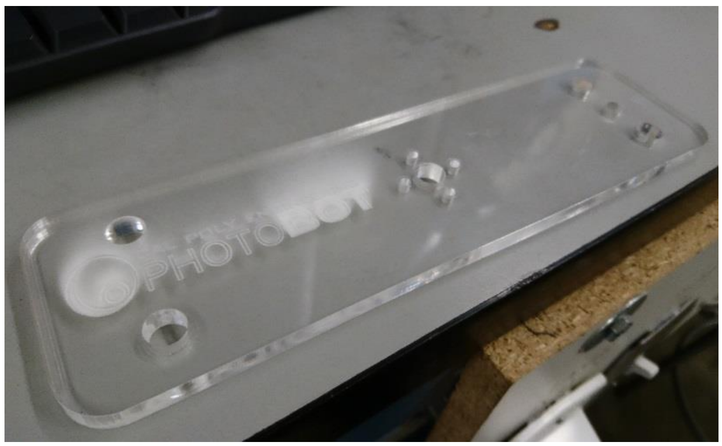



Figure 63. Laser cut panel for the idler pulley assembly

The two idler pulleys and the driving pulley were made from ABS plastic on a 3D printer. These parts were also designed on SolidWorks and sent to be print. Some hand filing and dremel tool drilling were done to the pulley to clean up and smooth the prototypes. Another prototype for the drive pulley was also made on a CNC machine from 6061 Aluminum. Shown below is a photo of the machining being done for this pulley.

Figure 64. CNC machining of aluminum drive pulley

Many of the screw holes for all assemblies were also made by hand pilot drilling and then installing the screws as the acrylic was a soft material. This was done because it was easier than

positioning the holes on the conceptual parts to be laser cut. The housing panels were also silicone glued together to keep them secure. The remainder of the manufacturing was simply assembly of all manufactured and purchased parts.

### *7.3 Future Manufacturing Recommendations*

Although using cast acrylic for many of the manufactured parts worked very well and made manufacturing simple, it is recommended to prototype some of the plates from sheet metal instead. This may cut down on the weight of the system and be more durable. There was an instance when once of the acrylic parts was dropped and cracked immediately. Using sheet metal would eliminate the possibility of plates breaking. Everything beside the drive pulley housing should be considered to be prototyped from sheet metal.

It would have also been beneficial to hand thread the pilot holes for the screws in the acrylic plates. It was difficult to install the screws without being previously threaded. In one instance, a screw sheared and broke because of the high friction from being manually threaded in the hole.

Using 3D printed pulleys as the final prototype also worked very well, but other materials such as nylon or aluminum could be considered for all pulleys. Increasing the friction between the pulley and the cable is a very important factor for the system, and a different material beside ABS plastic could perform better.

## 8.0 Design Verification

In this section, the testing and design verification will be discussed. Based on the verification plan and the specification table, several tests were conducted to verify cable *material selection*, *ease of installation*, *waterproofing*, *battery life*, and *software stability*.

### *8.1 Cable Material Test*

Several materials were tested for the cable: 3/32" vinyl coated galvanized steel cable, 65lbf stealth braid SpiderWire, and 135 lb, 0.085" diameter nylon coated stainless steel leader wire. The steel cable needed to use a crimped aluminum ferrule to hold the two ends together. The ends of the SpiderWire were simply knotted together. The ends of the leader wire were held together by a crimped sleeve.

The steel cable performed very well and experienced very little slip on the pulleys. However, the aluminum ferrule on the cable is relatively very large and takes up a lot of space. It would get caught on the lip of the pulleys when rotating. It was harder to tension this cable as is relatively thick. Crimping the ferrule was also timely and difficult to do without at least two people. The 3/32" steel cable is shown in Figure 65 below.

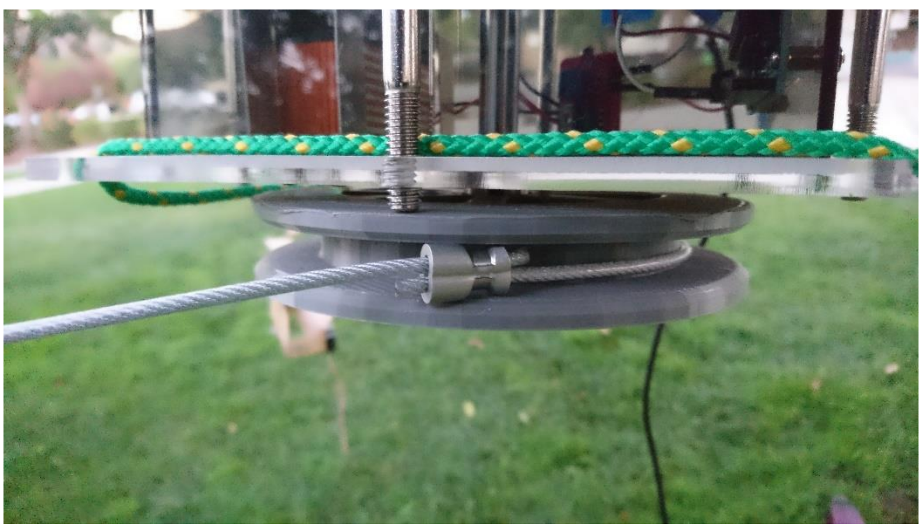


Figure 65. Steel cable test.

The SpiderWire performed very well and also experience very little slip on the pulleys. Since all connections were tied knots, nothing got caught up on the pulley. It was very easy to tension and install. Using this wire also slightly reduced the overall weight of the system. However, the creep of

the SpiderWire loosened the tension in the wire over time. Also, since this particular wire was not rated for a very high strength, the wire is susceptible to breaking over time. Even is the wire is doubled up, it could break. A higher strength SpiderWire would be more sufficient.

### *8.2 Installation Test*

Several parameters needed to be verified for installation: ease of setup, single-person installation, line length, tensioning system, and roping methods. From our conceptual design it was known that ropes would be used to raise and tie off the pulleys. The exact roping method was not yet known since that needed to be tested. From field tests, it was found that the drive pulley was the hardest to raise and tie-off. The following figures demonstrate different roping methods that were tested for the drive pulley. The results of the tests are summarized in Table 14.


Figure 66. A rope was routed through the top plate's holes and another rope was routed through the bottom plate holes.


Figure 67. The same setup is used as in method 1, except an additional line is tied off (shown on the right). This additional line is tied to the ground using a stake.

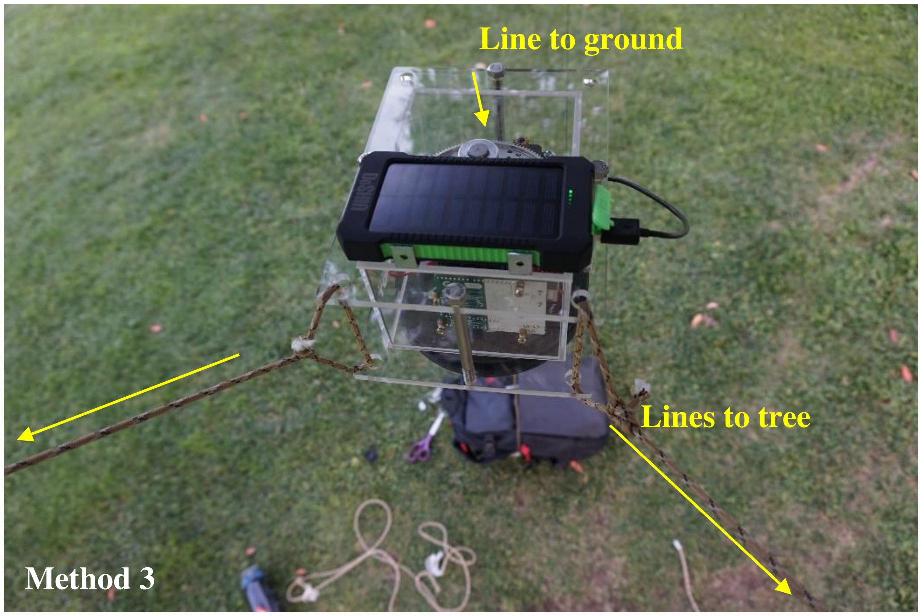



Figure 68. This method utilizes the same concept as method 2, except the lines going to the tree are angled and tied at the rear of the pulley. Though not visible, there is still a line pulling down which is secured to the front.

Table 14. Summary of installation tests for drive pulley

| Test Method | Results: |
|---|---|
| 1 | As shown in the figure, this method worked but the pulley seemed unstable. The pulley was observed to tilt up which poses a hazard in which the line may slip off the pulley. |
| 2 | By adding the additional line pulling the drive pulley downwards, the system was considerably more stable. An issue that is still evident was that the pulley could still rotate about the axis which perpendicular to the tree. |
| 3 | This method proved to work the best. By angling the tie off ropes going to the tree, the drive pulley was completely secure. |

## *8.3 Waterproofing test*

Due to the fact that the PhotoBot system needs to operate in humid or wet environments, all electronics were installed in a sealed enclosure. In addition, all circuit boards and exposed wiring were sprayed with a urethane viscous liquid coating. According to the manufacturer's description, the spray is capable of insulating electrical equipment from water and moisture. Time permitting, actual tests will be conducted to verify the capability of this waterproofing technique.

Another test that was performed was to observe any affects that water might have on the cable/pulley friction. For this test, water was sprayed on all the pulleys while the system was operating. It was found that there was no noticeable loss of friction, since there was no slip during wet operation.

## *8.4 Battery Life Test*

Since PhotoBot must be able to operate as long as possible, it was important to test the duration of the battery. A test fixture was made such that a small-scale system could be installed indoors as shown in Figure 69.

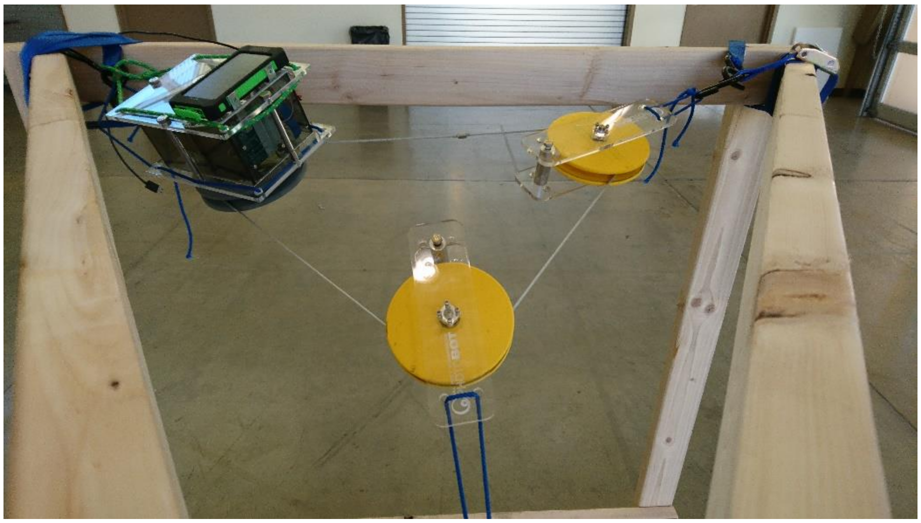


Figure 69. Test rig for measuring battery life.

For the main test, a single 20,000 mAH battery was connected to the drive pulley. The PhotoBot was attached to the line and the system was tensioned. The motor was turned on and allowed to run continuously until the battery gave out.

Table 15. Battery lifetime test results

| **Battery Test Results:** |
| --- |
| • It was found that the motor could run for at a minimum of **5 hours** continuously.<br>• Actual duration is expected to be much longer since in actual operation the motor will run intermittently after long rest intervals. |

### *8.5 Software Test*

There were numerous software tests that the PhotoBot team had to implement in order to create reliable software. First, wireless is inherently unreliable and fails occasionally. Therefore, I had to add the ability for the phone to reconnect with the MSP430's Wifi unit. The team tested this by bringing the phone in and out of range of the Wifi unit to test the unreliability and ensure the wireless device could reconnect on its own. The team also had to test the functionality and reliability; both of these were tested by making the program operate much faster than it would run in the rainforest, which showed the reliability of the phone app and microcontroller code because they were able to sustain many iterations of the program. In the rain forest the program will mostly be in sleep mode so, in addition, the team tested the sleep mode by extending the sleep timer and making sure it could operate over long periods of time as well.

Furthermore, the team tested the power consumption of the program and the phone and realized that wireless video streaming over Wifi was too much of a burden on the battery; the total power was reduced by at least 50% over the course of the expo. Therefore, I simply added a remote file transfer program that can transfer pictures in real time and can be used to line up camera shots while being much more power efficient. Furthermore, when testing I realized that only one app can utilize the camera at a time—if one app is using the camera device then the other app will receive an error when it tries to access the camera. This not only meant that Dr. Christopher would had to have go up into the canopy to disable the wireless webcam app before running in automatic mode, but he also wouldn't have been able to take pictures via the app while simultaneously using the video feed. There were simply to many problems with using the video feed and our testing revealed the flaws that the team fixed.

## 9.0 Conclusion

Overall, PhotoBot was a challenging engineering project which tested our team's ability to design and test a product capable of fulfilling the needs of our sponsor. Our final product proved that it is possible to setup a multi-pulley cable system that is capable of moving a camera in a complete loop, taking pictures and remotely sending them to a laptop. From our battery tests it was also shown that the drive motor on the pulley was capable of lasting for long periods of time. With proper adjustments of the operating parameters such as time delay between camera movements and software efficiency, it is possible for PhotoBot to last for long periods of time between charges. From this first iteration, many milestones were completed but many improvements could still be implemented.

For any future iterations of this project our team recommends looking into redesigning the drive pulley and making it slimmer. A reduced bulk in the drive pulley would help simplify installation and increase the stability of the system. Another improvement that could be made is with the electronics, Wi-Fi connectivity should be considered for the drive pulley's motor so that a user can operate the motor via the laptop in the same method as the PhotoBot servo motor. This would help simplify operation and it could lead to better methods for scheduling when the camera takes a picture.

Finally, as with any new product that was never been on the market, it is important to perform extensive tests in order to ensure a reliable and successful product. With the limited amount of time that we had, our team's tests were heavily focused on the setup and battery performance of PhotoBot. Our recommendations for future testing of PhotoBot include extensive software stability tests, more testing to verify waterproof abilities, mechanical durability tests, and environmental tests to try and account for any unknown variables.

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14. "Carry-on Baggage." – Size & Restrictions – American Airlines. N.p., n.d. Web. 02 Feb. 2016.
15. "Camera." *Camera*. Google Inc., n.d. Web. 23 Feb. 2016.
16. "Verykool S505 Spark 5.0" IPS TFT LCD 1.3GHz Quad-Core 4G HSPA+ 12MP Dual SIM Android 4.2 Wifi MP3 GPS Factory Unlocked- Carrier Packaging-Black." *Cell Phones & Accessories*. Amazon, n.d. Web. 25 Feb. 2016.
17. "Cubot X15 5.5" Inches IPS 1080×1920 FHD Touch Screen 4G FDD-LTE Google Android 5.1 OS MTK6735M 64bit Quad Core 2GB RAM 16GB ROM 8MP 16.0MP 2750mAh Li-Battery WCDMA GSM Unlocked Cellphone." *Cell Phones & Accessories*. Amazon, n.d. Web. 25 Feb. 2016.
18. "The Gondola Project." *The Gondola Project RSS*. N.p., n.d. Web. 26 Feb. 2016.

# 11.0 Appendix A: Existing Cable Cam System Specifications

### LineCam-Flow X1

Note: The following specifications regarding the LineCam-Flow X1 were retrieved from the LineCam Systems' website [8].


- Weight: approx. 5 pounds (shuttle only)
- Water resistant
- Length: 20.75 inches
- Power system: Lithium Polymer (LiPo) rechargeable batteries
- Speed: 0-70+ mph (depending on battery configuration)
- Line angle: 0-45 degrees (depending on payload)
- Payload capacity: 20 pounds
- Regenerative Braking
- Electronic speed controller
- Construction: Precision CNC'd 6061 Aluminum
- Utilizes Plasma® 12 Strand rope, a heavy duty double pulley rope
- ratchet and a Quick-cleat™ rope anchor.
- Cost of basic kit: $3900 (includes shuttle, battery, charger, controller and cable and basic cable set-up equipment)

### Speed Line

Note: The following specifications regarding the Speed Line were retrieved from the Speed Line cable- cam's website and from an article from videoandfilmmaker.com [9,10].

- Size: 103 x 40 x 25.5 cm
- Max. Camera weight: 4.9kg (10.8lbs)
- Max total setup weight: 12kg (26.5lbs)
- Min. speed: 5kph (3.1 mph)
- Max. speed: 45kph (28.0 mph)
- Operating voltage: 14.8Vdc
- Constant amps: 180A
- Max amps: 760A
- Regenerative braking
- Stabilized 3 axis brush-less gimbal
- Compatible with 6-8mm cable
- Cost of basic kit: $5198 (includes shuttle, gimbal, battery, charger, controller and programming card)

**FlyLine**

Note: The following specifications regarding the FlyLine were retrieved from an article from photoshipone.com [11].

- Size: 100 x 65 x 18 cm (including 3X Pro HD camera head)
- Construction: aluminum, carbon fiber, and stainless steel
- Weight (with batteries and gyros – without camera): 5kg (11 lbs)
- Max. camera weight: 4.5kg (9.9lbs)
- Max camera size: 20 x 22 x 25 cm
- Max. speed: 40kph (25mph)
- Max. cable slope: 19% grade (11 degrees)
- Operating voltage: 11-16Vdc
- Max amps: 50A
- Regenerative braking: Yes
- 5-7km travel distance duration (charged batteries with moderate current draw)
- 90 min. battery duration @ idle
- Closed loop proportional velocity control: Optional
- Gyro stabilized: Optional
- Controlled wirelessly with a range of 1km
- Controlled via RC airplane/helicopter type wireless 2.4ghz controllers. One controller is used by a trolley drive operator and one controller is used by the camera operator.
- Recommended cable is 8mm Dyneema climbing rope
- Cost of kit: $5000 (without optional gyro or accessories)-$12000 (fully loaded)
- US patent number is 9122130

**_Links to YouTube videos of similar homemade cable cams:**

"Heavy fast homemade cable cam |first test|"

https://www.youtube.com/watch?v=L1dY61-I5SA&feature=youtu.be&t=56

"Remote Control Cable Cam"

https://youtu.be/-5EPxsX1jC0?t=89

"Cable Cam 2.0"

https://youtu.be/ddD7vOV7YI8?t=197

"Acrobat Cable Cam."

https://www.youtube.com/watch?v=nMOvBf_7TlU&feature=youtu.be

# 12.0 Appendix B: Cable/Rope Specifications

Table 1. Specifications of typical ropes/wires used in existing cable cam systems.
(Note: based on existing products, rope/wire diameter range from 5mm-8mm)

| Material | Diameter | Tensile Strength (lbs) | Weight (lbs/100ft) | Price Per Foot |
|---|---|---|---|---|
| Plasma® 12 Strand rope | 5mm | 5,500 | 1.12 | Not listed |
| Plasma® 12 Strand rope | 6mm | 8,000 | 1.6 | Not listed |
| Plasma® 12 Strand rope | 9mm | 17,500 | 5.5 | *$3.35 |
| AmSTEEL 12-STRAND | 5mm | 5,000 | 1 | *$0.92 |
| AmSTEEL 12-STRAND | 6mm | 6,600 | 1.6 | *$1.40 |
| AmSTEEL 12-STRAND | 8mm | 9,800 | 2.7 | *2.34 |
| AmSTEEL Blue | 6mm | 8,600 | 1.6 | *$1.46 |
| AmSTEEL Blue | 8mm | 13,700 | 2.7 | *$2.42 |
| Nylon coated steel cable | 3mm-5mm | 2,000 | 3.8 | **$0.546 (+500 ft) |
| Nylon coated steel cable | 5mm-6mm | 4,200 | 7.8 | **$0.713 (+500 ft) |

*prices from Rope Inc. [12]

**prices from webriggingsupply.com [13]

## 13.0 Appendix C: Quality Function Deployment Chart

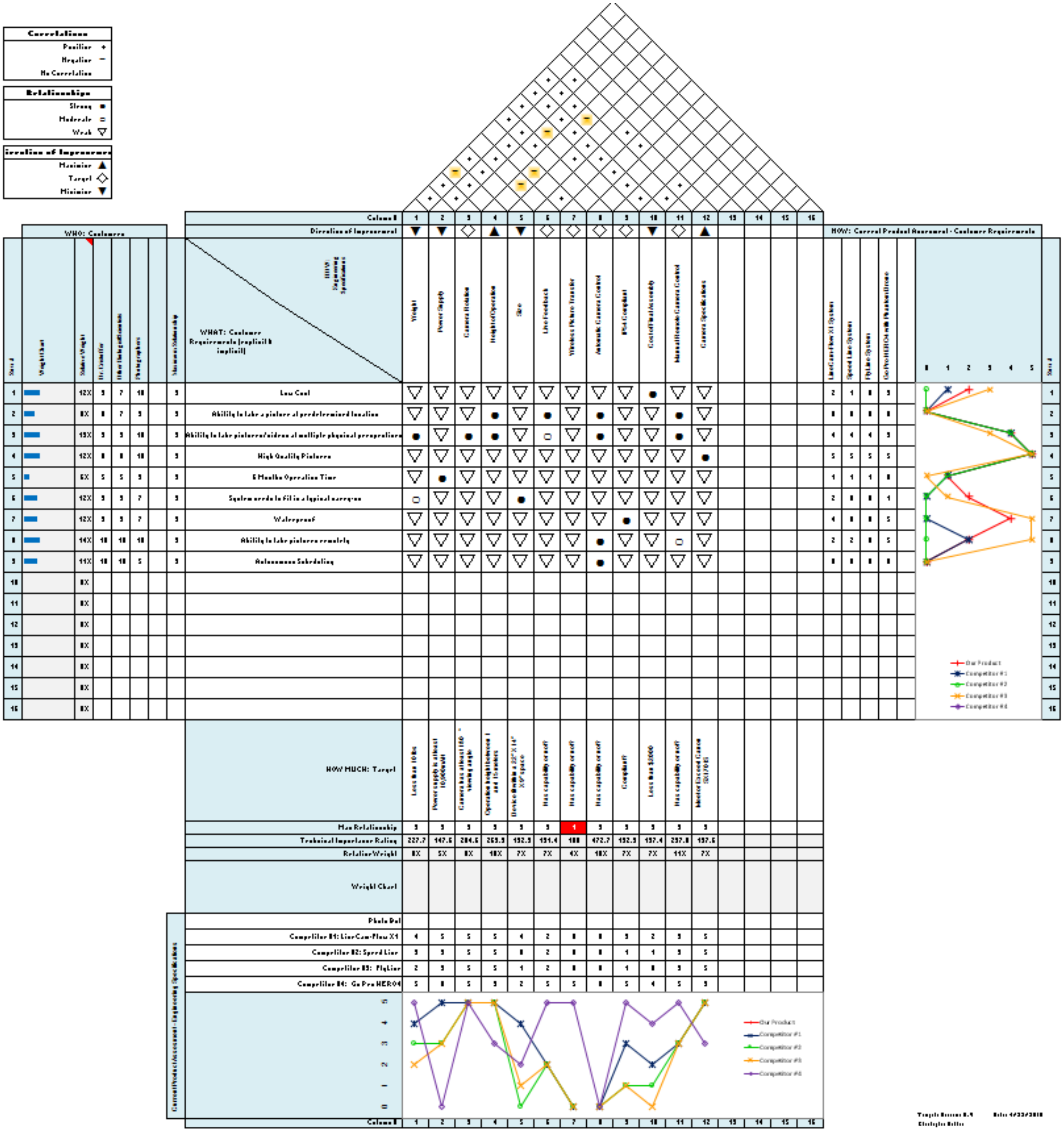



Figure 20. Quality Function Deployment Chart

## 14.0 Appendix D: Pugh Charts for PhotoBot Functions

Table 11. Pugh Chart for Positioning PhotoBot

| Criteria \ Concept | Polygon Brackets | Single Line Cam | Circle Track | Tri-Wire | Pulley Line |
|---|---|---|---|---|---|
| Weight | D | + | S | - | - |
| Size | | + | + | S | + |
| Cost | A | + | S | - | - |
| Setup Ease | | + | S | S | + |
| Position X-Y | T | - | - | S | S |
| Position Z | | - | S | + | - |
| Remote Picture | U | S | S | S | S |
| Waterproof | | S | S | - | - |
| Ease of Use | M | + | S | - | S |
| Feasibility | | + | - | - | + |
| Σ+ | | 6 | 1 | 1 | 3 |
| Σ- | | 2 | 2 | 5 | 4 |
| ΣS | | 2 | 7 | 4 | 3 |

