ENGR-11 Solar Energy Generator

Final Report

Simon Criswell
Kyle O'Reilly
Elizabeth Wade

2022-2023

Oregon State University

Project Sponsor: Dave Wills
Instructor: Mark McGuire

Oregon State University
College of Engineering

DISCLAIMER

ABSTRACT

The solar electricity generator project was proposed by Dave Wills, who owns a satellite dish that has been turned into a parabolic solar furnace. This means the dish has been outfitted with reflective material so that it reflects solar energy to a specific point. At the focal point, Wills mounts a keg for brewing beer or boiling water. For this project, Wills has asked an OSU capstone team to implement a sun tracking system that will orient the dish towards the sun throughout the day and optimize its solar intake. There will be pan axis motion, moving the dish to the left and right, and tilt axis motion, moving the dish up and down. As a hand down from a prior capstone team, the design of a partial pan axis movement system was already in progress.

The system consists of two motors. There is one pan axis motor which drives a chain to turn the dish along the horizon and one linear actuator which can tilt the dish vertically from the horizon. The system must know its position for it to be moved and oriented toward the sun. In order for the system to know its position in the pan rotation direction, an encoder is used with the pan motor. In order for the system to know which angle it is pointed at in the tilt axis, an accelerometer is used. Additionally, a limit switch is used in order to home the pan axis and give it a starting position for the encoder to measure from. This movement is controlled by an Arduino Nano computer chip which uses date, time, and location data to calculate the angles necessary to determine where the sun is located throughout the day. The time and date information is collected from a GPS computer chip. The Arduino Nano then instructs the motors that control the pan and axis movement to orient the dish to those angles using a motor controller circuit chip.

The team has successfully implemented this design.

ACKNOWLEDGEMENTS

The team would like to thank a few individuals who have helped make this project successful. Dave Wills was the project sponsor and lead. He proposed an extremely interesting project that tested the abilities of the team and helped each person on the team to grow as engineers. Wills always made sure that the team had everything it needed when out on site and took time to teach each member new skills which the team is very grateful to have learned.

Raven is a mechanical engineer who designed the dish and completed its initial construction. Raven's help was crucial to our system implementation by helping with welding and system setup. He also offered valuable guidance throughout the project on design limitations and options for moving forward whenever the team hit roadblocks.

Mark McGuire and Chris Holms were the instructors for this capstone project. The team received a lot of helpful feedback and guidance throughout the design and implementation phases of the project. The team appreciates their immeasurable contributions to the success of the capstone project.

Also, the team would like to thank all the dogs that made appearances while the team was working on the farm.

TABLE OF CONTENTS

1 BACKGROUND

1.1 Introduction

Dave Wills, the client, is the owner of Freshops which is a hops distribution company located west of Corvallis. He also brews beer with these hops, and he uses a parabolic solar furnace to reflect sunlight in order to boil the water for this beer. In order to optimize this water boiling process, Dave Wills has requested the creation of a solar tracking mechanism to be implemented onto his parabolic solar dish. Wills intends to use this dish to brew beer, cook food, and in the future he seeks to implement solar electricity generation from the dish. The dish can be seen in Figure 1.

Figure 1: Images of the current satellite dish with system and counterweight

The goal of the project is to automate the movement of the solar furnace so that it is able to point at the sun throughout the day. This objective includes: moving the dish in the pan axis, moving the dish in the tilt axis, tracking the position of these axes, and knowing the position of the sun.

This system will benefit Wills in that it will lower his electricity costs. Wills is a business owner and seeks to lower operating costs wherever possible. Using the solar dish to boil water will reduce overall energy costs. Additionally, Wills seeks to use this solar furnace for more than just heating water. In the future he intends for the system to generate electricity. In order for the system to maximize its energy output it must be pointed at the sun throughout the entire day, which is why the work of the 2022-2023 capstone team is of importance to Wills.

Further, the impact of this project extends beyond just the hop farm. This solar tracking project is an exercise in sustainable energy production. As the world shifts more towards renewable energy sources, there will be the need for the installation and design of solar energy systems. This project, while on a very small scale comparatively, served as an introduction to renewable energy for the three team members. This project has exposed three engineers to renewable energy projects prior to their graduation and in turn can pave the way for renewable energy careers in the future.

1.2 Project Scope

For the scope of this project the team will focus on turning the solar furnace to face the sun. This means actuating the device in the pan and tilt axis. The pan axis is the dish rotating horizontally along the horizon, and the tilt axis is the dish moving up and down vertically along the horizon.

Tasks pertaining to the motors included in this project scope are: pan axis motor mounting, pan axis motor control, tilt axis motor mounting, tilt axis motor control, and having a feedback system capable of identifying the current position of each motor.

Tasks pertaining to the general electronics and control system include: making the system solar powered, making the system easy to control, and ensuring that the system can be controlled to easily load and unload a keg of water from the dish.

Things not included in the project scope include: generating electricity from steam produced, repairing or replacing the current dish mounting system, and maintaining the area around the dish.

This scope was determined through discussions with the client and was agreed upon when finalizing the project House of Quality. This table can be found in Appendix B. Through these discussions, the project scope was refined into customer requirements and engineering specifications.

In summary, the scope of this project is to design and implement an electromechanical system capable of turning a parabolic solar dish so that it faces the sun over the course of the day. This system is to maximize the energy harnessed by the solar dish. The end use of the system will be to bring water to a boil for the purpose of brewing. The scope of this project is only to implement a solar tracking system by articulating the pan and tilt axis of the solar dish. The project scope does not include electricity generation from the dish beyond supplementing operation of solar tracking articulation.

2 DESIGN PROCESS

The design process began with an assessment of the project passed down from the previous capstone team that worked on the pan movement of the dish. The materials passed down were a battery, DC motor, motor controller, encoder, GPS chip, and adafruit microcontroller. The project scope was identified through discussions with the client, the team then brainstormed ideas for concept variants and then narrowed down those ideas until a design was agreed upon.

2.1 Background and Prior Work

A previous Oregon State capstone team began work on the pan axis movement but was unable to see the project through to completion due to time constraints. This team's work consisted of a motor case and gearbox which could be mounted to the satellite in order to turn the dish along the pan axis.

This year's capstone team conducted research into existing solar tracking sensors as well as satellite actuation systems. The team conducted research into the different methods used to track the sun. The two main methods discovered through the research were the use of solar tracking sensors, or the use of astronomical calculations to determine the location of the sun[1]. Solar sensors are available in high-quality, purpose built devices, or as much cheaper and less robust photoresistors. The solar tracking equations can be very accurate, but require the time of day as well as the date in order to return a result.

In order to articulate the tilt axis movement, the team found solutions that included the use of linear actuators as well as direct drive gear systems [2]. A linear actuator is a mechanical device which can use an electric motor to extend and contract. They can lift weights ranging from hundreds to thousands of pounds. These