Table 12. Pugh Chart for Setting up Cable

| Criteria \ Concept | Throw a Weight | Grabber Arm | Launcher | Climb Tree |
|---|---|---|---|---|
| Weight | D | - | - | + |
| Size | | - | - | + |
| Cost | A | - | - | + |
| Setup Ease | | + | + | + |
| Position Z | T | - | - | - |
| Ease of Use | | S | - | - |
| Feasibility | U | - | - | - |
| Safety | | + | - | - |
| Σ+ | M | 2 | 1 | 4 |
| Σ- | | 5 | 7 | 4 |
| ΣS | | 1 | 0 | 0 |

Table 13. Pugh Chart for Camera System

| Criteria \ Concept | GoPro | Android Phone | Trail Camera | Canon DSLR |
|---|---|---|---|---|
| Weight | D | - | - | + |
| Size | | - | - | + |
| Cost | A | - | - | + |
| Power Integration | | + | + | + |
| Control Implementation | T | - | - | - |
| Picture Quality | | S | - | - |
| Remote Picture | U | - | - | - |
| Waterproof | | + | - | - |
| Ease of Use | M | | | |
| Σ+ | | 2 | 1 | 4 |
| Σ- | | 5 | 7 | 4 |
| ΣS | | 1 | 0 | 0 |

# 15.0 Appendix E: Supporting Calculations

## Cable Deflection and Slope Calculator

Model Assumptions:
Level Span -Single Load with a Single Load at Any Point

**This calculator can be used to determine the maximum deflection based on the parameters of a cable system loaded at one point
*** References from Tramway Engineering, LTD: Advanced Cable Equations

In a constant tension span the deflection *at the load* may be determined from:

$$y = \frac{Gx(s-x)}{st} + \frac{wx(s-x)}{2t} \qquad (35)$$

Also the deflection of the cable may be determined for any point in the span, with the load at any point, $x_1$ $y_1$ being coordinates to points to the left of G and $x_2$ $y_2$ being coordinates of points to the right of G.

$$y_1 \text{ (points left of G)} = \frac{Gx_1}{st}(s-m) + \frac{wx_1}{2t}(s-x_1) \qquad (36)$$

The cable slope at left support, when $x_1 = 0$, is:

$$\tan \beta_1 = \frac{G}{st}(s-m) + \frac{ws}{2t} \qquad (38)$$

The cable slope at right support, when $x_2 = s$, is:

$$\tan \beta_2 = \frac{Gm}{st} + \frac{ws}{2t} \qquad (39)$$

Inputs:

| | | |
|---|---|---|
| *G* | 5 | lbs |
| *w* | 0.12 | lbs |
| *s* | 10 | ft |
| *t* | 60 | lbs |
| *x* | 5 | ft |

(Assuming 1/4" Steel Cable)

*y=* *Deflection*
*G=* *Point Load*
*t=* *Tension*
*w=* *Weight/Length of Cable*
*s=* *Span of Cable Section*

Max Deflection:

| | | |
|---|---|---|
| *y max* | 0.233 | ft |
| | 2.800 | in |

Deflection at any Distance, x

| | | |
|---|---|---|
| *x* | 0.5 | ft |
| *y* | 0.044 | ft |
| | 0.532 | in |

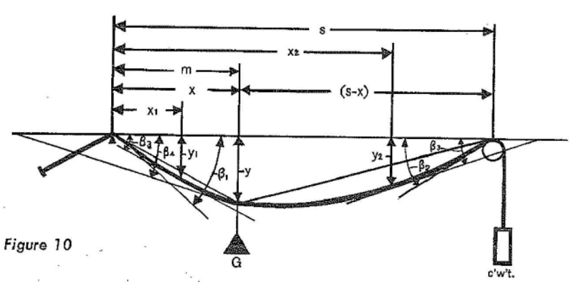
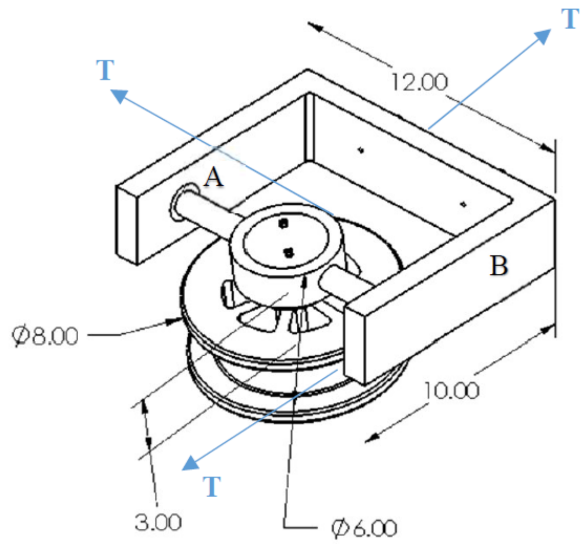



Figure 10

# Initial Strength Calculations for Bracket Concept

| | | |
|---|---|---|
| *Tension Applied* | 60 | lbf |

| Shear Stress at Location Point A | | |
|---|---|---|
| V | 60 | lbf |
| Shaft Diameter | 1 | in |
| I | 0.049 | in^4 |
| w | 1 | in |
| A | 0.785 | in^2 |
| τ | 102 | psi |




| Tensile Stress at Location Point B | | |
|---|---|---|
| Tensile Load | 60 | lbf |
| Base | 1 | in |
| Height | 3 | in |
| Area | 3 | in^2 |
| Tensile Stress | 20 | psi |

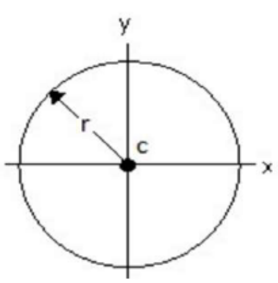
## References:

$$\tau = \frac{VQ}{Iw}$$

$V =$ *Shear force*
$I =$ *area moment of inertia*
w= *the width of the cross section*

For a circular cross section:

$$\tau_{max} = \frac{4V}{3A}$$




$$A = \pi r^2$$

$$I_x = \frac{1}{4}\pi r^4$$

$$I_y = \frac{1}{4}\pi r^4$$

## 16.0 Appendix F: Pert Chart

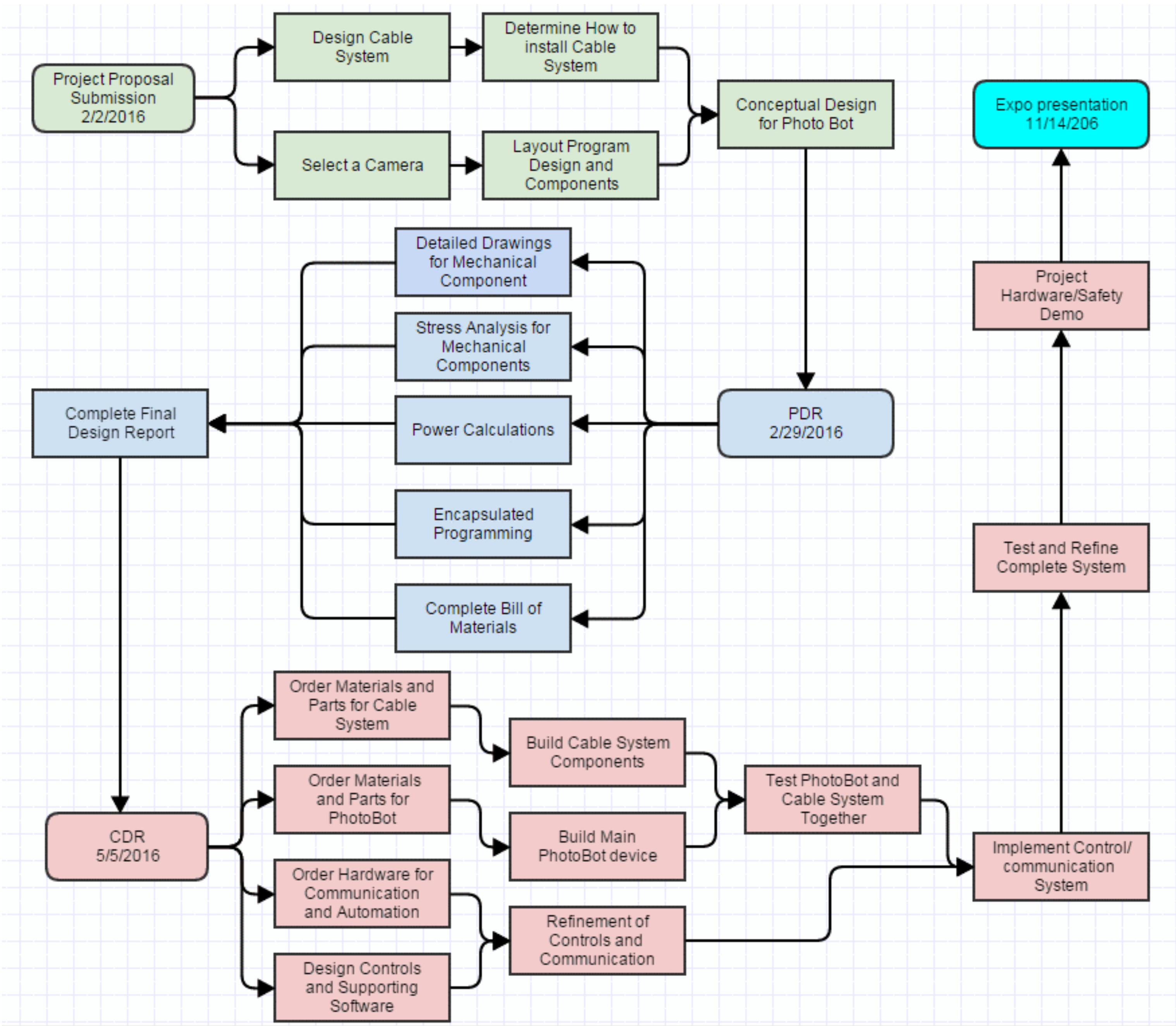
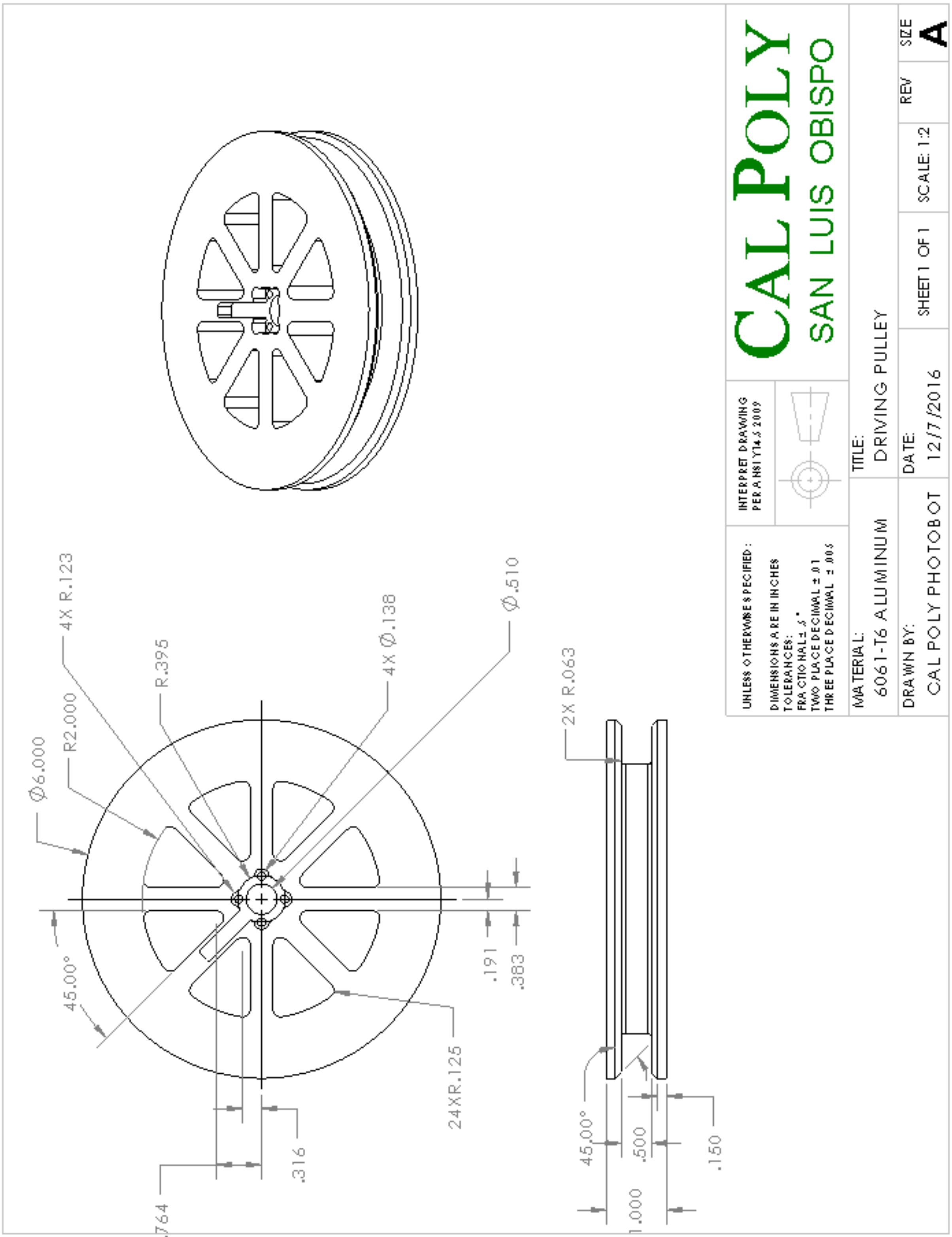
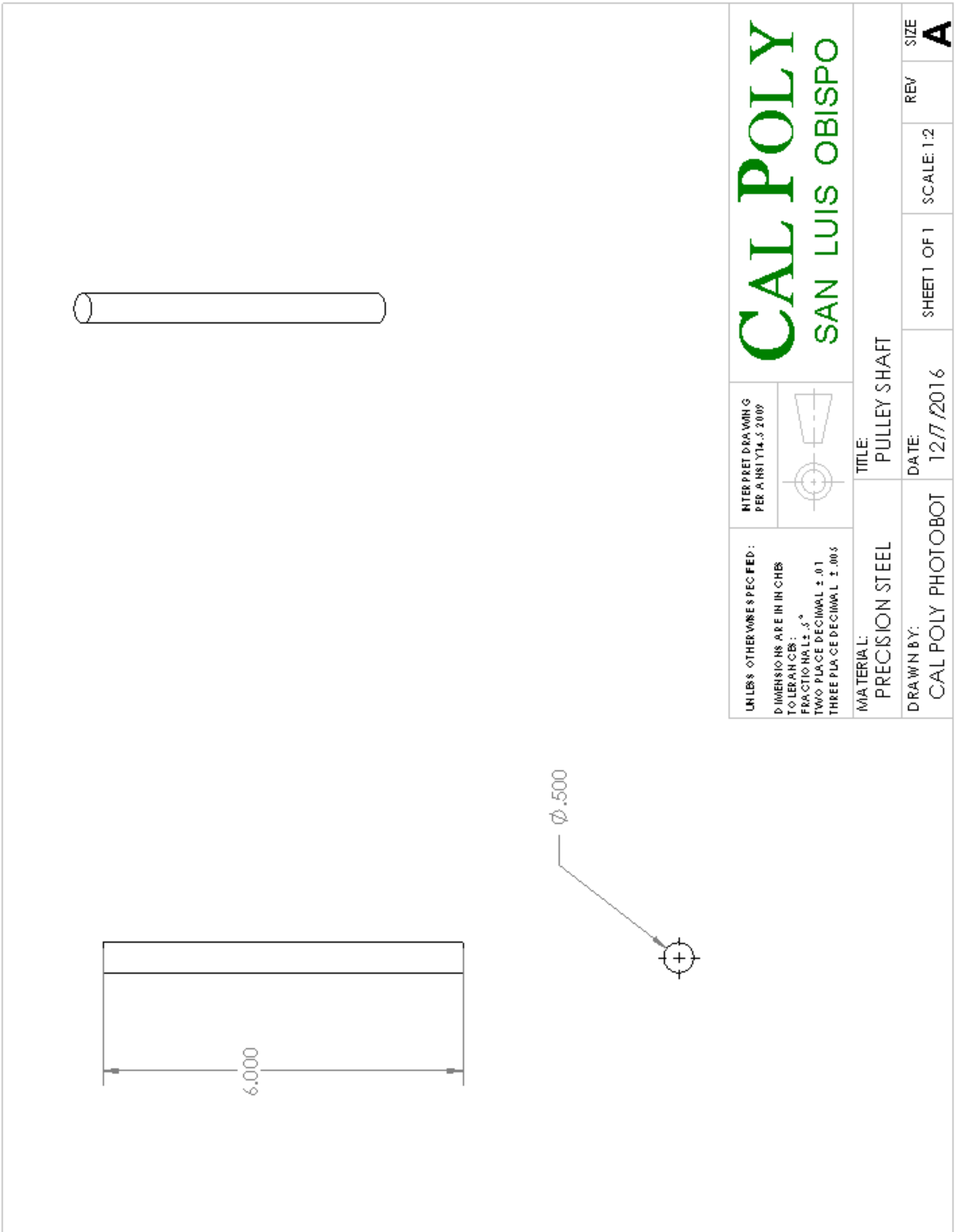



Figure 23. Pert Chart for PhotoBot progress

# 17.0 Appendix G: Engineering Drawings – Driving Pulley

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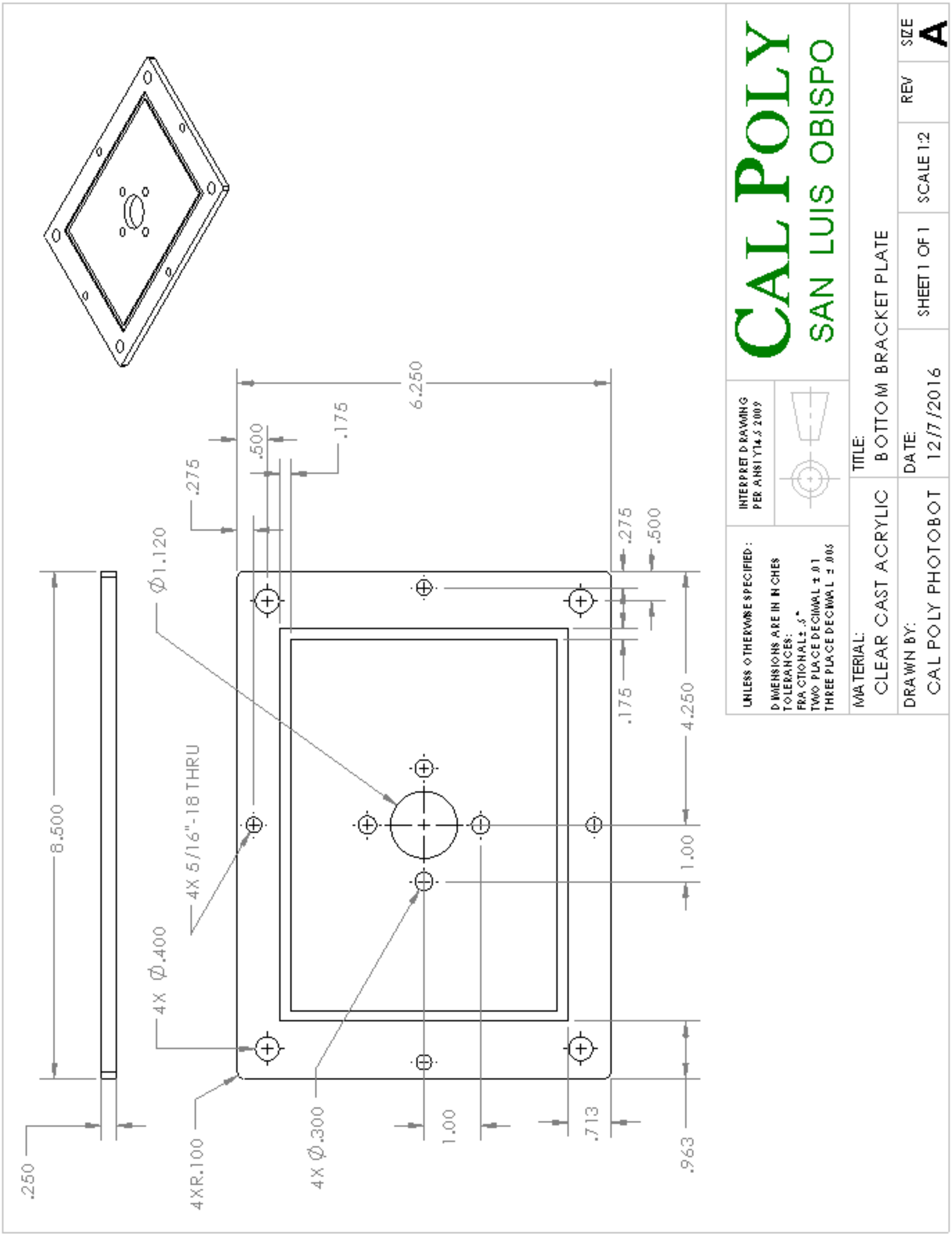
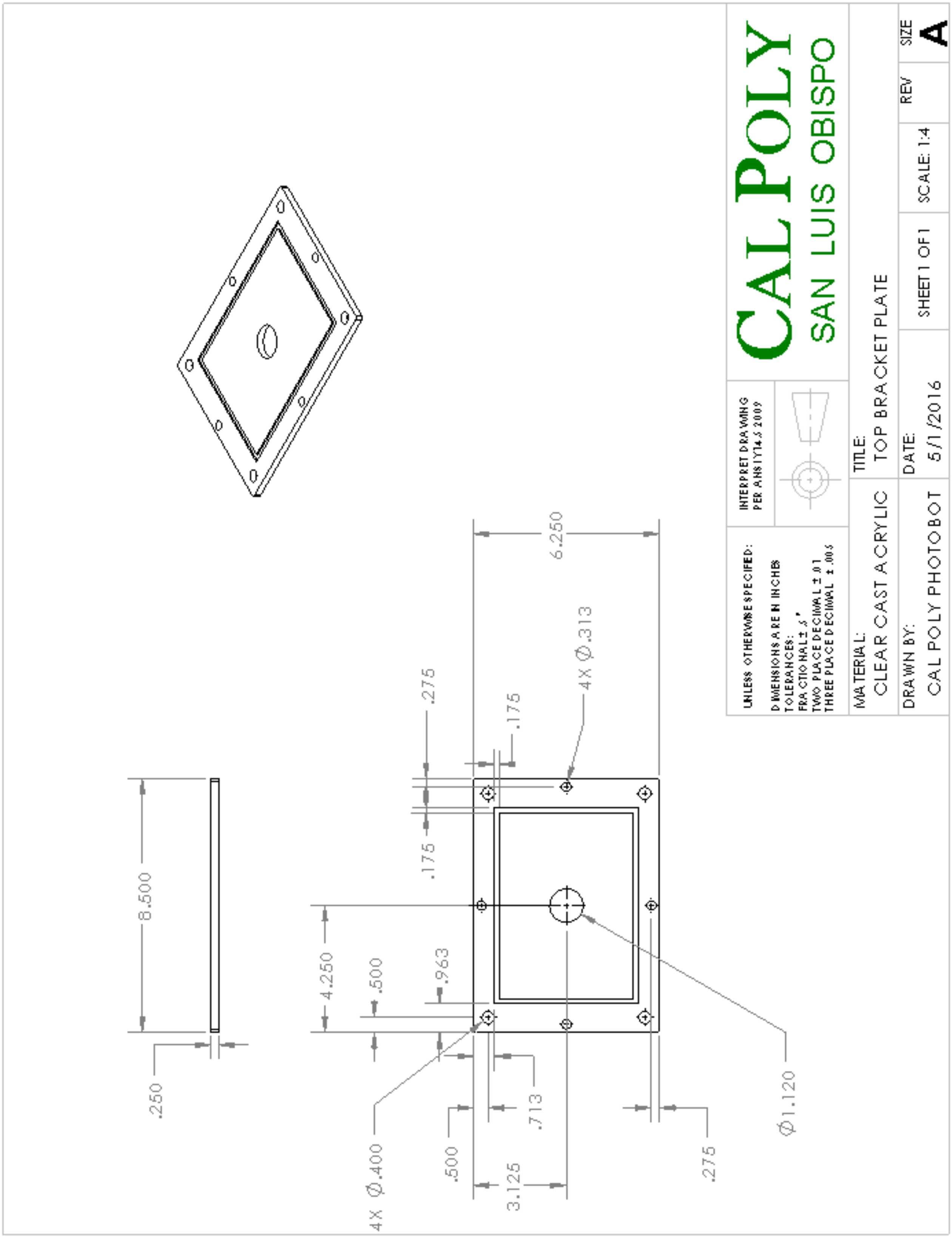
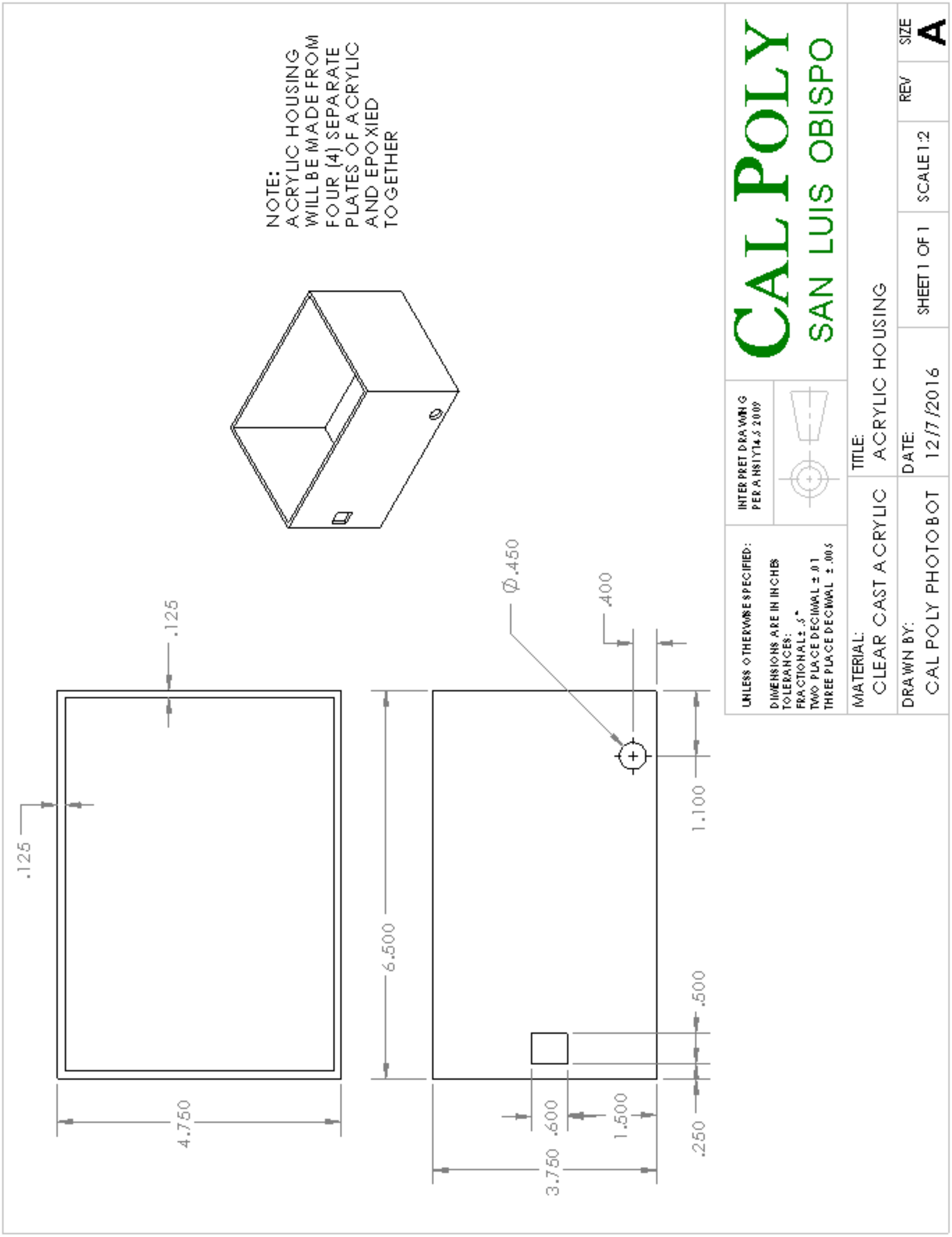
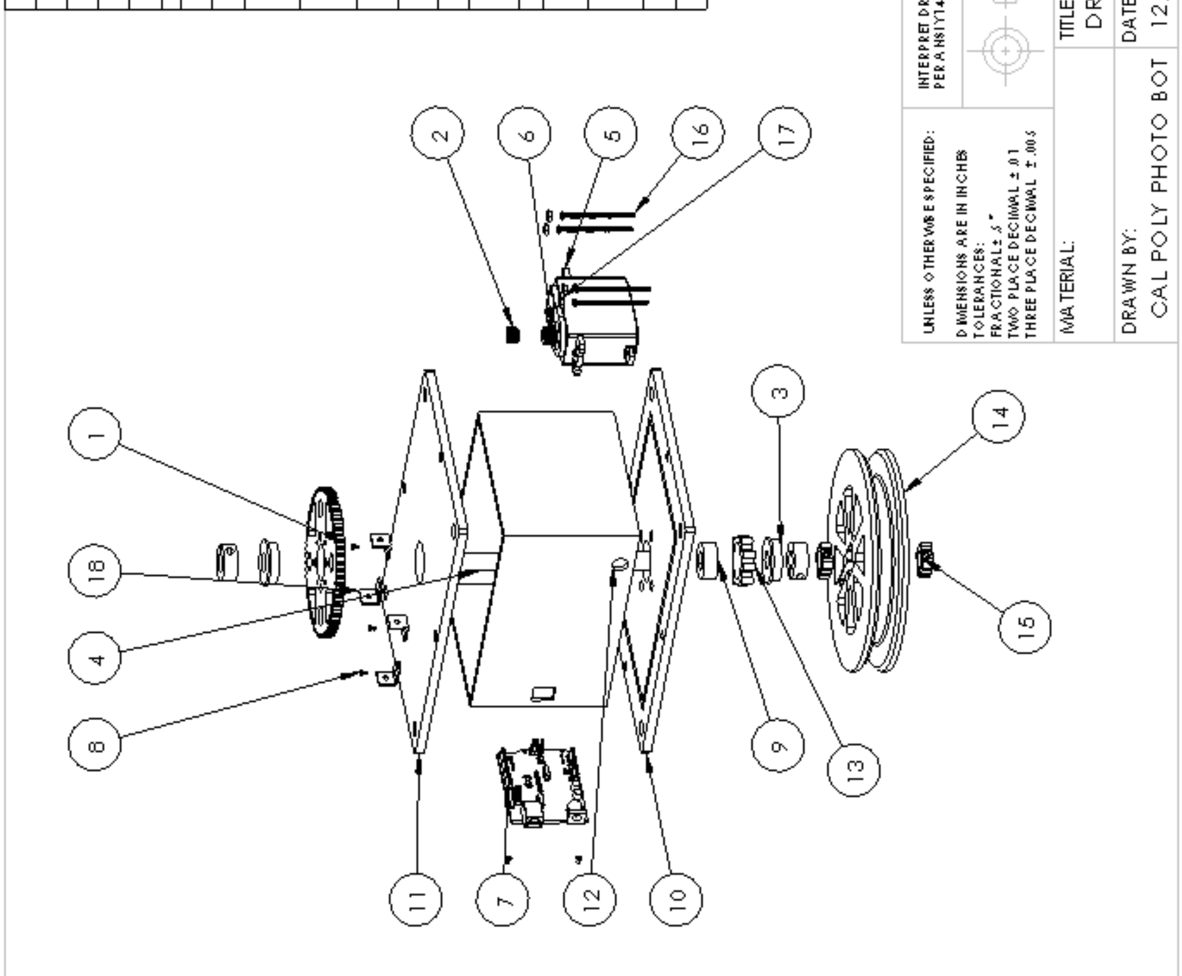
SAN LUIS OBISPO
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± .5°
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005
INTERPRET DRAWING
PER ANSI Y14.5 2009
MATERIAL:
PRECISION STEEL
TITLE:
PULLEY SHAFT
DRAWN BY:
CAL POLY PHOTOBOT
DATE:
12/7/2016
SHEET 1 OF 1
SCALE: 1:2
REV
SIZE
A
Ø.500
6.000


6.250
.175
.500
.275
Ø1.120
.275
.500
.175
4.250
1.00
4X 5/16"-18THRU
4X Ø.400
8.500
.250
4XR.100
4X Ø.300
1.00
.713
.963
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± .5°
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005
INTERPRET DRAWING PER ANSI Y14.5 2009
CAL POLY
SAN LUIS OBISPO
MATERIAL:
CLEAR CAST ACRYLIC
TITLE:
BOTTOM BRACKET PLATE
DRAWN BY:
CAL POLY PHOTOBOT
DATE:
12/7/2016
SHEET 1 OF 1
SCALE 1:2
REV
SIZE
A

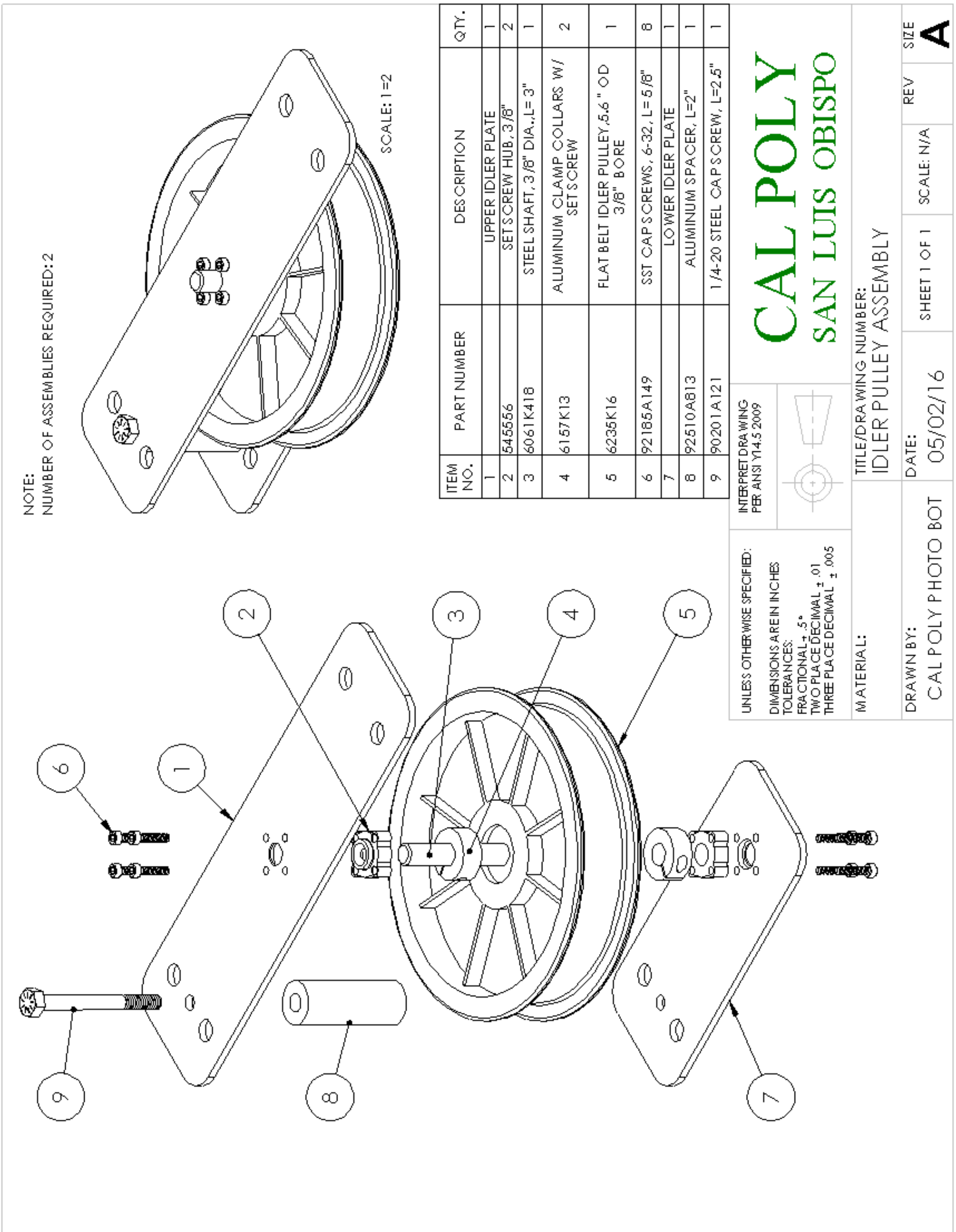

CAL POLY
SAN LUIS OBISPO
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± .5°
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005
INTERPRET DRAWING PER ANSI Y14.5 2009
MATERIAL:
CLEAR CAST ACRYLIC
TITLE:
TOP BRACKET PLATE
DRAWN BY:
CAL POLY PHOTOBOT
DATE:
5/1/2016
SHEET 1 OF 1
SCALE: 1:4
REV
SIZE
A
8.500
.250
4.250
.500
.963
.175
.275
.175
6.250
4X Ø.313
4X Ø.400
.500
3.125
.713
.275
Ø1.120

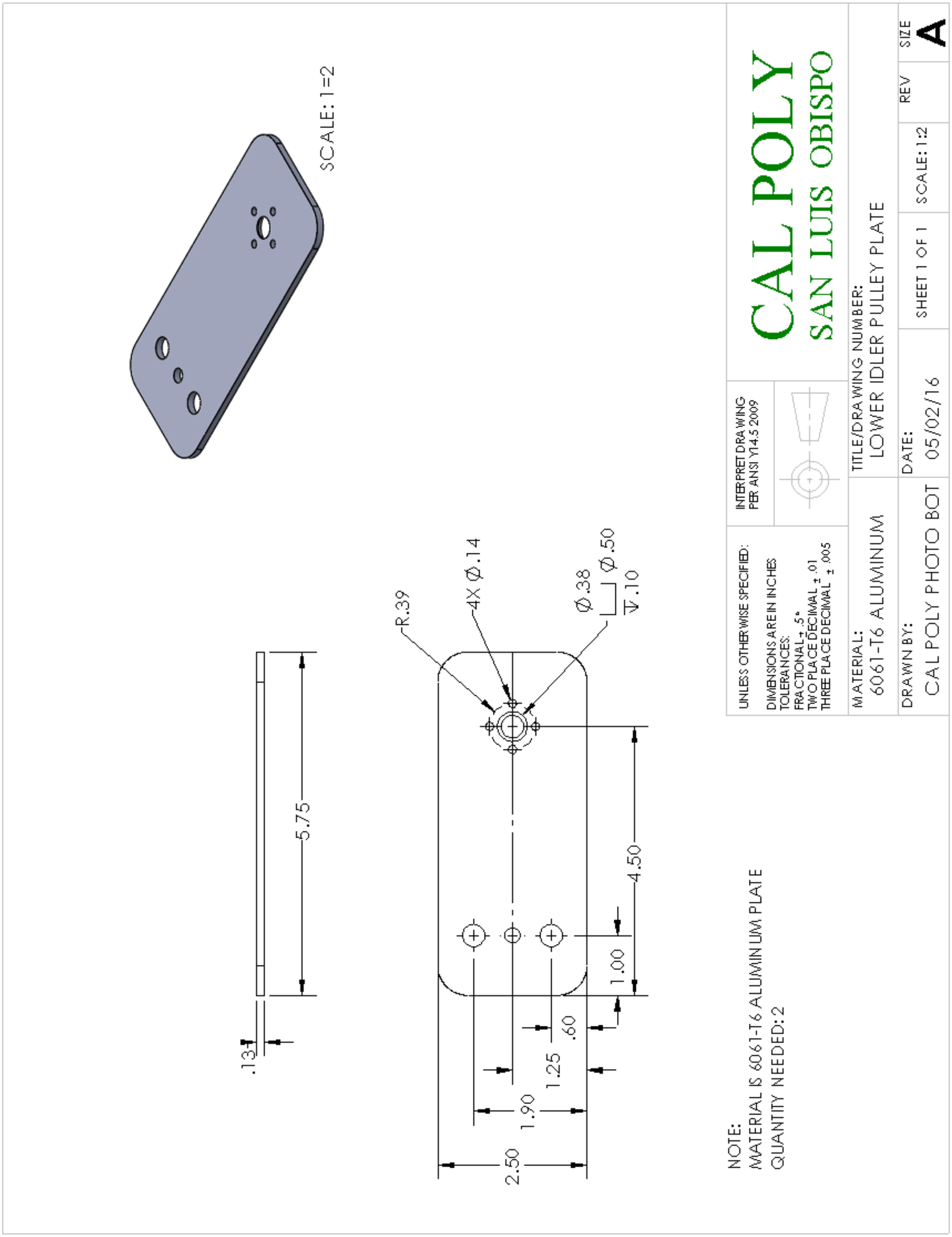

NOTE:
ACRYLIC HOUSING
WILL BE MADE FROM
FOUR (4) SEPARATE
PLATES OF ACRYLIC
AND EPOXIED
TOGETHER
.125
.125
4.750
6.500
Ø.450
.400
1.100
.500
.600
1.500
.250
3.750
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± .5°
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005
INTERPRET DRAWING
PER ANSI Y14.5 2009
CAL POLY
SAN LUIS OBISPO
MATERIAL:
CLEAR CAST ACRYLIC
TITLE:
ACRYLIC HOUSING
DRAWN BY:
CAL POLY PHOTOBOT
DATE:
12/7/2016
SHEET 1 OF 1
SCALE 1:2
REV
SIZE
A

| ITEM NO. | PART NUMBER | QTY. |
|---|---|---|
| 1 | 128T Aluminum Gear | 1 |
| 2 | 12T Pinion | 1 |
| 3 | Ball Bearing | 2 |
| 4 | 6" Shaft | 1 |
| 5 | Servo Motor | 1 |
| 6 | 15T Pinion | 1 |
| 7 | Arduino Uno | 1 |
| 8 | 2/56 1/4" Phillips Machine Screw | 8 |
| 9 | 1/2" ID Set Screw Collar | 3 |
| 10 | Bottom Plate | 1 |
| 11 | Top Plate | 1 |
| 12 | Servo Housing | 1 |
| 13 | 0.5in Bore Clamping Hub | 1 |
| 14 | 6" OD Pulley | 1 |
| 15 | 1/2" Bore Set Screw Hub | 2 |
| 16 | 4-40 2" Phillips Rounded Head | 4 |
| 17 | 4-40 Hex Nut | 4 |
| 18 | Battery L Bracket | 4 |



# 18.0 Appendix H: Engineering Drawings – Idler Pulleys





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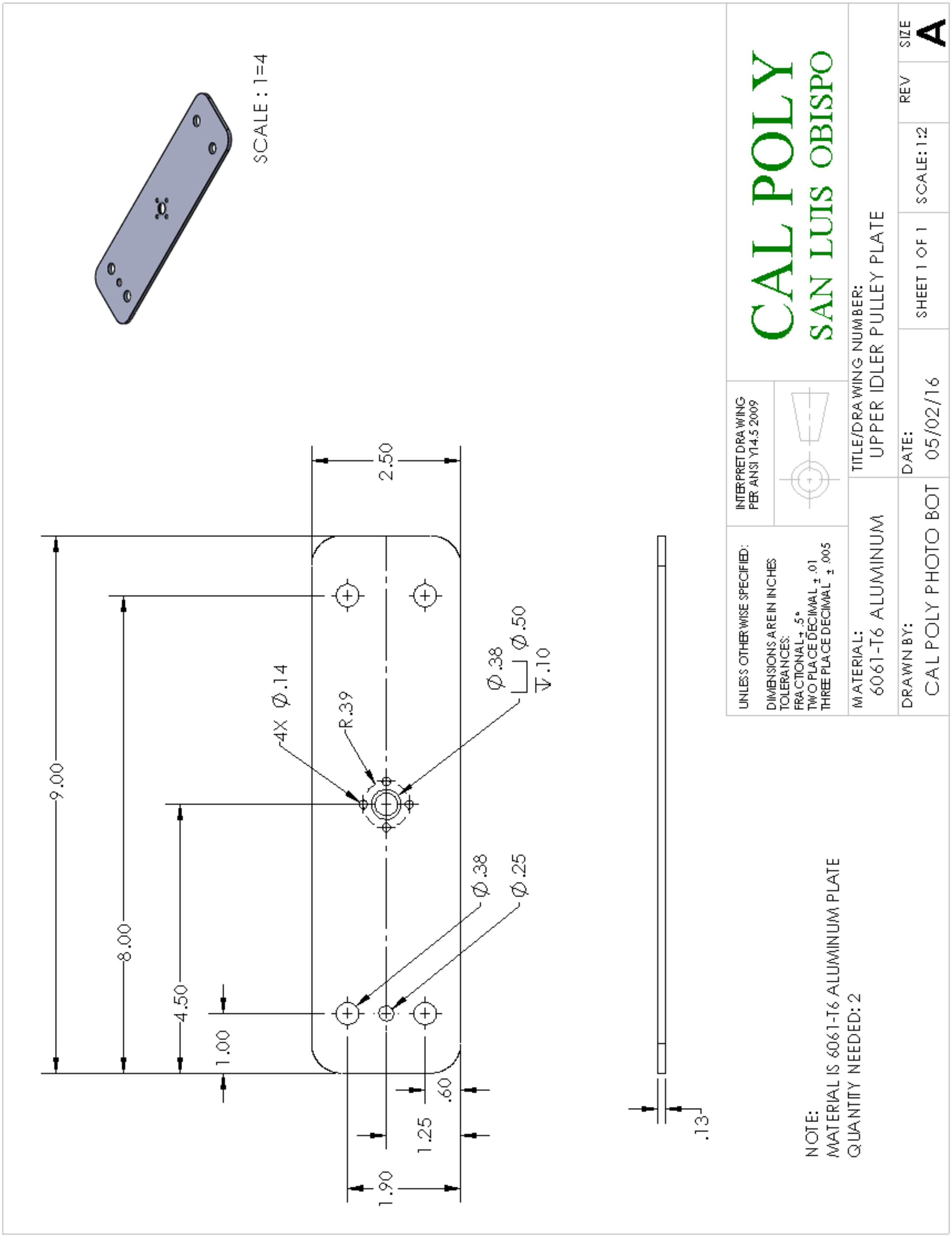
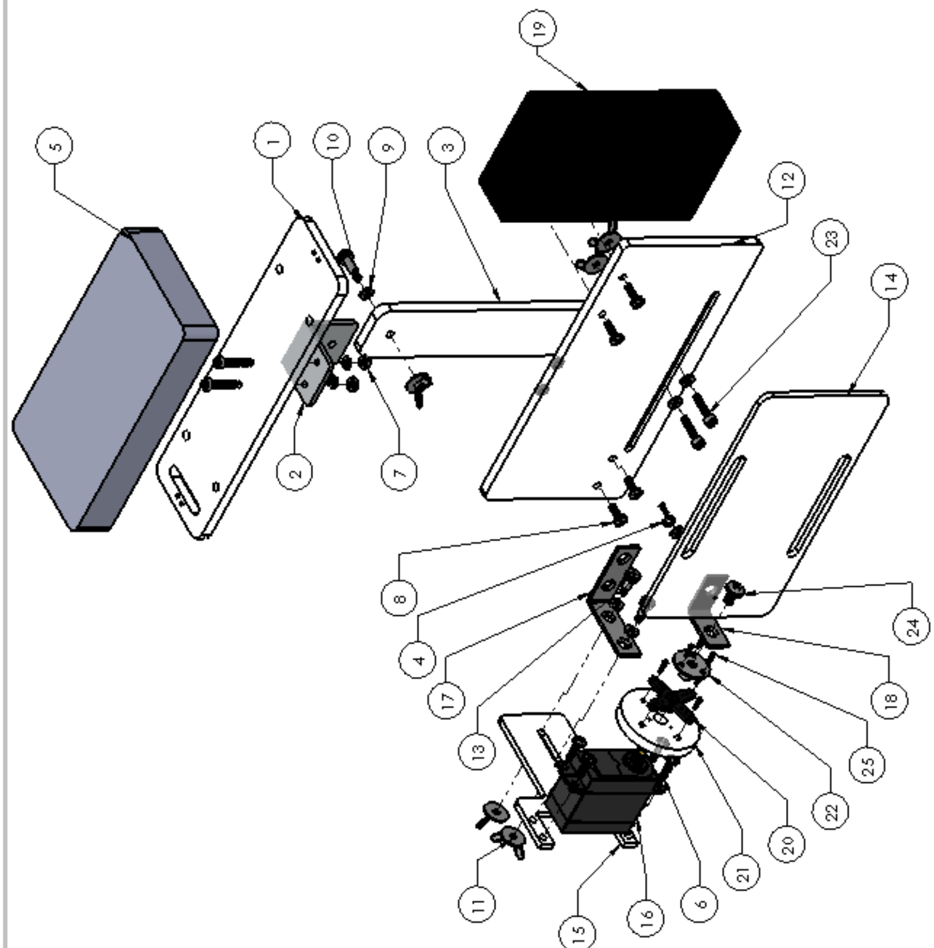
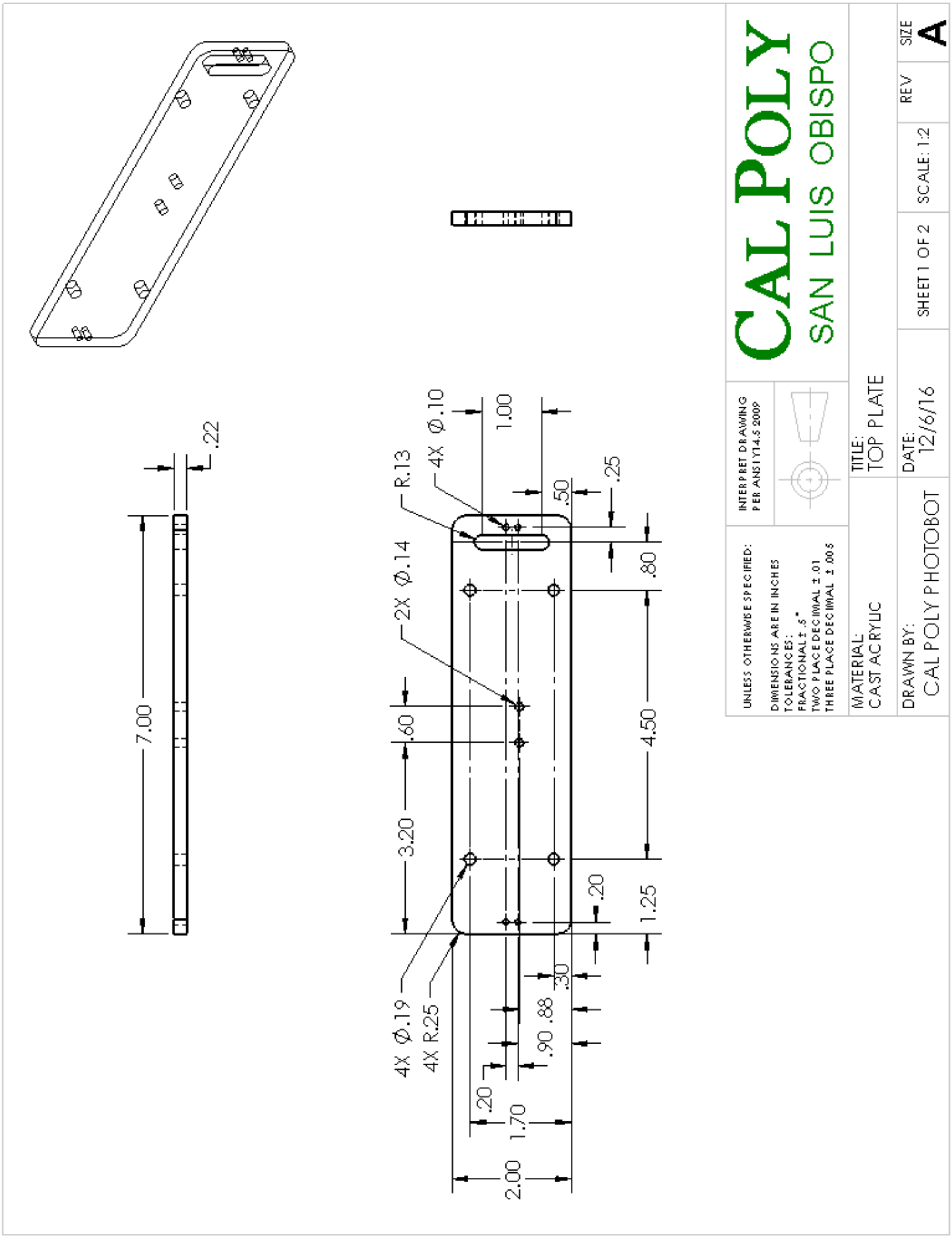
.13
5.75
R.39
4X Ø.14
Ø.38
⌴ Ø.50
↧.10
4.50
1.00
.60
1.25
1.90
2.50
NOTE:
MATERIAL IS 6061-T6 ALUMINUM PLATE
QUANTITY NEEDED: 2
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± .5°
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005
INTERPRET DRAWING PER ANSI Y14.5 2009
CAL POLY
SAN LUIS OBISPO
MATERIAL:
6061-T6 ALUMINUM
TITLE/DRAWING NUMBER:
LOWER IDLER PULLEY PLATE
DRAWN BY:
CAL POLY PHOTO BOT
DATE:
05/02/16
SHEET 1 OF 1
SCALE: 1:2
REV
SIZE
A


SCALE : 1=4
9.00
8.00
4.50
1.00
2.50
4X Ø.14
R.39
Ø.38
Ø.50
↧.10
Ø.38
Ø.25
.60
1.25
1.90
.13
NOTE:
MATERIAL IS 6061-T6 ALUMINUM PLATE
QUANTITY NEEDED: 2
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± .5°
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005
INTERPRET DRAWING PER ANSI Y14.5 2009
CAL POLY
SAN LUIS OBISPO
MATERIAL:
6061-T6 ALUMINUM
TITLE/DRAWING NUMBER:
UPPER IDLER PULLEY PLATE
DRAWN BY:
CAL POLY PHOTO BOT
DATE:
05/02/16
SHEET 1 OF 1
SCALE: 1:2
REV
SIZE
A

# 19.0 Appendix I: Engineering Drawings – PhotoBot

| ITEM NO. | PART NUMBER | DESCRIPTION | QTY. |
|---|---|---|---|
| 1 | N/A | TOP PLATE | 1 |
| 2 | N/A | LARGE TOP BRACKET | 1 |
| 3 | N/A | BACK SUPPORTING ARM | 1 |
| 4 | 92147A420 | SPLIT LOCK WASHER | 3 |
| 5 | N/A | SOLAR BATTERY | 1 |
| 6 | 91735A147 | TOP PLATE | 6 |
| 7 | 90760A007 | NARROW HEX NUT | 4 |
| 8 | 91735A146 | SHORT PAN HEAD PHILIPS MACHINE SCREW | 2 |
| 9 | 92141A006 | FLAT WASHER | 6 |
| 10 | 91259A162 | LONG SHOULDER SCREW | 1 |
| 11 | 92239A102 | FLANGE WING NUT | 5 |
| 12 | N/A | BACK FRAME | 1 |
| 13 | 91259A161 | SHORT SHOULDER SCREW | 2 |
| 14 | N/A | PLATE FOR PHONE | 1 |
| 15 | N/A | SIDE ARM | 1 |
| 16 | 900-00005 | SERVOMOTOR | 1 |
| 17 | 1556A42 | TWO HOLE L BRACKET | 1 |
| 18 | 1556A41 | ONE HOLE L BRACKET | 1 |
| 19 | N/A | ELECTRONICS BOX | 1 |
| 20 | N/A | SERVO PROPELLER | 1 |
| 21 | N/A | CUSTOM PROPELLER PLATE | 1 |
| 22 | 90611A340 | SCREW-MOUNT NUT | 1 |
| 23 | 92185A149 | SOCKET HEAD SCREW | 4 |
| 24 | 90272A826 | SCREW FOR SCREW-MOUNT | 1 |
| 25 | 90272A030 | SMALL DIAMETER SCREW | 8 |

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SAN LUIS OBISPO
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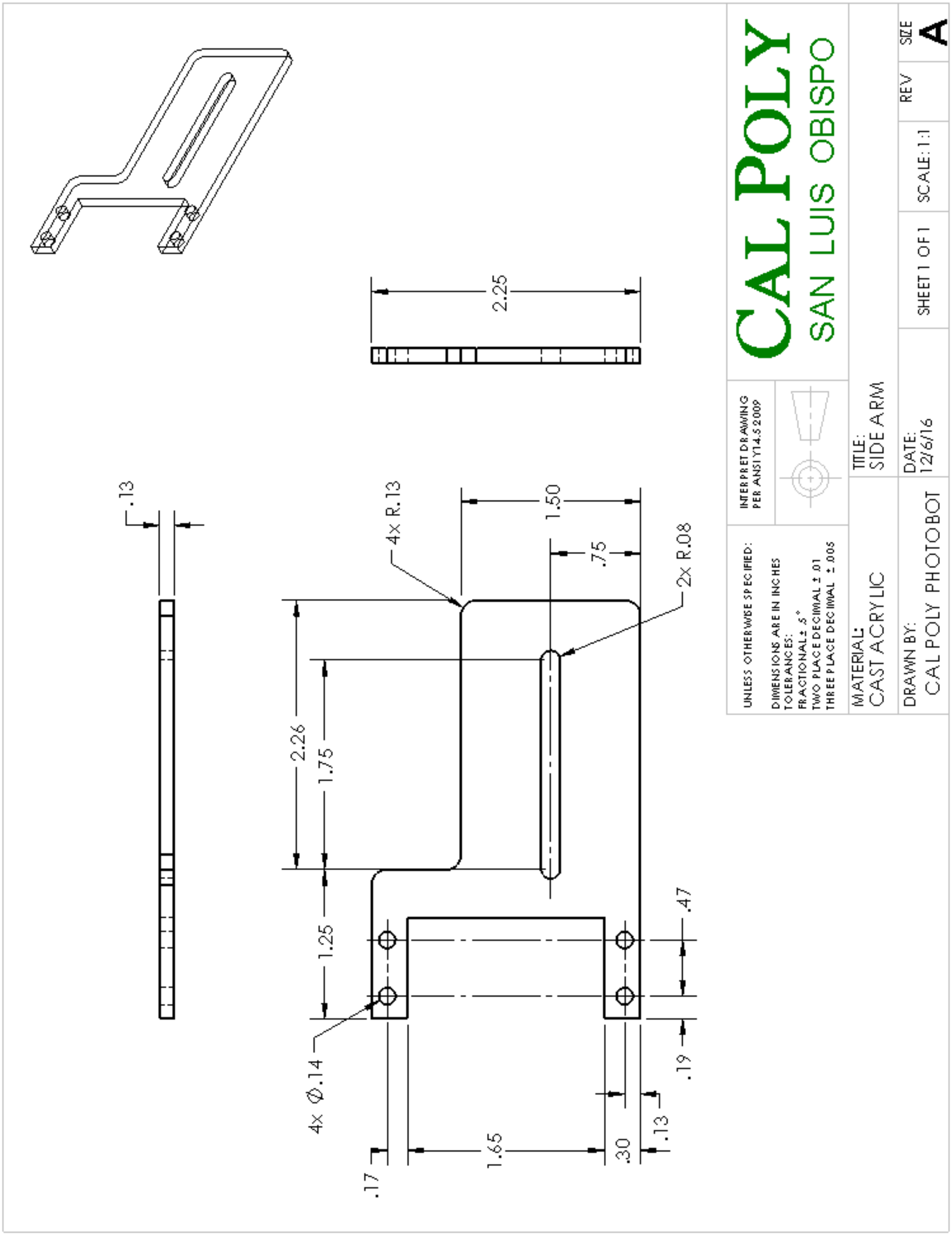
TOLERANCES:
FRACTIONAL ± .5°
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005
INTERPRET DRAWING PER ANSI Y14.5 2009
MATERIAL:
CAST ACRYLIC
TITLE:
TOP PLATE
DRAWN BY:
CAL POLY PHOTOBOT
DATE:
12/6/16
SHEET 1 OF 2
SCALE: 1:2
REV
SIZE
A
7.00
.22
R.13
4X Ø.10
1.00
.50
.25
2X Ø.14
.80
.60
3.20
4.50
.20
1.25
4X Ø.19
4X R.25
.30
.88
.90
.20
1.70
2.00



UNLESS OTHERWISE SPECIFIED:
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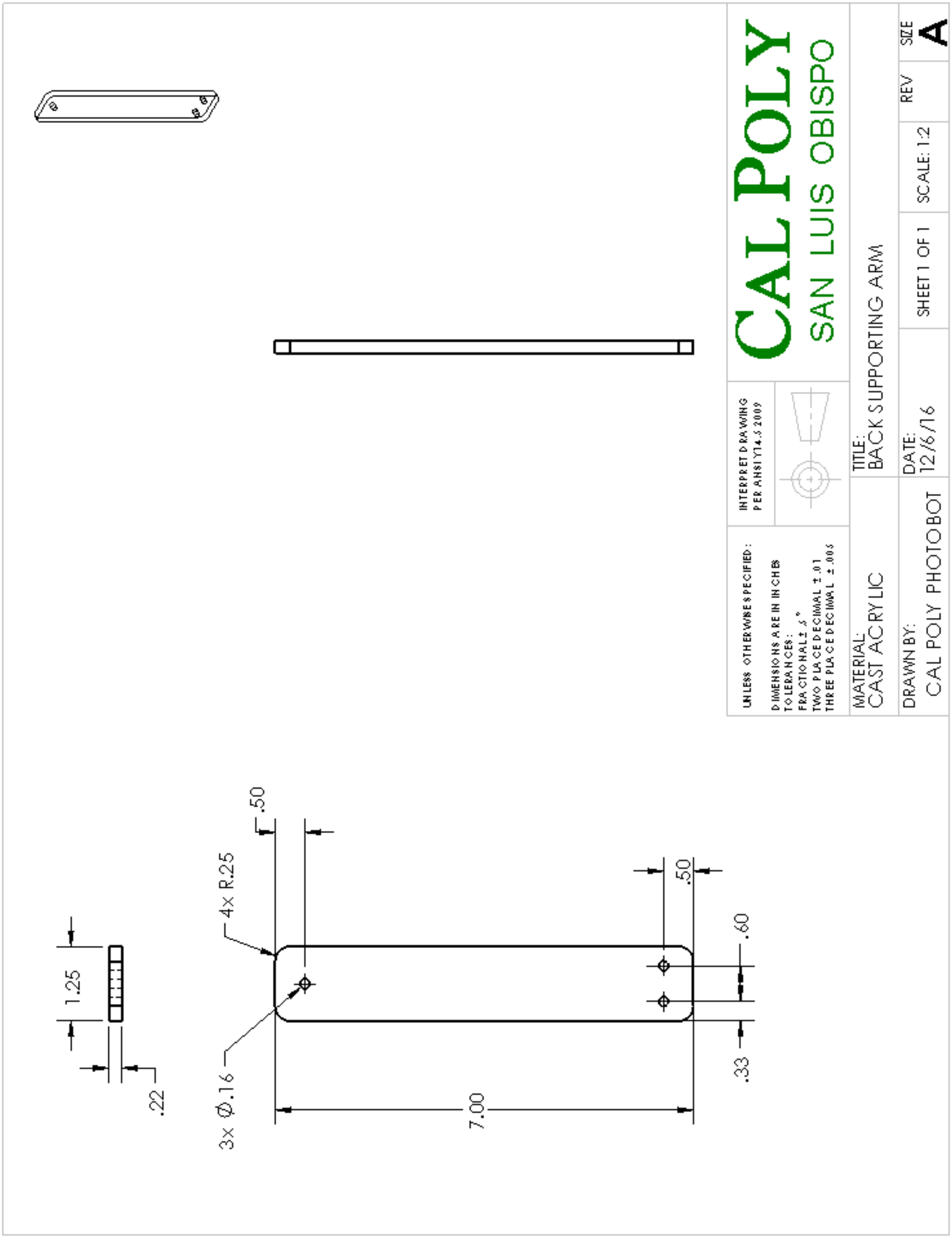
TOLERANCES:
FRACTIONAL ± .5°
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005
INTERPRET DRAWING PER ANSI Y14.5 2009
MATERIAL:
CAST ACRYLIC
DRAWN BY:
CAL POLY PHOTOBOT
TITLE:
SIDE ARM
DATE:
12/6/16
CAL POLY
SAN LUIS OBISPO
SHEET 1 OF 1
SCALE: 1:1
REV
SIZE
A
2.25
.13
4X R.13
1.50
.75
2X R.08
2.26
1.75
1.25
.47
.19
4X Ø.14
.17
1.65
.30
.13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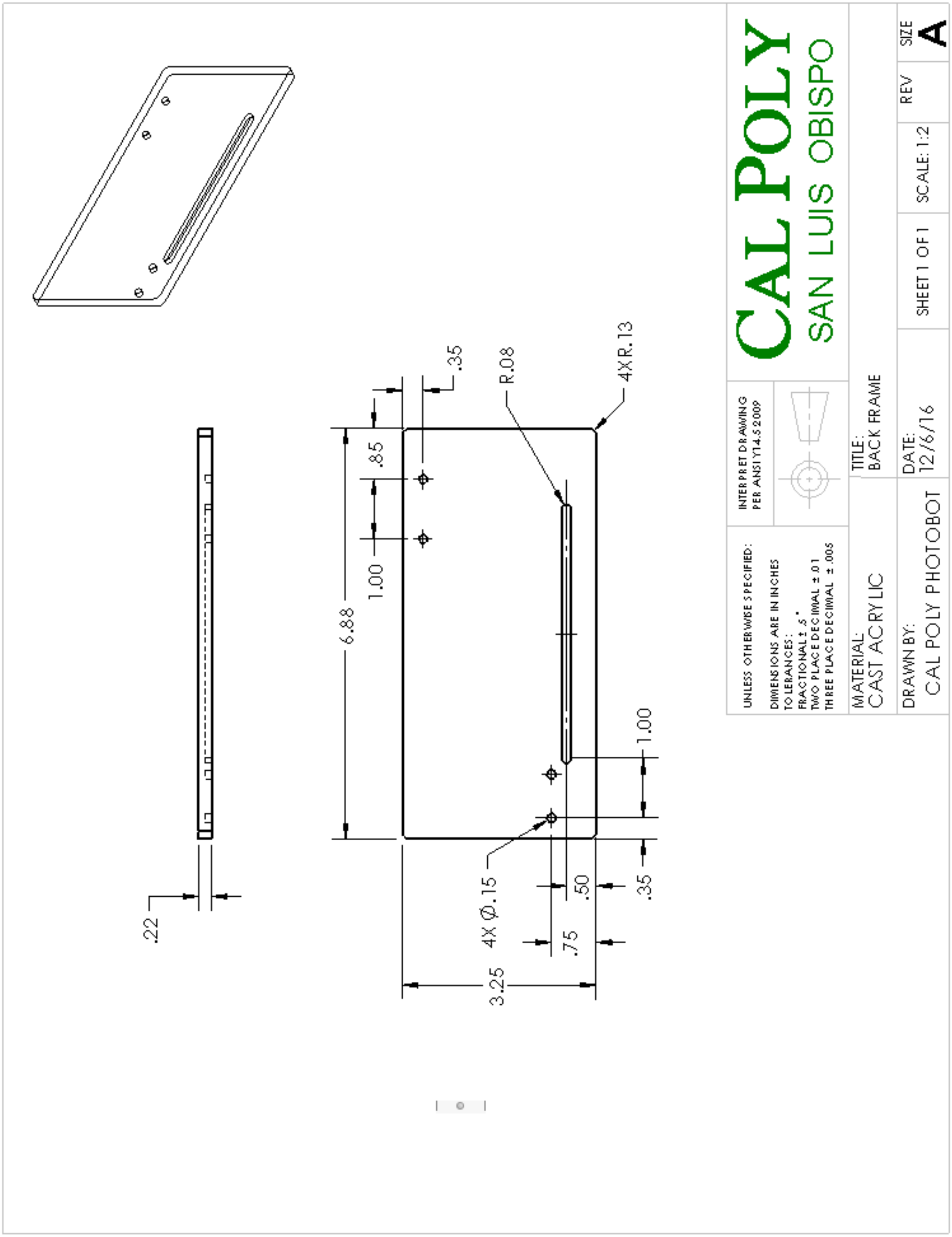
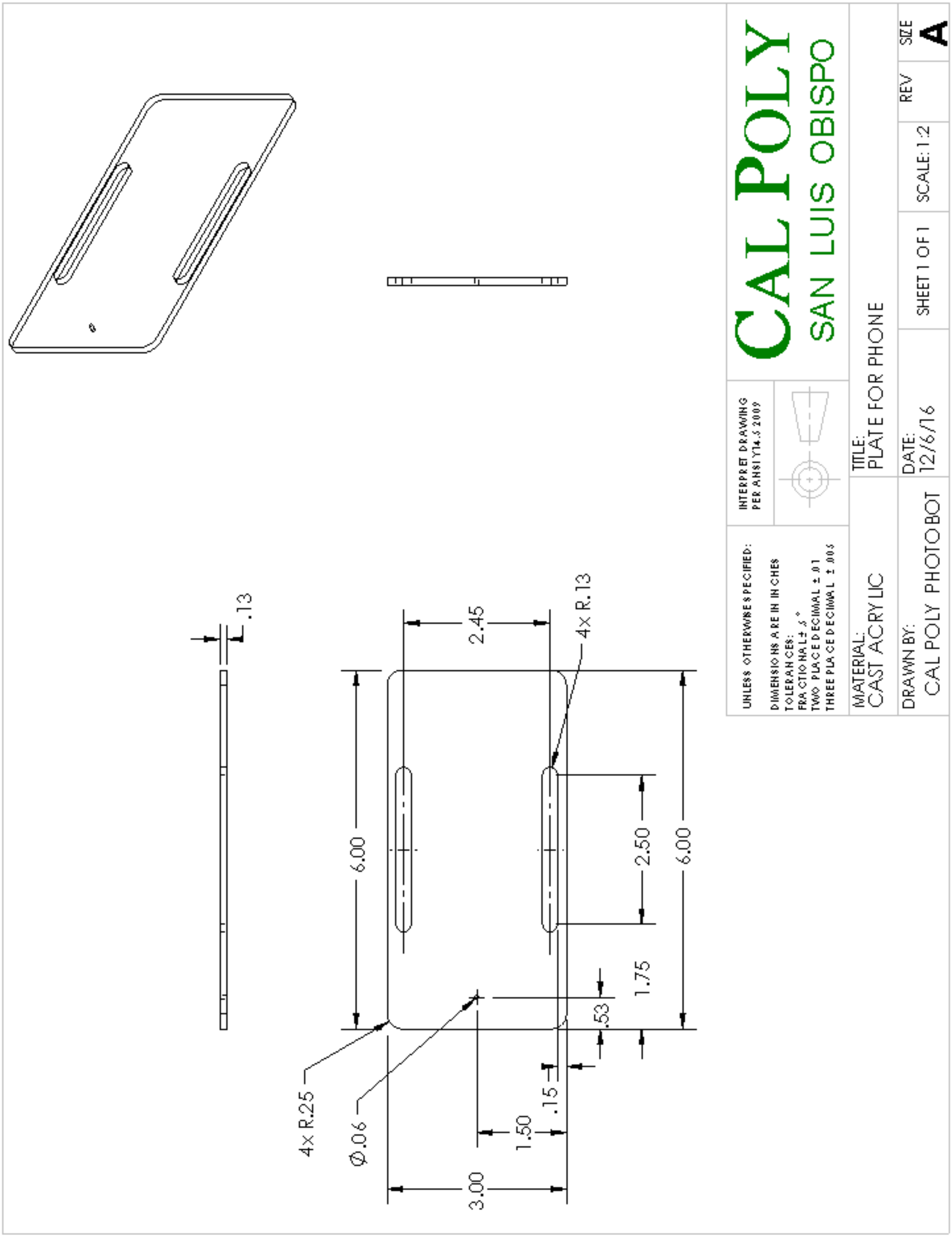
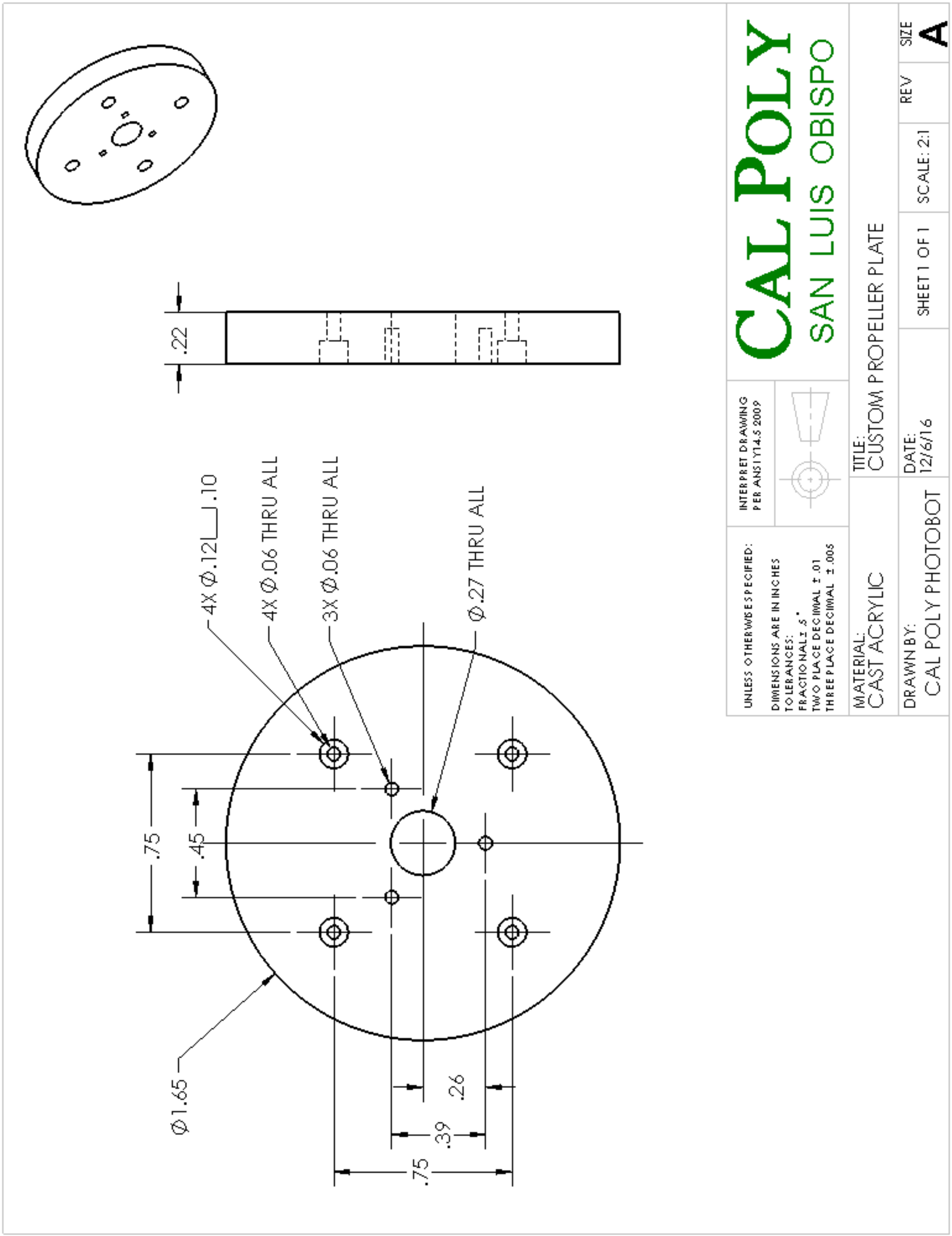
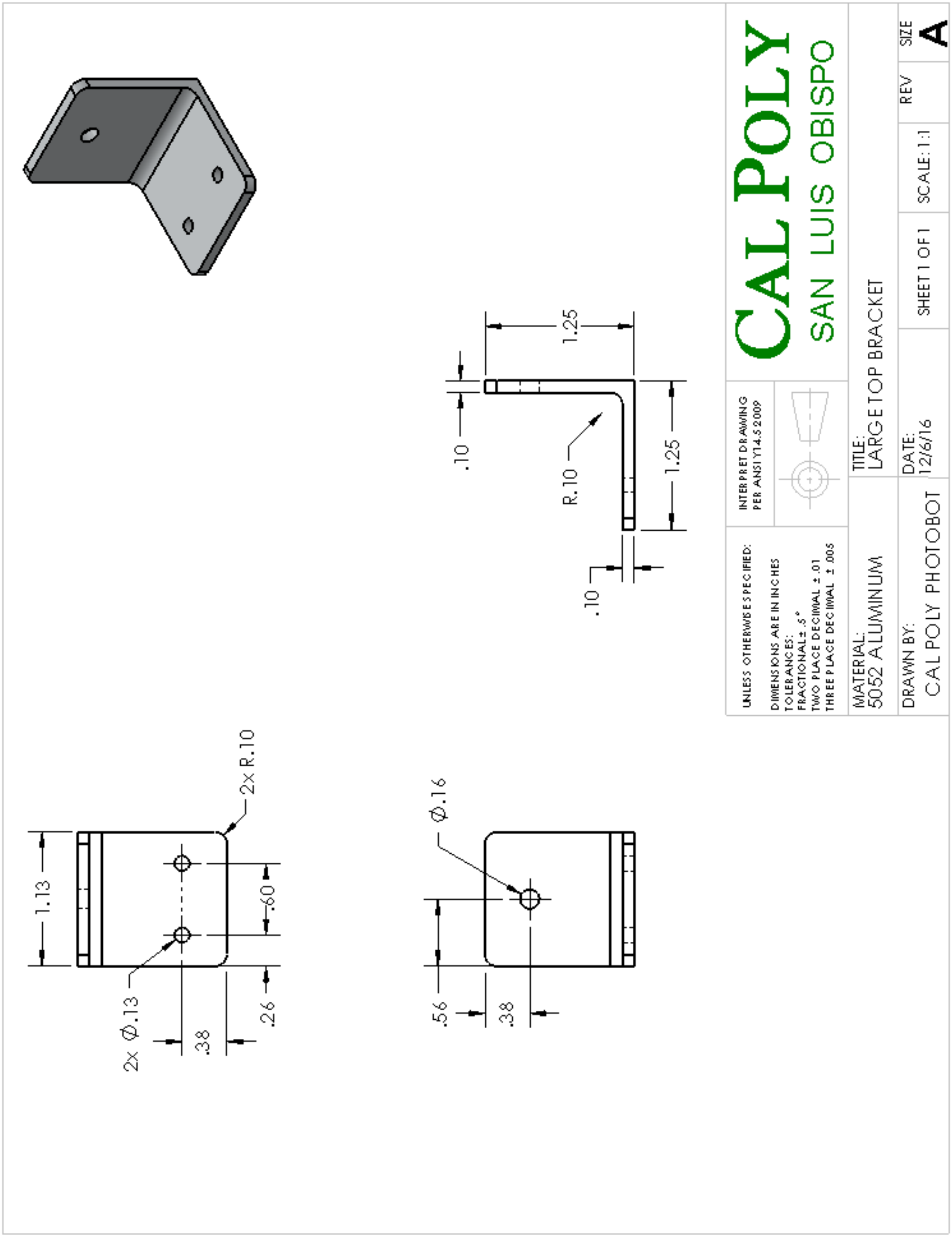
SAN LUIS OBISPO
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± .5°
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005
INTERPRET DRAWING PER ANSI Y14.5 2009
MATERIAL:
CAST ACRYLIC
TITLE:
BACK SUPPORTING ARM
DRAWN BY:
CAL POLY PHOTOBOT
DATE:
12/6/16
SHEET 1 OF 1
SCALE: 1:2
REV
SIZE
A
1.25
.22
4X R.25
3X Ø.16
.50
.50
.60
.33
7.00

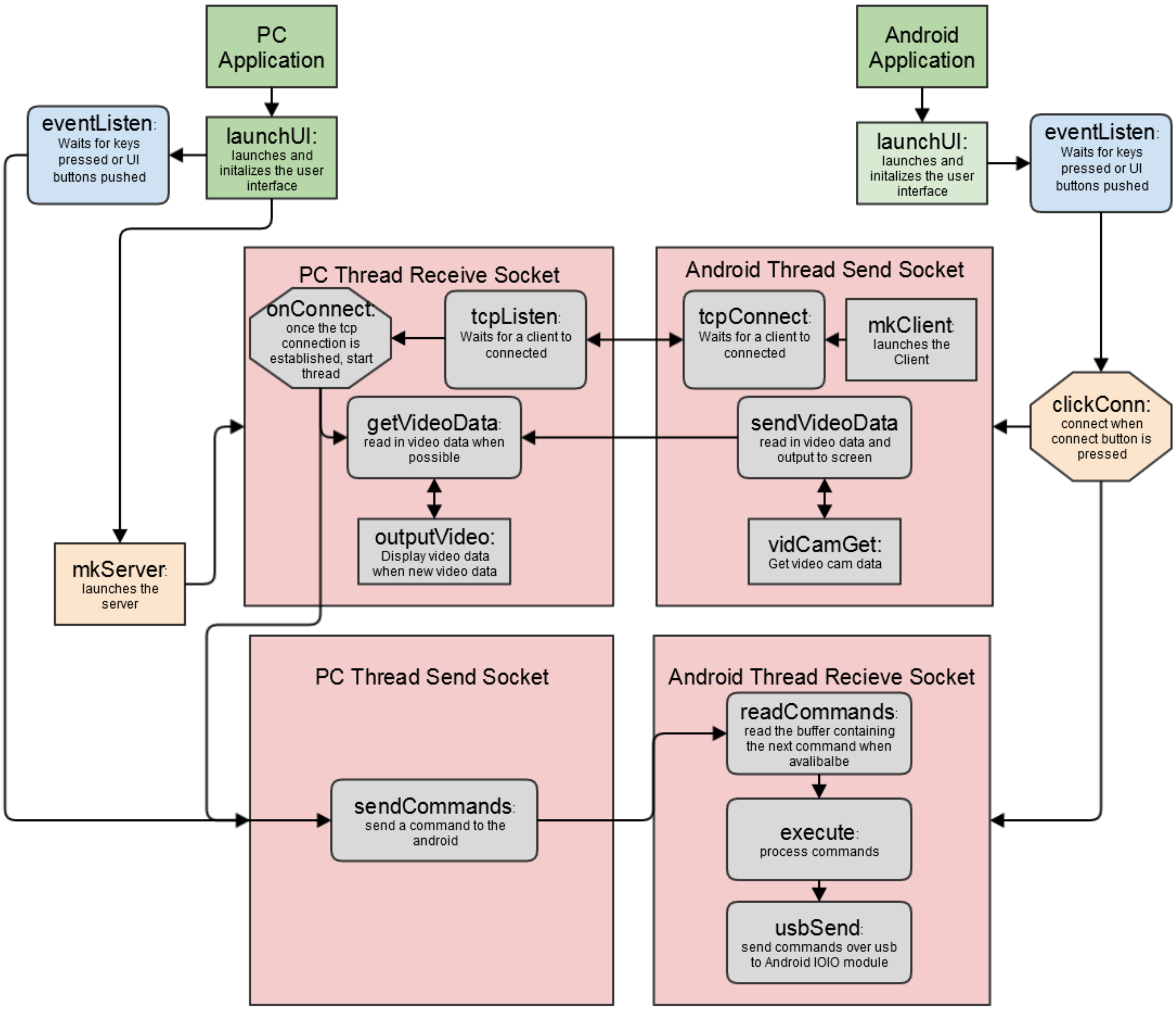

CAL POLY
SAN LUIS OBISPO
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± .5°
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005
INTERPRET DRAWING PER ANSI Y14.5 2009
MATERIAL:
CAST ACRYLIC
TITLE:
BACK FRAME
DRAWN BY:
CAL POLY PHOTOBOT
DATE:
12/6/16
SHEET 1 OF 1
SCALE: 1:2
REV
SIZE
A
.22
.35
.85
1.00
6.88
R.08
4X R.13
4X Ø.15
1.00
.35
.50
.75
3.25


CAL POLY
SAN LUIS OBISPO
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± .5°
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005
INTERPRET DRAWING PER ANSI Y14.5 2009
MATERIAL:
CAST ACRYLIC
TITLE:
PLATE FOR PHONE
DRAWN BY:
CAL POLY PHOTOBOT
DATE:
12/6/16
SHEET 1 OF 1
SCALE: 1:2
REV
SIZE
A
.13
2.45
4× R.13
6.00
2.50
6.00
1.75
.53
.15
1.50
3.00
4× R.25
Ø.06


4X Ø.12⌴ ↧.10
4X Ø.06 THRU ALL
3X Ø.06 THRU ALL
Ø.27 THRU ALL
.22
.75
.45
Ø1.65
.26
.39
.75
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± .5°
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005
INTERPRET DRAWING PER ANSI Y14.5 2009
CAL POLY
SAN LUIS OBISPO
MATERIAL:
CAST ACRYLIC
TITLE:
CUSTOM PROPELLER PLATE
DRAWN BY:
CAL POLY PHOTOBOT
DATE:
12/6/16
SHEET 1 OF 1
SCALE: 2:1
REV
SIZE
A


CAL POLY
SAN LUIS OBISPO
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± .5°
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005
INTERPRET DRAWING PER ANSI Y14.5 2009
MATERIAL:
5052 ALUMINUM
DRAWN BY:
CAL POLY PHOTOBOT
TITLE:
LARGE TOP BRACKET
DATE:
12/6/16
SHEET 1 OF 1
SCALE: 1:1
REV
SIZE
A
1.25
1.25
.10
.10
R.10
1.13
2x R.10
.60
.26
.38
2x Ø.13
Ø.16
.56
.38

# 20.0 Appendix J: Software Diagrams and Code Samples



## Android Client Code--

```
package com.PhotoBot.PhotoBot;
import java.io.BufferedInputStream;
import java.io.ByteArrayOutputStream;
import java.io.File;
import java.io.FileInputStream;
import java.io.FileOutputStream;
import java.io.IOException;
import java.io.InputStream;
import java.io.OutputStream;
import java.net.Socket;
import java.net.UnknownHostException;
import android.os.AsyncTask;
import android.os.Handler;
import android.os.Message;
import android.widget.TextView;
import android.util.Log;
public class Client extends AsyncTask<Void, Void, Void> {

  String dstAddress;
  int dstPort;
  String response = "";
  TextView textResponse;
  Custom_CameraActivity cameraObj;
  Client(String addr, int port, TextView textResponse) {
     dstAddress = addr;
     dstPort = port;
     this.textResponse = textResponse;
  }

  @Override
  protected Void doInBackground(Void... arg0) {

     BufferedInputStream bis;
     Handler mHandler = MainActivity.getHandler();
     Socket socket = null;
     byte[] bytes;
     File file;
     String end = "end";
     try {
        socket = new Socket(dstAddress, dstPort);

        ByteArrayOutputStream byteArrayOutputStream = new ByteArrayOutputStream(
              1024);
        byte[] buffer = new byte[1024];

        int bytesRead;
        InputStream inputStream = socket.getInputStream();
        OutputStream outputStream = socket.getOutputStream();
      /*
       * notice: inputStream.read() will block if no data return
       */
```

```
        while (true) {
            if (inputStream.available() > 0)
            {
                bytesRead = inputStream.read(buffer);
                byteArrayOutputStream.write(buffer, 0, bytesRead);
                response = byteArrayOutputStream.toString("UTF-8");
                if (response.equals("take_photo"))
                {
                    Message message = mHandler.obtainMessage(0, 0);
                    message.sendToTarget();
                    response = "-";
                }
            }
            try{
                Thread.sleep(1000);
            }catch (InterruptedException e)
            {

            }

        }

    } catch (UnknownHostException e) {
        // TODO Auto-generated catch block
        e.printStackTrace();
        response = "UnknownHostException: " + e.toString();
    } catch (IOException e) {
        // TODO Auto-generated catch block
        e.printStackTrace();
        response = "IOException: " + e.toString();
    } finally {
        if (socket != null) {
            try {
                socket.close();
            } catch (IOException e) {
                // TODO Auto-generated catch block
                e.printStackTrace();
            }
    }
    return null;
}

@Override
protected void onPostExecute(Void result) {
    textResponse.setText(response);
    super.onPostExecute(result);
}

}
```

13.2 Android App Main Activity Code

```
package com.PhotoBot.PhotoBot;

import android.content.Intent;
import android.graphics.Bitmap;
import android.graphics.BitmapFactory;
import android.hardware.Camera;
import android.net.Uri;
import android.os.Bundle;
import android.os.Environment;
import android.os.Handler;
import android.os.Looper;
import android.os.Message;
import android.util.Log;
import android.view.SurfaceView;
import android.view.View;
import android.app.Activity;
import android.view.View.OnClickListener;
import android.widget.Button;
import android.widget.EditText;
import android.widget.TextView;

import java.io.File;
import java.io.FileNotFoundException;
import java.io.FileOutputStream;
import java.io.IOException;

public class MainActivity extends Activity {
  TextView response;
  EditText editTextAddress, editTextPort;
  Button buttonConnect, buttonClear;
  static int count = 0;
  Camera camera; // camera object
  static SurfaceView view;
  static Handler mHandler;
  public static final int MEDIA_TYPE_IMAGE = 1;

  public static String getDirectory()
  {
     return Environment.getDataDirectory().toString() + "/photo" + count + ".jpg";
  }
  public static Handler getHandler()
  {
     return mHandler;
  }
  @Override
  protected void onCreate(final Bundle savedInstanceState) {
     super.onCreate(savedInstanceState);
     setContentView(R.layout.activity_main);
     editTextAddress = (EditText) findViewById(R.id.addressEditText);
     editTextPort = (EditText) findViewById(R.id.portEditText);
```

```
    buttonConnect = (Button) findViewById(R.id.connectButton);
    buttonClear = (Button) findViewById(R.id.clearButton);
    response = (TextView) findViewById(R.id.responseTextView);
    view = new SurfaceView(this);
    Log.d("view123", view.toString());
    buttonConnect.setOnClickListener(new OnClickListener() {

        @Override
        public void onClick(View arg0) {
            Client myClient = new Client(editTextAddress.getText()
                    .toString(), Integer.parseInt(editTextPort
                    .getText().toString()), response);
            myClient.execute();
        }
    });
    mHandler = new Handler(Looper.getMainLooper()) {

        public void handleMessage(Message message) {
            camera = Camera.open();
            try {
                camera.setPreviewDisplay(view.getHolder()); // feed dummy surface to surface
            } catch (IOException e) {
                // TODO Auto-generated catch block
                e.printStackTrace();
            }
            camera.startPreview();
            camera.takePicture(null, null, null, jpegCallBack);
        }
    };
    buttonClear.setOnClickListener(new OnClickListener() {

        @Override
        public void onClick(View v) {
            response.setText("");
        }
    });
    }
Camera.PictureCallback jpegCallBack=new Camera.PictureCallback() {
    public void onPictureTaken(byte[] data, Camera camera) {
        // set file destination and file name
        File destination = new File("/data/photo/myPictureTest.jpg");
        try {
            // set file out stream
            FileOutputStream out = new FileOutputStream(destination);
            // set compress format quality and stream
            out.write(data, 0, data.length);

        } catch (FileNotFoundException e) {
            // TODO Auto-generated catch block
            e.printStackTrace();
        } catch (IOException e) {
        // TODO Auto-generated catch block
```

```
          e.printStackTrace();
         }

      }
  };
  }
```

13.3 PC App Server-

```java
package test;

//File Name GreetingServer.java

import java.net.*;
import java.awt.Container;
import java.awt.Insets;
import java.awt.event.ActionEvent;
import java.awt.event.ActionListener;
import java.awt.event.KeyEvent;
import java.awt.event.KeyListener;
import java.io.*;
import java.util.*;

import javax.swing.JButton;
import javax.swing.JFrame;
import javax.swing.JLabel;
import javax.swing.JTextField;

public class GreetingServer extends Thread
{
private ServerSocket serverSocket;
private Socket server;
private static int port;
private static String ipAddress;
static boolean connectedToServer = false;
static JFrame frame1;
static Container pane;
static JButton btnConnect, btnDisconnect;
static JLabel errorOrStatusMessage, stateOutput, lblPassword, lblPort;
static JTextField txtServer, txtUsername, txtPassword, txtPort;
static Insets insets;

public GreetingServer(int port) throws IOException
{
serverSocket = new ServerSocket(port);

}

public void run()
{
        DataInputStream in = null;
guiSet();
```

```
while(true)
{
  try
  {
        if (connectedToServer == false)
        {
                errorOrStatusMessage.setText("Waiting for connection");
            server = serverSocket.accept();
            in = new DataInputStream(server.getInputStream());
            errorOrStatusMessage.setText("<html>Just connected to:<br>" +
                          server.getRemoteSocketAddress() + "</html>");
            connectedToServer = true;
        }

        if (connectedToServer == true && in != null && in.available() > 0)
        {
            System.out.println(in.readUTF());
        }
  }catch(SocketTimeoutException s)
  {
        connectedToServer = false;
                errorOrStatusMessage.setText("Socket Connection timed Out");
    break;
  }catch(IOException e)
  {
        connectedToServer = false;
    e.printStackTrace();
    break;
  }
  try {
                Thread.sleep(100);
        } catch (InterruptedException e) {
                // TODO Auto-generated catch block
                e.printStackTrace();
        }
}
try {
        server.close();
} catch (IOException e) {
        // TODO Auto-generated catch block
        e.printStackTrace();
}
}

private String ipAddressRet()
{
        NwAddress networkAddressing = new NwAddress();
        ipAddress = networkAddressing.returnIpAddress(true);
        return ipAddress;

}
```

```
private void setGuiAttrib()
{
  pane = frame1.getContentPane();
  insets = pane.getInsets();
  //Apply the null layout
  pane.setLayout (null);
  frame1.setVisible(true);
  frame1.setSize (300,300);
  btnConnect.setBounds(60, 100, 140, 30);
  stateOutput.setBounds(90, 20, 140, 60);
  errorOrStatusMessage.setBounds(90, 140, 140, 30);
  frame1.add(stateOutput);
  frame1.add(btnConnect);
  frame1.add(errorOrStatusMessage);
  stateOutput.setText("<html>Your ip Address is:<br>" +
                ipAddressRet() + "<br>On port:<br>" + port  + "</html>");
}

private void guiSet()
{
  //Create the frame
        final File outputImage = new File("C:\\imagesTest\\testimage.jpg");
  frame1 = new JFrame ("Sample GUI Application");
  //Prepare panel
  frame1.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
  btnConnect = new JButton("Take photo");
  stateOutput = new JLabel();
  errorOrStatusMessage = new JLabel();
  btnConnect.addActionListener(new ActionListener()
  {
   public void actionPerformed(ActionEvent e)
   {
        if (connectedToServer == true)
        {
                try {
            DataOutputStream out = new DataOutputStream(server.getOutputStream());
            out.writeBytes("take_photo");
            out.flush();
            Thread.sleep(1000);
                  errorOrStatusMessage.setText("Taking Photo");
                  DataInputStream in = new DataInputStream(server.getInputStream());
                  while (in.available() == 0)
                  {
            Thread.sleep(100);
                  }
                  byte[] buffer = new byte[10000000];
                  in.read(buffer);
                  OutputStream outStream = new FileOutputStream(outputImage);
                  outStream.write(buffer);
                  outStream.close();

                }
```

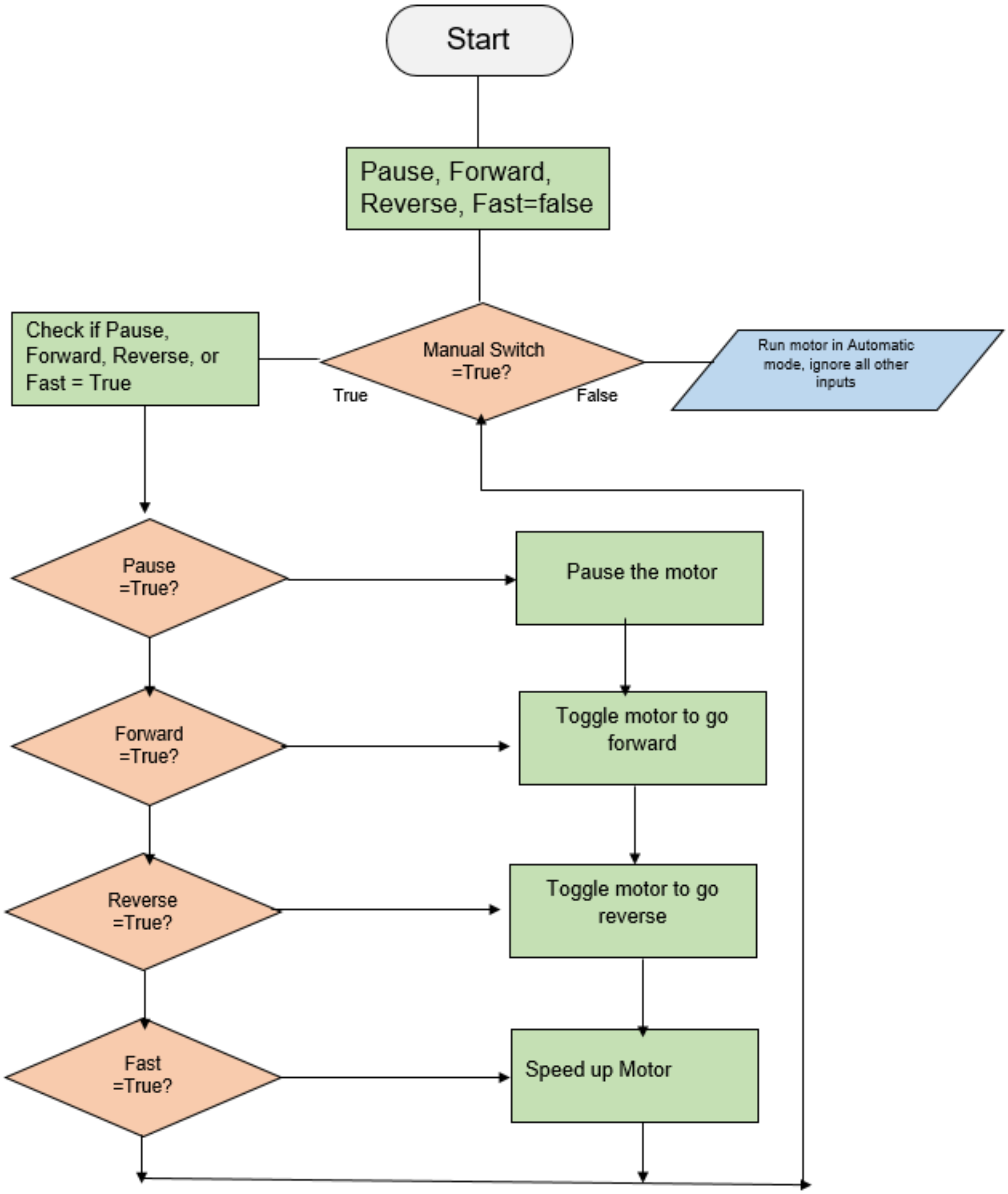
```
            catch(SocketTimeoutException s)
            {
                  connectedToServer = false;
               System.out.println("Socket timed out!");
            }
                  catch(IOException j)
            {
                  connectedToServer = false;
                j.printStackTrace();
            } catch (InterruptedException e1) {
                                    // TODO Auto-generated catch block
                                    e1.printStackTrace();
                           }

          }

    }

  });
  setGuiAttrib();
}

public static void main(String [] args)
{

        if (args.length == 0)
        {
                port = 3000;
        }
        else
        {
                port = Integer.parseInt(args[0]);
        }

try
{
  Thread t = new GreetingServer(port);
  t.start();
}catch(IOException e)
{
  e.printStackTrace();
}
}
}
```

13.4 PC App Get the IP Address

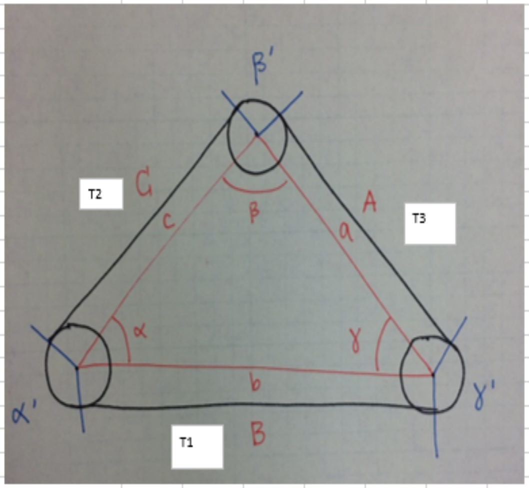
```
package test;

import java.net.InetAddress;
import java.net.NetworkInterface;
import java.util.Collections;
```

```
import java.util.List;

public class NwAddress {
        /**
        * Get IP address from first non-localhost interface
        * @param ipv4  true=return ipv4, false=return ipv6
        * @return  address or empty string
        */
        private static String getIPAddress(boolean useIPv4) {
          try {
             List<NetworkInterface> interfaces =
Collections.list(NetworkInterface.getNetworkInterfaces());
             for (NetworkInterface intf : interfaces) {
                List<InetAddress> addrs = Collections.list(intf.getInetAddresses());
                for (InetAddress addr : addrs) {
                   if (!addr.isLoopbackAddress()) {
                      String sAddr = addr.getHostAddress();
                      //boolean isIPv4 = InetAddressUtils.isIPv4Address(sAddr);
                      boolean isIPv4 = sAddr.indexOf(':')<0;

                      if (useIPv4) {
                         if (isIPv4)
                            return sAddr;
                      } else {
                         if (!isIPv4) {
                            int delim = sAddr.indexOf('%'); // drop ip6 zone suffix
                            return delim<0 ? sAddr.toUpperCase() : sAddr.substring(0,
delim).toUpperCase();
                         }
                      }
                   }
                }
             }
          } catch (Exception ex) { } // for now eat exceptions
          return "";
        }

        public String returnIpAddress(boolean useIpv4)
        {
                String outputIp = getIPAddress(useIpv4);
                if (outputIp.length() == 0)
                {
                        outputIp = "null";
                }
                return outputIp;
        }
}
        }
```

# Arduino Motor Control Flow Diagram



## 21.0 Appendix K: Sample Calculation Results for Required Pulley Torque




| | Rα | Rβ | Rγ |
|---|---|---|---|
| in | 2.25 | 2.25 | 2.25 |
| ft | 0.1875 | 0.1875 | 0.1875 |

| | α | β | γ |
|---|---|---|---|
| degrees | 5.000 | 5.000 | 170.000 |
| radians | 0.087 | 0.087 | 2.967 |

| | α' | β' | γ' |
|---|---|---|---|
| radians | 3.05 | 3.05 | 0.17 |
| degrees | 175.00 | 175.00 | 10.00 |

| | a | b | c | Area |
|---|---|---|---|---|
| ft | 5 | 5 | 9.96 | 2.1706 |

| | A | B | C |
|---|---|---|---|
| ft | 5 | 5 | 9.961946981 |

| | arc α' | arc β' | arc γ' |
|---|---|---|---|
| ft | 6.87 | 6.87 | 0.39 |

| | L total |
|---|---|
| ft | 34.10 |

| | Vα | Vβ | Vγ |
|---|---|---|---|
| ft/s | 0.5 | 0.5 | 0.5 |

| T1/T2 | T2/T3 | T1/T3 |
|---|---|---|
| 6.250 | 6.250 | 1.110 |

Tension when stationary:
60 lbf

Coefficient of friction between cable and pulley:
0.6

Desired bot speed:
0.5 ft/s

Desired wheel speed:
2.7 rad/s
25.465 RPM
0.424413182 RPS

Time to accelerate:
5 sec

Acceleration:
0.533333333 rad/s^2

Mass of pulley:
3 lbf
0.093242991 slug
3 lbm

Mass moment of interia:
0.001639037 slug ft^2

Motor Torque (T):
20 lbf ft

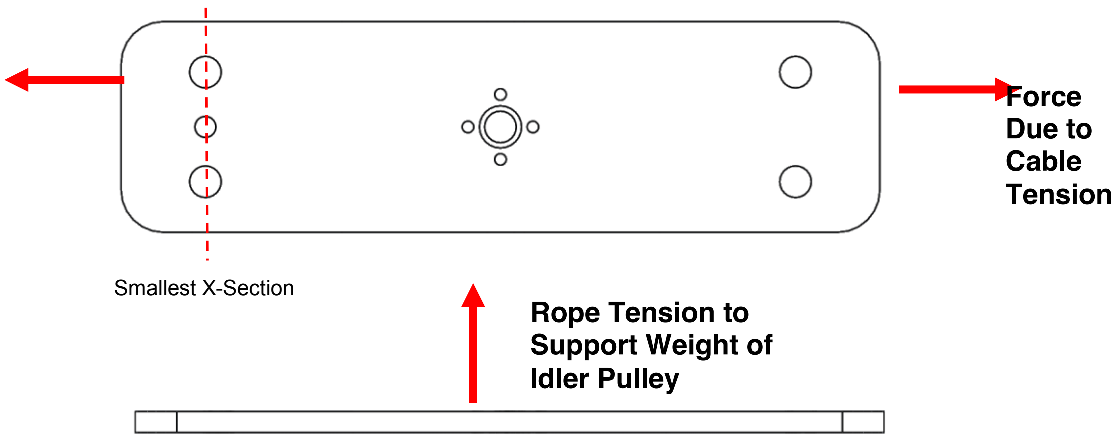
ANALYSIS AT WHEEL α

Iα
0.0009 slugft^2/s^2

| P | T | Trest | T1 | T2 | T3 | T1/T2 | T2/T3 | T1/T3 |
|---|---|---|---|---|---|---|---|---|
| | | | | | | 6.250 | 6.250 | 1.110 |
| hp | lbf ft | lbf | lbf | lbf | lbf | T1/T2 | T2/T3 | T1/T3 |
| 0 | 0 | 0 | -0.006 | -9E-04 | 180.01 | 6.250 | 0.000 | 0.000 |
| 0.0048 | 1 | 1.0159 | 6.3436 | 1.015 | 172.64 | 6.250 | 0.006 | 0.037 |
| 0.0097 | 2 | 2.0317 | 12.693 | 2.0308 | 165.28 | 6.250 | 0.012 | 0.077 |
| 0.0145 | 3 | 3.0476 | 19.042 | 3.0467 | 157.91 | 6.250 | 0.019 | 0.121 |
| 0.0194 | 4 | 4.0634 | 25.391 | 4.0625 | 150.55 | 6.250 | 0.027 | 0.169 |
| 0.0242 | 5 | 5.0793 | 31.74 | 5.0784 | 143.18 | 6.250 | 0.035 | 0.222 |
| 0.0291 | 6 | 6.0951 | 38.09 | 6.0942 | 135.82 | 6.250 | 0.045 | 0.280 |
| 0.0339 | 7 | 7.111 | 44.439 | 7.1101 | 128.45 | 6.250 | 0.055 | 0.346 |
| 0.0388 | 8 | 8.1268 | 50.788 | 8.126 | 121.09 | 6.250 | 0.067 | 0.419 |
| 0.0436 | 9 | 9.1427 | 57.137 | 9.1418 | 113.72 | 6.250 | 0.080 | 0.502 |
| 0.0485 | 10 | 10.159 | 63.486 | 10.158 | 106.36 | 6.250 | 0.096 | 0.597 |
| 0.0533 | 11 | 11.174 | 69.836 | 11.174 | 98.991 | 6.250 | 0.113 | 0.705 |
| 0.0582 | 12 | 12.19 | 76.185 | 12.189 | 91.626 | 6.250 | 0.133 | 0.831 |
| 0.063 | 13 | 13.206 | 82.534 | 13.205 | 84.261 | 6.250 | 0.157 | 0.980 |
| 0.0679 | 14 | 14.222 | 88.883 | 14.221 | 76.896 | 6.250 | 0.185 | 1.156 |
| 0.0727 | 15 | 15.238 | 95.232 | 15.237 | 69.531 | 6.250 | 0.219 | 1.370 |
| 0.0776 | 16 | 16.254 | 101.58 | 16.253 | 62.166 | 6.250 | 0.261 | 1.634 |
| 0.0824 | 17 | 17.27 | 107.93 | 17.269 | 54.801 | 6.250 | 0.315 | 1.970 |
| 0.0873 | 18 | 18.285 | 114.28 | 18.285 | 47.436 | 6.250 | 0.385 | 2.409 |
| 0.0921 | 19 | 19.301 | 120.63 | 19.3 | 40.071 | 6.250 | 0.482 | 3.010 |
| 0.097 | 20 | 20.317 | 126.98 | 20.316 | 32.706 | 6.250 | 0.621 | 3.882 |
| 0.1018 | 21 | 21.333 | 133.33 | 21.332 | 25.34 | 6.250 | 0.842 | 5.261 |
| 0.1067 | 22 | 22.349 | 139.68 | 22.348 | 17.975 | 6.250 | 1.243 | 7.770 |
| 0.1115 | 23 | 23.365 | 146.03 | 23.364 | 10.61 | 6.250 | 2.202 | 13.763 |
| 0.1164 | 24 | 24.381 | 152.37 | 24.38 | 3.2454 | 6.250 | 7.512 | 46.952 |
| 0.1212 | 25 | 25.396 | 158.72 | 25.396 | -4.12 | 6.250 | -6.164 | -38.528 |
| 0.1261 | 26 | 26.412 | 165.07 | 26.411 | -11.48 | 6.250 | -2.300 | -14.373 |
| 0.1309 | 27 | 27.428 | 171.42 | 27.427 | -18.85 | 6.250 | -1.455 | -9.094 |
| 0.1358 | 28 | 28.444 | 177.77 | 28.443 | -26.21 | 6.250 | -1.085 | -6.781 |
| 0.1406 | 29 | 29.46 | 184.12 | 29.459 | -33.58 | 6.250 | -0.877 | -5.483 |
| 0.1455 | 30 | 30.476 | 190.47 | 30.475 | -40.94 | 6.250 | -0.744 | -4.652 |

# 22.0 Appendix L: Sample Calculation Results for Idler Pulley Strength

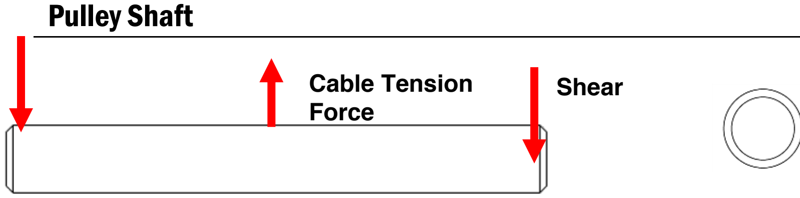
## Upper Bracket




| Material | Aluminum 6061-T6 | |
|---|---|---|
| Elastic Modulus | 1.00E+07 | *psi* |
| Tensile Yield Strength | 40000 | *psi* |
| Thickness | 0.125 | *in* |
| Width | 2.5 | *in* |
| Smallest Cross-Sectional Area | 0.1875 | *$in^2$* |
| Factor of Safety | 3 | - |
| Max Cable Tension | 1250 | *lbf* |

$$F = (\sigma_y * Area)/F.S.$$

## Pulley Shaft




| Material | Steel | |
|---|---|---|
| Elastic Modulus | 2.90E+07 | *psi* |
| Tensile Yield Strength | 36000 | *psi* |
| Shear Yield Approx. | 20880 | *psi* |
| Diameter | 0.375 | *in* |
| Length-Corrected | 2 | *in* |
| Cross-Sectional Area | 0.1104466 | *$in^2$* |
| Moment of Inertia | 0.0009707 | *$in^4$* |
| Q | 0.0043945 | *$in^3$* |
| b | 0.375 | *in* |
| Factor of Safety | 3 | - |
| Max Cable Force | 994 | *lbf* |

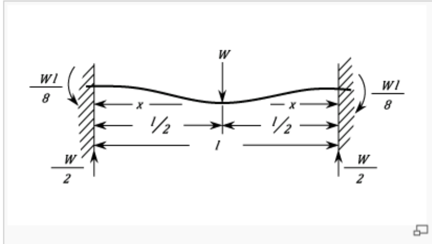
$$\tau = \frac{VQ}{Ib} \qquad b = 2r$$

$$I = \frac{\pi r^4}{4} \quad \text{for solid section}$$

The shear stress at the neutral axis;

$$Q = Ay = \left(\frac{\pi r^2}{2}\right)\left(\frac{4r}{3\pi}\right) = \frac{2r^3}{3}$$

## Deflection Method for Pulley Shaft and Clamping Bolt




The Stress between each end and the Load: $S = \frac{W}{2\,Z}\left(\frac{1}{4}\,l - x\right)$

The Stress at each end is : $S_e = \frac{W\,l}{8\,Z}$

The Stress at the middle is: $S_m = -\frac{W\,l}{8\,Z}$

These are the maximum Stresses and are equal and opposite.

The stress is zero at $x = \frac{1}{4}\,l$

The Deflection at any point is given by: $y = \frac{W\,x^2}{48\,E\,I}\,(3l - 4x)$

The Maximum Deflection is at the Load and is: $\hat{y} = \frac{W\,l^3}{192\,E\,I}$

| | |
|---|---|
| Desired Factor of Safety | 3 |

| Pulley Shaft | | |
|---|---|---|
| Diameter of Shaft | 0.38 | *in* |
| Cable Force | 288.3 | *lbf* |
| Shear Force per Support | 144.1 | *lbf* |
| Z | 0.00518 | *in*$^3$ |
| Max Deflection of Shaft | 2.67E-05 | *in* |
| Max Stress | 6.96E+03 | *psi* |
| Difference in F.S. | 0.00 | - |
| **Max Cable Tension Allowed** | **144.13** | ***lbf*** |

| Bolt | | |
|---|---|---|
| Diameter of Bolt | 0.25 | *in* |
| Cable Force | 427.1 | *lbf* |
| Shear Force per Support | 213.5 | *lbf* |
| Z | 0.00153 | *in*$^3$ |
| Max Deflection of Shaft | 2.00E-04 | *in* |
| Max Stress | 3.48E+04 | *psi* |
| Difference in F.S. | 0.00000 | - |
| **Max Cable Tension Allowed** | **213.53** | ***lbf*** |

## 23.0 Appendix M: Sample Calculation Results for PhotoBot

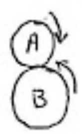
TORQUE CALCULATIONS FOR
SERVOMOTOR ON PHOTO BOT

TORQUE OF PARALLAX STANDARD SERVOMOTOR: 38 oz-in @ 6V

WANT TO ASSURE THAT THE SERVOMOTOR CAN TURN THE WEIGHT OF THE PHONE ∴

DESIRED TORQUE > 64 oz-in (CONSERVATIVE)

SCHEMATIC OF GEAR STAGE




KNOW: $\frac{T_A}{T_B} = \frac{RPM_B}{RPM_A} = \frac{TEETH_A}{TEETH_B}$

IF SERVOMOTOR IS DIRECTLY DRIVING PINION A, $T_A$ = 38 oz-in

SOLVE FOR $T_B$:

$$T_B = T_A \times \frac{\text{TEETH B}}{\text{TEETH A}}$$

$$T_B = 38\ \text{oz-in} \times \frac{\text{TEETH B}}{\text{TEETH A}}$$

LET GEAR B TO HAVE 24 TEETH
GEAR A TO HAVE 12 TEETH

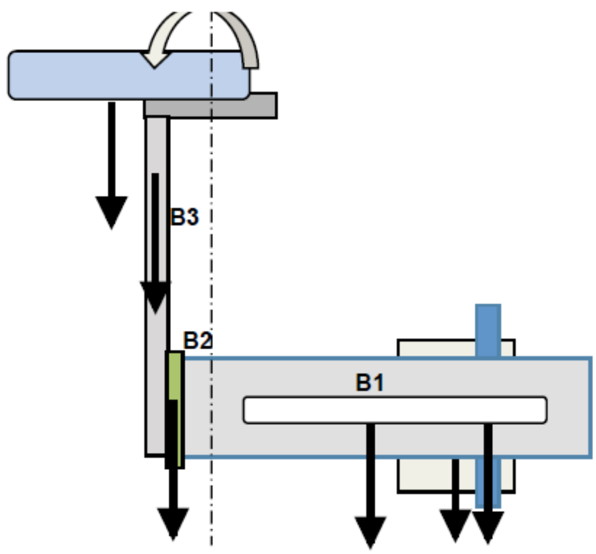
∴ $T_B$ = 76 oz-in > DESIRED TORQUE OF 64 oz-in

∴ IT IS SUFFICIENT TO LET GEAR B TO HAVE 24 TEETH AND GEAR A TO HAVE 12 TEETH

# Finding Center of Mass of Photo Bot

| Item: | Weight (lbm) | Moment Arm (in) | Moment(lbm-in) |
|---|---|---|---|
| Servo Motorw/Housing &Gears | 0.14 | -2.15 | -0.31 |
| Phone & Phone Plate | 0.47 | -1.91 | -0.90 |
| B1=Side Arm | 0.05 | -1.84 | -0.09 |
| B2=Electronics Housing | 0.24 | 0.30 | 0.07 |
| B3=Supporting Arm | 0.11 | 0.56 | 0.06 |
| Battery | 0.52 | 0.50 | 0.26 |
| | 1.5280 | | -0.91 |

**values for weight and the moment arm are based on actual final design



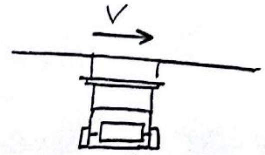

NOTE:Summed the moments from the point at which the bot will hang from (center of the top plate) to determine if the system will tilt forwards or backwards. As a result, determined that the bot will slightly tilt down in a clockwise motion. To fix this problem, we can put weight in the housing for the electronics and if need be mount it behind the supporting arm.

## 24.0 Appendix N: Sample Calculation Results for Power Estimate

# PHOTO BOT SPEED CALCULATIONS

$rpm_{motor} = 55$ @ 7.2V , Gear ratio = 10.67 or 128:12

$r_{drive\ pulley} = 2.25\ in$



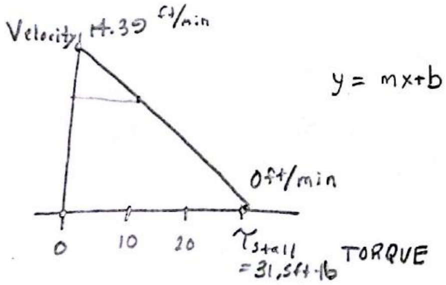

CONVERT RPM TO RAD/S:

$$55\,rpm \times \frac{1\,min}{60\,sec} \times \frac{2\pi\,rad}{1\,rev} = 5.759\ rad/s$$

$\omega = v\,r \quad \therefore \quad V = \frac{\omega}{r}$ , $V = \frac{5.759\ rad/s}{2.25\,in}$

$V_{pinion} = 2.559\ \frac{ft}{s}$ , $V_{OUT} = 2.559\ \frac{ft}{s} \div 10.67$

$V_{OUT} = 0.239\ ft/s \Rightarrow$ **14.39 $\frac{ft}{min}$ @ NO LOAD**




$y = mx + b$ , $y = -\left(\frac{14.39 - 0}{31.5}\right)x + 14.39$

$y = 0.4568x + 14.39$

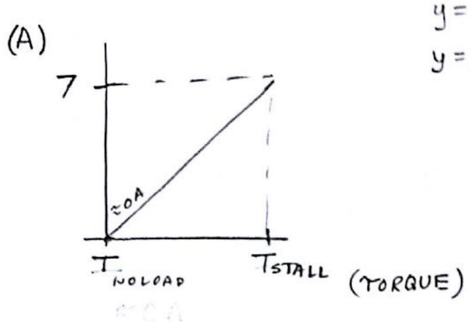
WE EXPECT TO OPERATE AT ABOUT 10 lbf-ft SO WE CAN EXPECT SPEEDS OF ABOUT

**$y(10) = 9.82\ ft/min$**

# PHOTOBOT POWER CALCULATIONS

ESTIMATING CURRENT DRAW:

$I_{STALL} \approx 7A$




$y = mx + b$

$y = \frac{7-0}{31.5}x$

IF $T_{operation} \approx 10 \, lbf\text{-}ft$, THEN $y(10) = 2.22\,A$

OUR MOTOR BATTERY PACK HAS A CAPACITY OF 40,000 MAH.

SO AS AN ESTIMATE:

$$t_{operation} = \frac{40\,AH}{2.22\,A} = \boxed{18.01 \text{ hours}}$$

EX. CALCULATION

GIVEN VELOCITY IS ABOUT 9.82 ft/min

ASSUME A LINE LENGTH OF $60 \frac{ft}{day}$ ← distance per day

$t = 6.109 \frac{min}{day}$

$t_{total} = 18.01 \text{ hours} = 1080.6 \text{ mins}$

$\boxed{t_{total} = 176.88 \text{ days of operation}}$

w/ a F.S of about 2

we can expect about 80 days of operation without accounting for the solar charging.

## 25.0 Appendix O: FMEA and DVP Charts

CAL POLY ENGINEERING PHOTOBOT

**Potential Failure Mode and Effect Analysis**
**(Design FMEA)**

Page 1 of 1

System: Photo Bot
Subsystem: Pulley System
Design Responsibility: Carlos E., Kassandra R., & Samantha C.
Key Date: 4/30/2016
FMEA Number: FMEA16-000002
Prepared By: Carlos Esquivel

| Componen | Item/Function | Potential Failure Mode | Potential Effect(s) of Failure | Sev | Potential Cause(s) Mechanism(s) of Failure | Occur | Crit | Recommended Action(s) | Responsibility & Target Completion Data | Actions Taken | Action Results | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | Sev | Occur | Crit |
| **Gear Box on Drive Pulley** | The gear box will provide the torque required to turn the drive pulley | *Insufficient Torque/ Stalling* | The motor may stall, and batteries will drain quicker | 7 | Excessive tension in the cable or resistive friction from other pulleys | 5 | 35 | Test to determine the torque required for pulley system, and overshoot then apply a factor of safety. | Carlos, Kassandra, 04/09/16 | A prototype system was made and it was estimated that the amount of torque required would be about 15 lb.-ft. | 2 | 3 | 6 |
| **Pulley Brackets** | The bracket will be used to support the cable pulleys. | *Excessive Stress* | Bracket can fail or yield | 8 | Too much tension in the cables | 4 | 32 | Perform a test to measure or estimate the amount of tension that will be **actually** be applied on bracket. Determine if material or thickness is adequate. | Carlos, Kassandra, Sam 05/14/16 | A full system test was carried out. The brackets were able to withstand the required cable tension. | 2 | 1 | 2 |
| **Drive Cable** | The drive cable or wire will be responsible for moving the Photo Bot | *Axial Stress* | Cable can fray or fail | 7 | Too much tension, fatigue, or wear | 3 | 21 | Test the setup to estimate the amount of tension that will be applied by user. Size the cable appropriately or use a different type of line. | Carlos, Kassandra, Sam 05/14/16 | Various cables and monofilaments with different load ratings were tested. It was found that still fishing line was able to withstand the loads without danger of fraying. Long term test were done to verify that the cable did not fatigue. | 2 | 2 | 4 |
| **Battery Photocell** | Photovoltaic Cells are part of the battery used to power the pulley motor and the Arduino controlling the movement. | *Power Failure* | Camera and motor may lose power after some time of operation. | 7 | Lack of Solar incidence may cause the battery to drain much more rapidly than anticipated. | 4 | 28 | Test the battery and power consumption of the system under different lighting conditions. Determine if a better battery is needed. | Carlos, Aubrey, 05/20/16 | Several battery tests were conducted in the dark and the battery was able to run for about 5 hours continuously. | 2 | 3 | 6 |

**ME428 DVP&R Format**

| Report Date | | 12/9/2016 | | Sponsor: Cris Cristoffer | | | | | Component/Assembly | Photo Bot | REPORTING ENGINEER: Carlos | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TEST PLAN | | | | | | | | | | TEST REPORT | | | |
| | | | | | | SAMPLES | | TIMING | | | TEST RESULTS | | |
| Item No | Specification or Clause Reference | Test Description | Acceptance Criteria | Test Responsibility | Test Stage | Quantity | Type | Start date | Finish date | Test Result | Quantity Pass | Quantity Fail | NOTES |
| 1 | Weight | The final Photo Bot Cradel and Camera Assembly will be weighed. | Must be under 5 lbs | Kassanda R. | PV | 1 | C | 5/30/2016 | 12/9/2016 | 3 lbf | 1 | 0 | |
| 2 | IP 54 Compliant | The electronics and motor housings will be tested to verify that it can protect against splashing water and foreign debris. Water will be sprayed from all driections to verify complete compliance. | No water or foreign particles may enter protected housings, all functionality must be retained. | Carlos E, Sam C. Kassandra R. | PV | 1 | C | 5/30/2016 | 12/9/2016 | -- | 0 | 1 | Condensation holes were drilled into bottom plate, water/debris may enter. However, all components are sprayed with protective sealant. |
| 3 | Operation Height | The Photo Bot camera and cradle will be tested in a mock set up to determine the maxiumum height at which the system could safetly be set up at. | Minimum height of operation must be at least 15 meters. | Carlos E, Sam C. Kassandra R., Aubrey R. | PV | 1 | C | 10/1/2016 | 12/9/2016 | 3m | 0 | 1 | System can realistically be setup around 3m. System can only easily be setup as far as the installer can toss the tensioner belt without getting caught in branches. |
| 4 | Motor Stall Tests | The complete system will be set up with varying tensions. At each tension, the motor's voltage-thus torque will be varied to determine the best operating conditions to prevent stall. | Motor should not stall with varying applied tension. | Carlos E, Sam C. Kassandra R., Aubrey R. | PV | 1 | C | 5/30/2016 | 12/9/2016 | -- | 1 | 0 | Even with tensions applied up to 90lbf and the cable being manually held so as to increase the needed torque, the motor did not stall and overcame all tension. |
| 5 | Cable Strength | Cable will be tested using hanging weights to tension the line. A failure load will be experimentally determined. | The line should be able to support at least 5 lbs. | Carlos E, Sam C. Kassandra R. | PV | 3 | C | 5/30/2016 | 12/9/2016 | 6lb | 3 | 0 | All cable materials used were rated at 65lbf or more. |
| 6 | Battery Photocell Lifetime and Effectiveness | A simple covering will be constructed to vary the amount of light that the solar panels are receiving. Data will be conllected to determine the time to discharge in each lighting condition and under the specified loading. | Minimum of 2 weeks operating time. | Carlos E, Sam C. Kassandra R., Aubrey R. | PV | 1 | C | 5/30/2016 | 12/9/2016 | 4hrs at least | 1 | 0 | System was tested running continuously with applied load for 4 hours on a fully charged battery. System was set in a shaded environment so as to minimize solar charging. System is expected to last much longer. Depending on daily operation time, system can be powered for longer than 2 weeks. |
| 7 | Tension Verification | Test the complete setup to estimate the amount of tension that will be applied by user. | Maximum of 80 lbf | Carlos E, Sam C. Kassandra R., Aubrey R. | PV | 3 | C | 5/30/2016 | 12/9/2016 | 65lbf | 2 | 1 | Braided fishing line failed after testing. Steel cable and steel fishing line supported highest tested tension of around 90lbf. |

# 26.0 Appendix P: Bill of Materials

| Item | Part Number | Part Description | Subsystem | Distributor | QTY | COST | TOTAL COST |
|---|---|---|---|---|---|---|---|
| 1 | S8218 | Digital 6V Metal Gear High Torque Servo Motor | Driving Pulley | SainSmart | 1 | $33.81 | $33.81 |
| 2 | 615274 | 12T 32P Hitec Brass Pinion | Driving Pulley | ServoCity | 1 | $14.99 | $14.99 |
| 3 | 615238 | 128T 32P Aluminum Gear | Driving Pulley | ServoCity | 1 | $16.99 | $16.99 |
| 4 | 535049 | .50" Bore Flanged Ball Bearing | Driving Pulley | ServoCity | 1 | $2.99 | $2.99 |
| 5 | 9946K15 | 1/2" Bore Aluminum Set Screw Collar | Driving Pulley | ServoCity | 1 | $4.50 | $4.50 |
| 6 | 545456 | .770" x .625" Hub Adaptor | Driving Pulley | ServoCity | 1 | $2.99 | $2.99 |
| 7 | 545352 | 1" Bore Clamping Hub | Driving Pulley | ServoCity | 1 | $5.99 | $5.99 |
| 8 | 545560 | 1/2" Bore 0.77" Set Screw Hub | Driving Pulley | ServoCity | 2 | $4.99 | $9.98 |
| 9 | 92323A588 | 6-32 1" Serrated Flange Head Cap Screw, (pk 50) [4] | Driving Pulley | McMaster | 1 | $5.17 | $5.17 |
| 10 | 90480A007 | 6-32 5/16" Wide 7/64" High Steel Hex Nut, (pk 100) [4] | Driving Pulley | McMaster | 1 | $1.24 | $1.24 |
| 11 | 91772A077 | 2-56 1/4" Long Stainless Steel Pan Head Phillips Machine Screw, (pk 100) [8] | Driving Pulley | McMaster | 1 | $4.49 | $4.49 |
| 12 | 91247A594 | 5/16"-18 2-3/4" Long Medium-Strength Zinc-Plated Steel Cap Screw, (10 pk) [4] | Driving Pulley | McMaster | 1 | $3.35 | $3.35 |
| 13 | 6061K13 | 1/2" Diameter 6" Long Hardened Precision Steel Shaft | Driving Pulley | McMaster | 1 | $4.75 | $4.75 |
| 14 | | SainSmart Arduino Uno | Driving Pulley | Amazon | 1 | $13.99 | $13.99 |
| 15 | | Loctite Epoxy Plastic Bonder | Driving Pulley | Amazon | 1 | $13.41 | $13.41 |
| 16 | 97345A11 | Type 316 Stainless Steel Shoulder Screw 5/32" Diam X 9/32" Lg Shldr, 6-32 Thrd | Driving Pulley | McMaster | 1 | $3.75 | $3.75 |
| 17 | | WiFi Module | Driving Pulley | Amazon | 3 | $5.99 | $17.97 |
| 18 | | Driver Module Arduino | Driving Pulley | Amazon | 1 | $5.99 | $5.99 |
| 19 | | Corner Brace 1" | Drive Pulley | Home Depot | 1 | $4.57 | $4.57 |
| 20 | | Corner Brace 1.5" | Drive Pulley | Home Depot | 1 | $3.98 | $3.98 |
| 21 | 706036 | 3/8in 100ft Diamond-Braid Poly Rope 244lbf | Pulley Line | HomeDepot | 4 | $8.98 | $35.92 |
| 22 | 91259A162 | 1.5" 6061-Aluminum Plate 6inX6in - Pulley | Pulley Line | McMaster | 1 | $52.36 | $52.36 |
| 23 | | Plasti Dip Black | Pulley Line | Amazon | 1 | $6.98 | $6.98 |
| 24 | 806380 | 3/32"Galvanized Steel Vinyl-Coated Wire Rope (13 gauge) | Pulley Line | HomeDepot | 1 | $10.00 | $10.00 |
| 25 | 91532101 | 1/8" Diameter Cable Cutter | Pulley Line | E-Rigging.com | 1 | $16.49 | $16.49 |
| 26 | 43244 | 3/32" Aluminum Ferrule (2) and Stop (2) Set | Pulley Line | HomeDepot | 2 | $1.37 | $2.74 |
| 27 | | Fishing Steel Wire (135 lbf test, 30ft) | Pulley Line | Amazon | 1 | $9.89 | $9.89 |
| 28 | | Fishing Wire Crimper and Cutter | Pulley Line | Amazon | 1 | $10.78 | $10.78 |
| 29 | | Barrel Crimp Sleeves | Pulley Line | Amazon | 1 | $10.05 | $10.05 |
| 30 | | Swaging Tool | Pulley Line | Amazon | 1 | $29.95 | $29.95 |
| 31 | | Strap Lash, 200 lbs | Pulley Line | ACE | 1 | $6.99 | $6.99 |
| 32 | | Ferrule & Stops 1/8" | Pulley Line | Home Depot | 2 | $1.48 | $2.96 |
| 33 | | Ferrule & Stops 3/32" | Pulley Line | Home Depot | 2 | $1.37 | $2.74 |
| 34 | | Cable Tie 10pk | Pulley Line | Home Depot | 1 | $2.27 | $2.27 |
| 35 | | MSP430 | PhotoBot | Amazon | 1 | $19.77 | $19.77 |
| 36 | | Sony Xperia Z1 C6903 (Honami) 16GB 20MP | PhotoBot | Amazon | 1 | $203.00 | $203.00 |
| 37 | | Android IOIO | PhotoBot | Amazon | 1 | $29.95 | $29.95 |
| 38 | | DoSHIn 20,000mah Solar Phone Charger | PhotoBot | Amazon | 3 | $18.99 | $56.97 |

| Item | Part Number | Part Description | Subsystem | Distributor | QTY | COST | TOTAL COST |
|---|---|---|---|---|---|---|---|
| 39 | 92147A420 | Split Lock Washer (pk 100) | PhotoBot | McMaster | 1 | $2.67 | $2.67 |
| 40 | 92320A032 | Unthreaded spacer | PhotoBot | McMaster | 1 | $1.29 | $1.29 |
| 41 | 91259A161 | Shoulder screw | PhotoBot | McMaster | 2 | $1.96 | $3.92 |
| 42 | 91259A162 | Shoulder screw | PhotoBot | McMaster | 5 | $1.99 | $9.95 |
| 43 | 92239A102 | Flange Wing nut (pk 10) | PhotoBot | McMaster | 1 | $5.72 | $5.72 |
| 44 | 91735A146 | 6-32 3/8" Pan Head Phillips Machine Screw (pk 50) | PhotoBot | McMaster | 1 | $5.37 | $5.37 |
| 45 | 91735A147 | 6-32 7/16" Pan Head Phillips Machine Screw (pk 50) | PhotoBot | McMaster | 1 | $6.72 | $6.72 |
| 46 | 900-00005 | Parallax Cont Rotation Servo | PhotoBot | Amazon | 1 | $13.99 | $13.99 |
| 47 | 88895K98 | Easy-to-Weld Corrosion-Resistant 5052 Aluminum, Sheet, 0.100" Thick, 4" x 24" | PhotoBot | McMaster | 1 | $11.89 | $11.89 |
| 48 | 88895K22 | Easy-to-Weld Corrosion-Resistant 5052 Aluminum, Sheet, 0.032" Thick, 6" x 24" | PhotoBot | McMaster | 1 | $5.49 | $5.49 |
| 49 | | Phone Armband | PhotoBot | Amazon | 1 | $5.49 | $5.49 |
| 50 | | A to B USB Cable | PhotoBot | Amazon | 1 | $6.54 | $6.54 |
| 51 | B00E8MRD2Y | Spiderwire Stealth Moss Green Braid Line, 65 lb, 125 Yards | PhotoBot | Amazon | 1 | $6.95 | $6.95 |
| 52 | 545556 | Set Screw Hub, 3/8: Shaft Diameter | Idler Pulley | Servo City | 4 | $4.99 | $19.96 |
| 53 | 6061K418 | Hardened Precision Steel Shaft, 3/8" Diameter, 3" Length | Idler Pulley | McMaster | 2 | $4.29 | $8.58 |
| 54 | 6157K13 | Aluminum Clamp Collars | Idler Pulley | Servo City | 4 | $4.99 | $19.96 |
| 55 | 6235K16 | Flat Belt Pulley with Ball Bearings, 5.6 " OD, Nylon, 3/8 " Bore | Idler Pulley | McMaster | 2 | $16.13 | $32.26 |
| 56 | 92185A149 | SST Socket Head Cap Screws, 6-32, L=5/8" 25 Pack | Idler Pulley | McMaster | 1 | $2.98 | $2.98 |
| 57 | 92510A813 | Aluminum Spacer, 3/4" OD, L=2" for 5/16" Screw | Idler Pulley | McMaster | 2 | $5.21 | $10.42 |
| 58 | 90201A121 | 1/4"-20 Steel Cap Screw, L=2.5", 10 Pack | Idler Pulley | McMaster | 1 | $5.89 | $5.89 |
| 59 | | Ball Bearing | Idler Pulley | Amazon | 1 | $11.97 | $11.97 |
| 60 | | Flexible Breadboard Jumper Wires | Driving Pulley & PhotoBot | Amazon | 1 | $6.87 | $6.87 |
| 61 | 8560K355 | Optically Clear Cast Acrylic Sheet 1/4" Thick, 12"X24" | PhotoBot,Idler & Driving Pulley | Mcmaster | 2 | $28.08 | $56.16 |
| 62 | 8560K257 | Optically Clear Cast Acrylic Sheet, 1/8" Thick, 12" x 24" | PhotoBot,Idler & Driving Pulley | McMaster | 1 | $15.76 | $15.76 |
| 63 | 8560K179 | Optically Clear Cast Acrylic Sheet, 7/32" Thick, 6" x 12" | PhotoBot,Idler & Driving Pulley | McMaster | 1 | $7.48 | $7.48 |
| 64 | | CRC Urethane Seal Coat | Misc. | Amazon | 1 | $12.12 | $12.12 |
| 65 | | Sand Paper | Misc. | Home Depot | 1 | $7.53 | $7.53 |
| 66 | | Case | Misc. | Amazon | 1 | $46.56 | $46.56 |
| 67 | | Misc Fasteners & hardware | Misc. | ACE | 1 | $5.29 | $5.29 |
| 68 | | Velcro Straps | Misc. | Home Depot | 1 | $9.27 | $9.27 |
| 69 | | Fasteners | Misc. | ACE | 3 | $0.30 | $0.90 |
| 70 | | Dualmatin/Metfield | Misc. | ACE | 1 | $9.99 | $9.99 |
| 71 | | 2X4 Wood, 96" | Test Frame | Home Depot | 7 | $2.83 | $19.81 |
| 72 | | Wood Screws | Test Frame | Home Depot | 1 | $5.98 | $5.98 |
| 73 | | Paracord 1/8"x 50' | Test Frame | Home Depot | 1 | $2.97 | $2.97 |
| 74 | | Adjustable Bungee | Test Frame | Home Depot | 1 | $3.48 | $3.48 |
| **Total Estimated Cost** | | | | | | | $1,092.89 |

## 27.0 Appendix Q: Safety Checklist

**SENIOR PROJECT CONCEPT DESIGN HAZARD IDENTIFICATION CHECKLIST**

Team: Cal Poly PhotoBot Advisor: Rossman

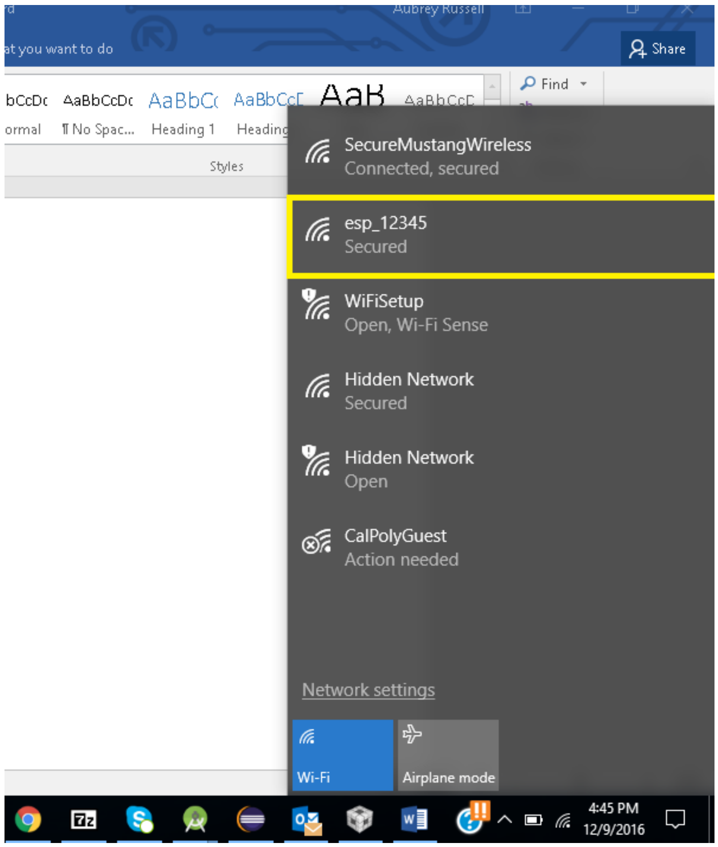
| Y | N | |
|---|---|---|
| ☐ | ☒ | Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points? |
| ☒ | ☐ | Can any part of the design undergo high accelerations/decelerations? |
| ☐ | ☒ | Will the system have any large moving masses or large forces? |
| ☐ | ☒ | Will the system produce a projectile? |
| ☒ | ☐ | Would it be possible for the system to fall under gravity creating injury? |
| ☒ | ☐ | Will a user be exposed to overhanging weights as part of the design? |
| ☐ | ☒ | Will the system have any sharp edges? |
| ☐ | ☒ | Will any part of the electrical systems not be grounded? |
| ☐ | ☒ | Will there be any large batteries or electrical voltage in the system above 40 V either AC or DC? |
| ☒ | ☐ | Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids? |
| ☐ | ☒ | Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system? |
| ☐ | ☒ | Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design? |
| ☐ | ☒ | Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design? |
| ☐ | ☒ | Can the system generate high levels of noise? |
| ☒ | ☐ | Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc? |
| ☐ | ☒ | Is it possible for the system to be used in an unsafe manner? |
| ☐ | ☒ | Will there be any other potential hazards not listed above? If yes, please explain on reverse. |

For any "Y" responses, add a complete description, list of corrective actions to be taken, and dates to be completed on the reverse side.

## 28.0 Appendix R: Operator's Manual

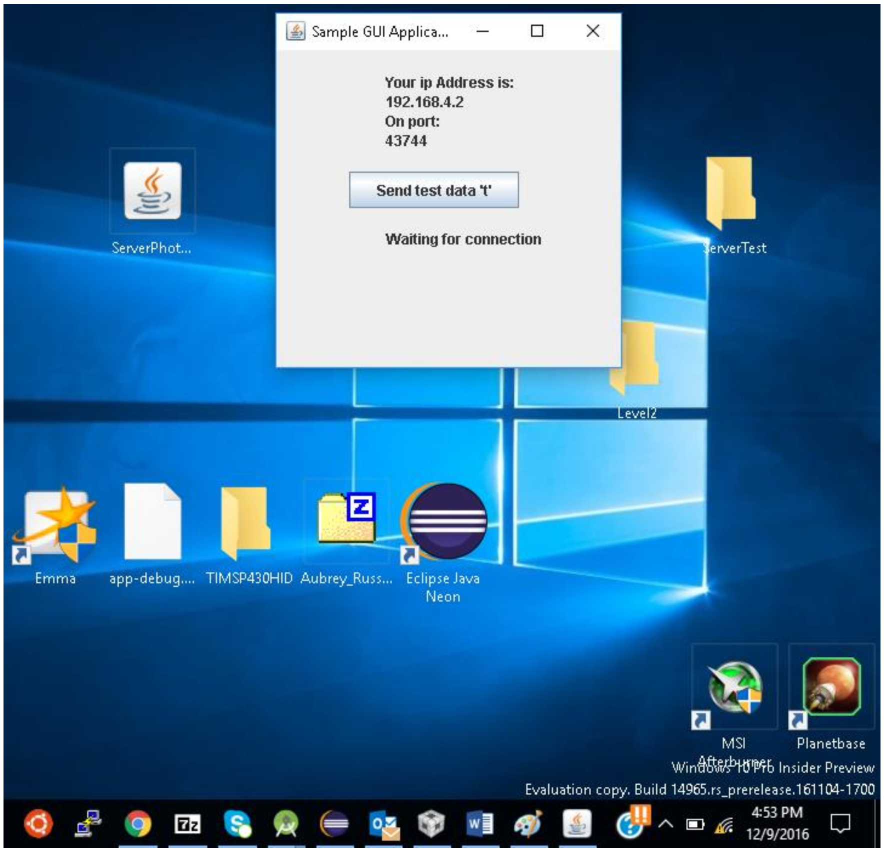
*Steps for using the PhotoBot App:*

1. Connect the USB cable from the black box on the PhotoBot to the green and black battery with the solar panel.
2. Connect the Android phone with a USB cable to the Wifi. DO NOT PUT THE PHONE IN THE CASE YET!
3. Connect to the esp_12345 Wifi network from your laptop. It might take a second to show up. Its looks like this:



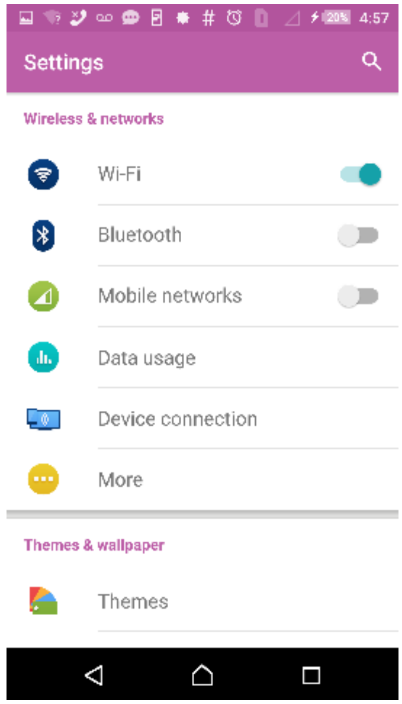

4. Enter msp430g2553 as the password. The computer might complain about the fact that there is no Internet—ignore it and continue to Step 5.

5. Launch the PC application to control the Bot (it's called ServerPhotoBot):

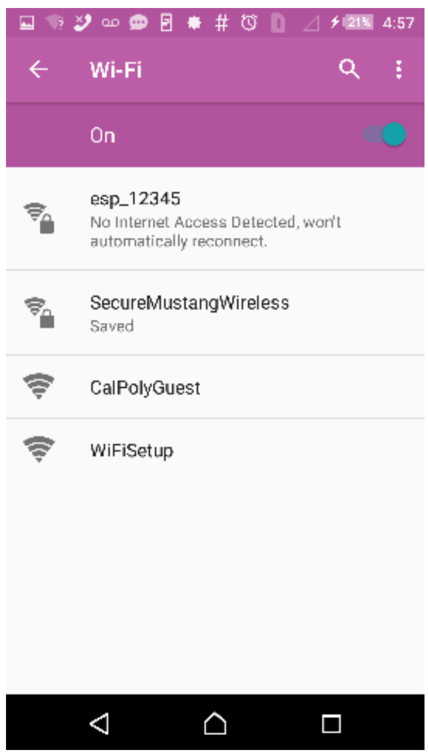



6. Now, press the small circular button on the Android phone to power it on.
7. On the main screen in the middle of the screen, click on the settings button. The picture below shows the settings app, the PhotoBot app, and ES file explorer app – all of which are needed for the device to work as expected. The ES file explorer app is used to get the pictures over Wifi.

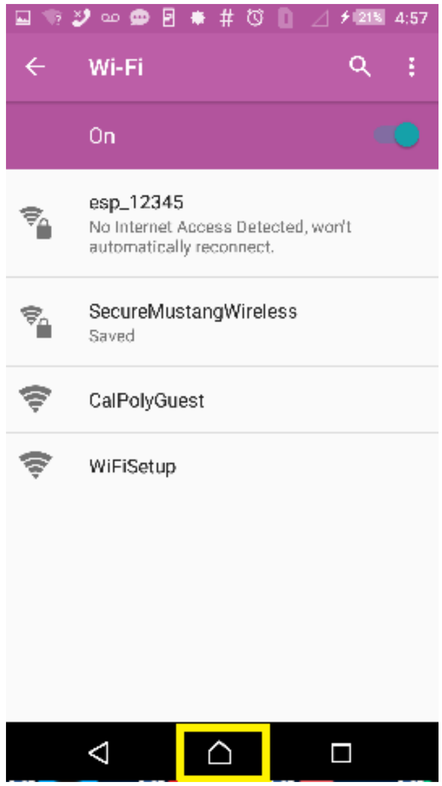

8. Click on Wifi which is at the top of the menu.



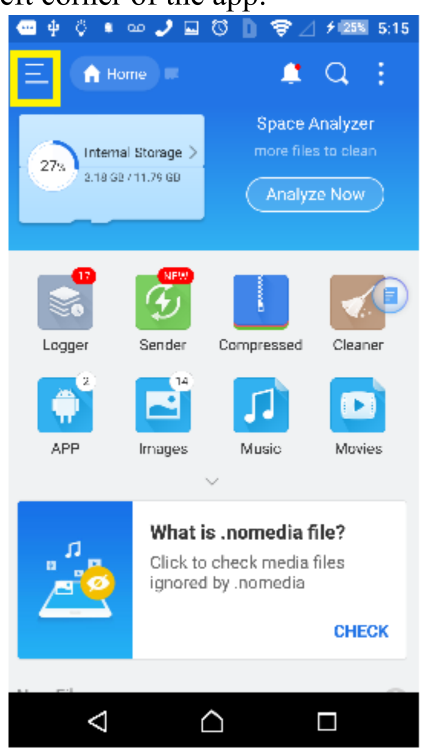

9. Then click on the esp_12345 network and connect



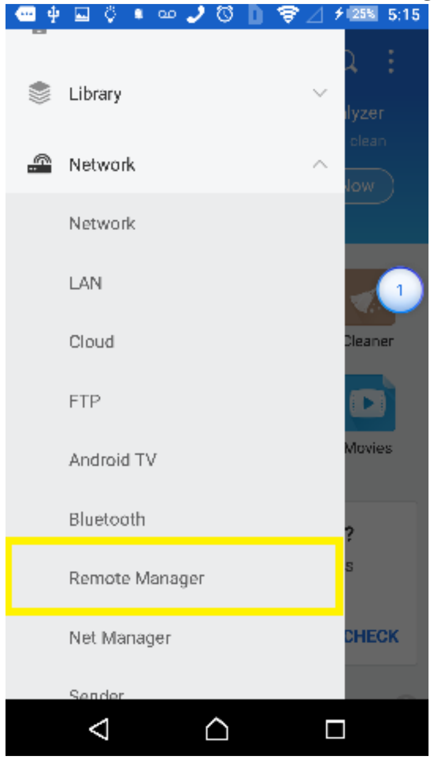
10. Once you're connected, press the center button at the bottom of the screen to go back to the main screen as shown below.



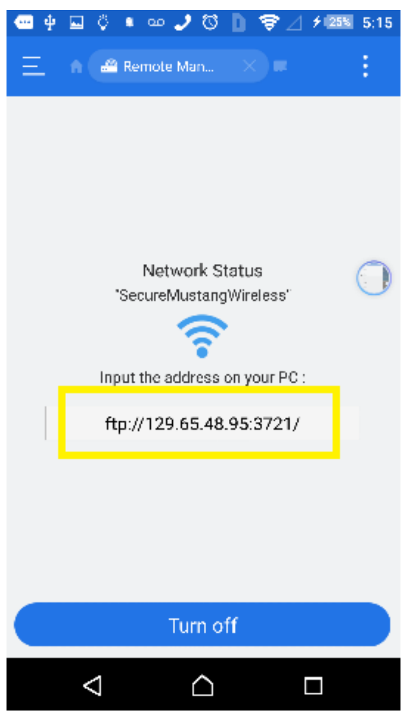

11. With Wifi setup, you need to setup remote picture downloads. Go into the ES file explorer app.
12. Click on the button at the top left corner of the app.



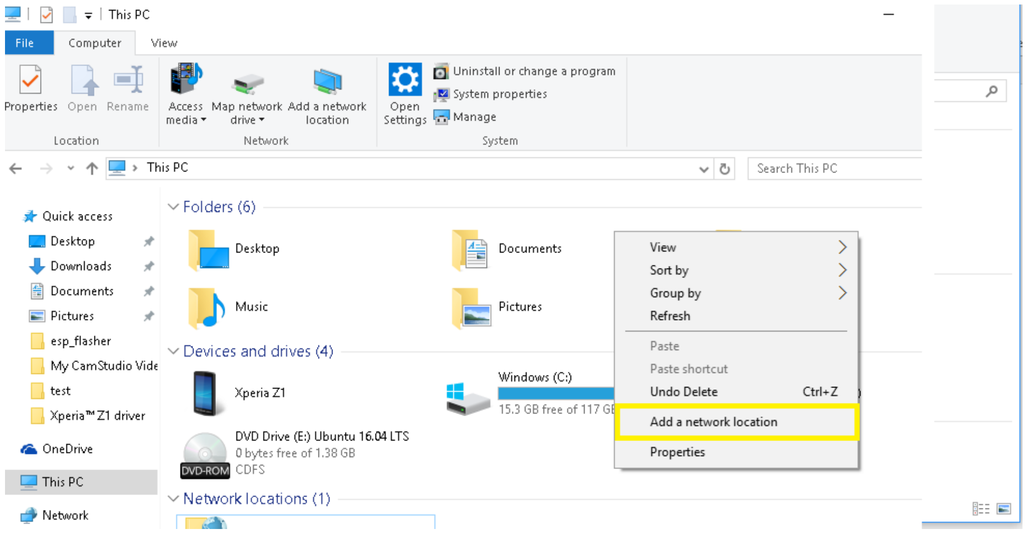
13. The left menu should open, then scroll down to "Remote Manager"

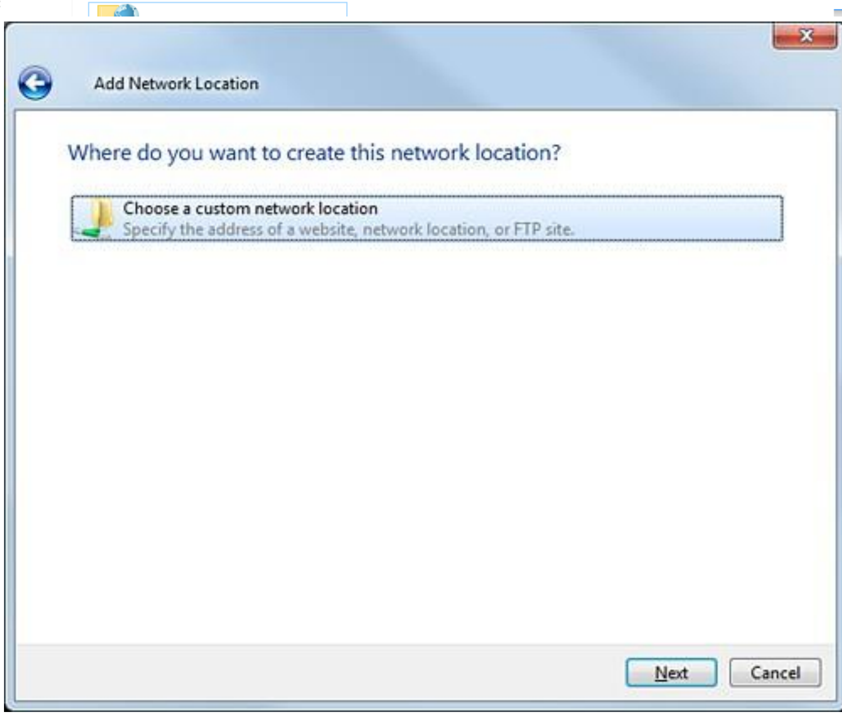



14. There should be an ftp address—you will need this to remotely connect on your laptop. Remember, the address in the picture below is not the address you should use. Make sure to get the address from the phone.

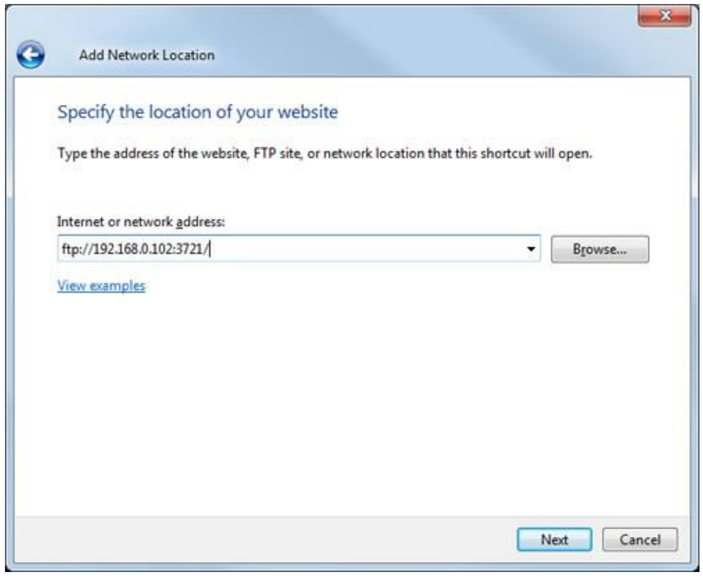


15. Go back to the pc. Go to My Computer. Right click in “My Computer,” which is sometimes referred to as This PC or some other variation. Then click right click the white area of the My Computer screen and select add network location.

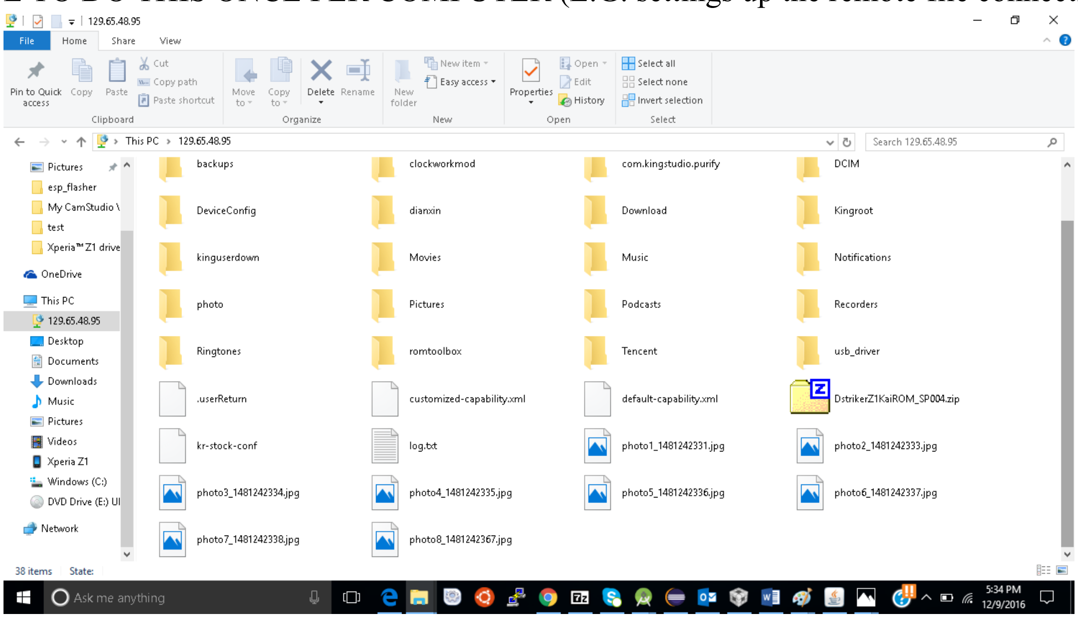



16. A screen will pop up. Copy the network address provided from the phone app exactly as demonstrated below.

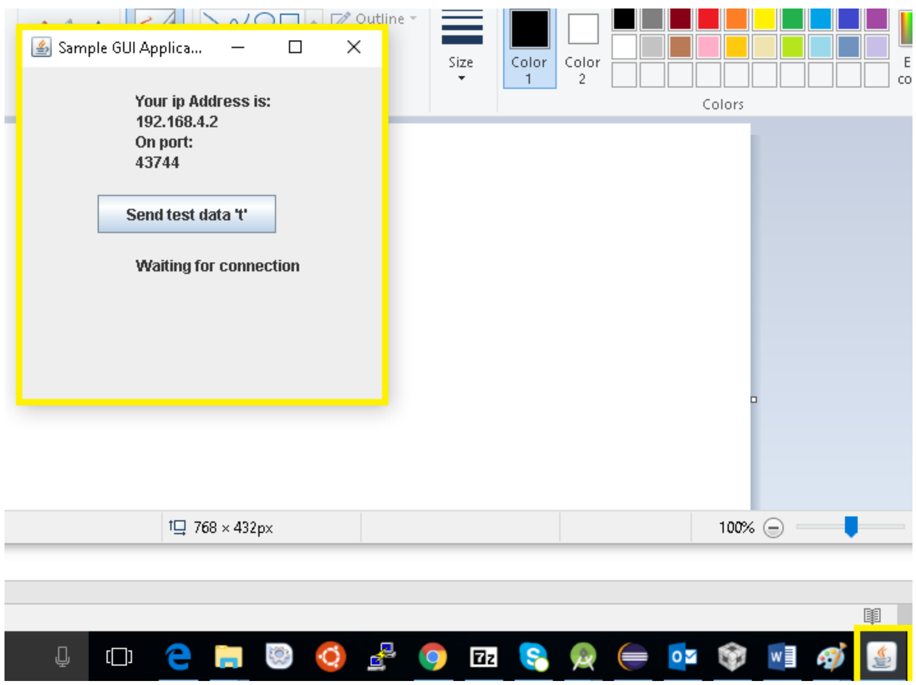



17. A window will now pop up and this contains the location of the pictures. For example, you should see something like the picture below. It's important to note THAT YOU ONLY HAVE TO DO THIS ONCE PER COMPUTER (E.G. settings up the remote file connection).




18. Now go back to the main menu of the Android, click the PhotoBot app, and then click "connect" on the app screen.


19. Now that you're connected you'll be able to control the PhotoBot. Make sure to go to the pc, click the ServerTest application that looks like a cup of coffee and click on the window shown below.




20. Now you can use the keyboard to control the PhotoBot as follows:

**t** => Rotate camera up
**g** => Rotate camera down
**r** => Reset camera to the default position

**a** => Add current camera position to the set of total positions where pictures are taken (This will be looped through and pictures will be taken at these locations).
**P** => Take a photo.
**x** => Disconnect PC from the network and start automatic picture taking (*WARNING*—This will put the PhotoBot in automatic mode and low power mode and the PhotoBot app will need to be reset in order to connect again. Click the "exit app" button from the PhotoBot app and relaunch it to reset it.

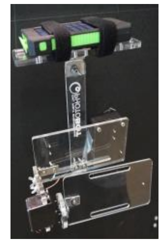
21. Now put the phone in the case and the PhotoBot will be ready.

*Steps for installing the system:*

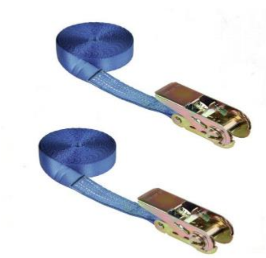
## Required Equipment

*Driving Pulley**

*(2) Idler Pulleys*



*PhotoBot**



*(2) 6 ft Ratchets**

*Rope**


*1X7 Stainless Steel Wire**

*AFW Crimp & Cutting Pliers*


*(1) AFW Sleeve #S5 or #7*


*SpiderWire**


*Waterproofing Tape*

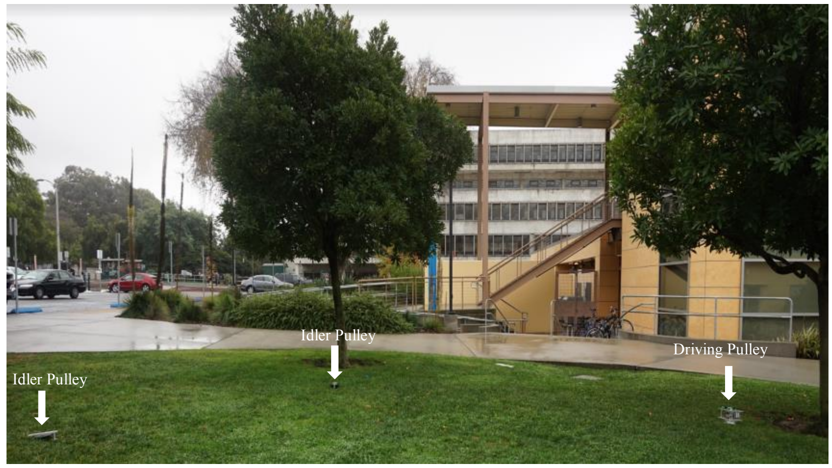
*Hammer (not included)*

*Ground Stakes (not included)*

*Note
- Make sure a solar battery is attached to the driving pulley.
- Make sure a solar battery and the Xperia Z1 phone is attached to the PhotoBot.
- May have to purchase longer ratchets depending on how high you want to mount the entire system.
- Assure that you have enough rope to raise up all three driving pulleys, may have to purchase more than what is given.
- Assure that you have enough stainless steel wire so that it may wrap around all three pulleys, may have to purchase more than what is given.
- Assure that you have enough SpiderWire so that you are able to tie the PhotoBot to the steel wire.

## <u>Step 1-*Sizing the System*</u>

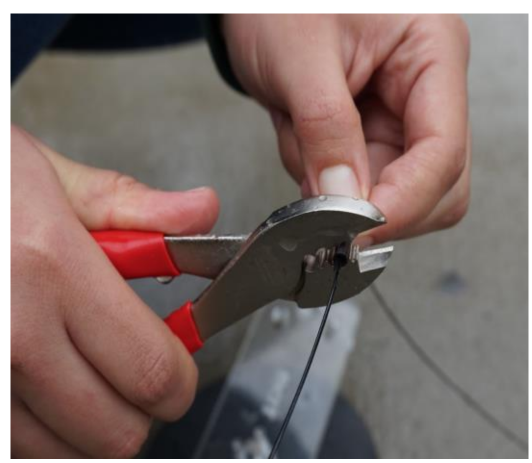
- Lay out pulleys on the ground to the desired shape and size.
- Make sure there is a nearby tree with branches for each pulley.




## <u>Step 2-*Setting the Steel Cable Wire*</u>

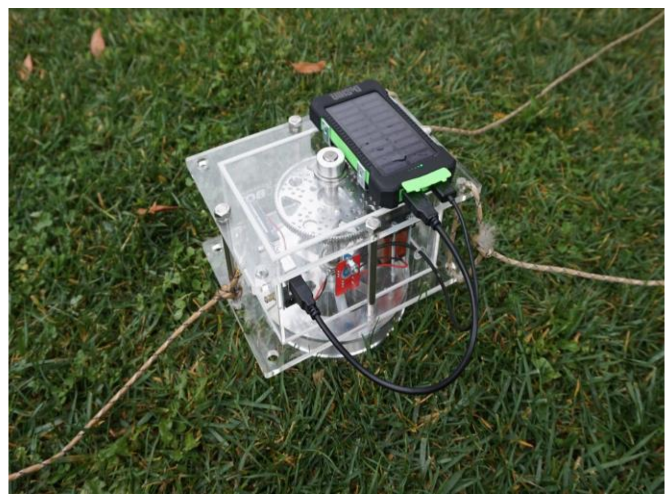
- Wrap the 1X7 stainless steel wire around the pulleys and cut to size using the AFW crimp and cutting wires.

- Feed both ends of the stainless steel wire in a AFW sleeve and crimp using the AFW crimp and cutting wires



## **Step 3-*Setting the Driving Pulley***

- Cut two pieces of rope that are about twice the length of the height at which the entire system will be raised at.
- Feed each rope through the holes located on the plates of the driving pulley and tie off as shown in the picture.



- Cut a piece of rope that is about the length of the height at which the entire system will be raised at.
- Tie off the rope to the housing of the driving pulley.

- With the driving pulley still being on the ground, throw the ends of the two ropes that are in parallel with another over the branches of a tree.

## **Step 4-*Setting the Idler Pulleys***

- Throw a ratchet over a tree branch.
- Cut a piece of rope (length varies depending on the size of your desired perimeter of the cable) and feed through the holes located on the top plate of the idler pulley.
- Tie the ends of the rope to the closed loop located at the end of the ratchet.

* Repeat Step 4 for each idler pulley.
* If desired, you can tie a rope at the front ends of the idler pulleys like you did for the driving pulley. This rope will allow you to correct the position of the pulley and its angle of tilt from the ground.

## **<u>Step 5-*Installing the PhotoBot*</u>**

- Cut two pieces of SpiderWire to about 5 inches.
- Feed each piece through the small holes located on the ends of the top plate of the PhotoBot

- Tie the ends around the steel cable wire.
- Use pieces of waterproofing tape to secure the SpiderWire to the steel cable wire.

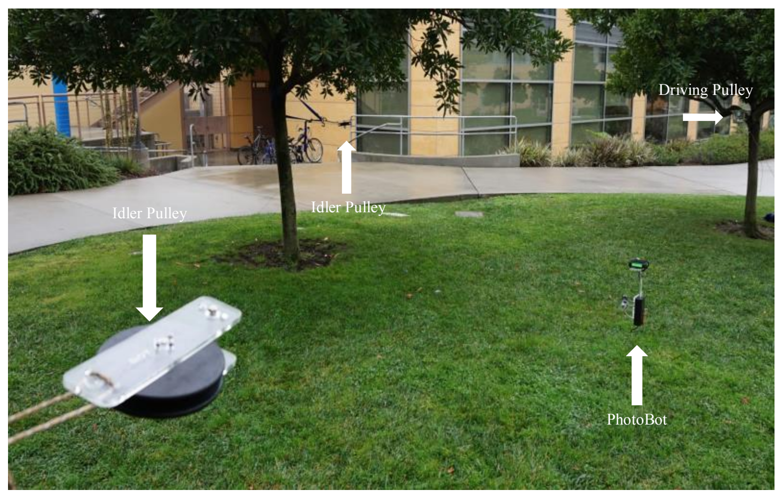
## **<u>Step 6-*Raising the system*</u>**

- Before raising the system, make sure that the steel cable wire is still wrapped around the pulleys.
- Press the power button on the battery pack. Note this will initialize the system, the motor will start running after 20 minutes.
- Slowly begin to raise the driving pulley by using the two ropes

● Pull the straps of the ratchets to raise the idler pulleys.

Raise the pulleys slowly in order to prevent the cable wire from slipping off. We suggest to alternate raising the pulleys, perhaps a few feet at a time.

● Once the pulleys are raised to the desired height, the ropes used to pull up the driving pulley can be wrapped around and tied to the tree, or even staked to the ground.



- If needed, use the rope that is tied to the pulleys to correct its position and angle of tilt.

Congratulations!
You've successfully installed the PhotoBot system.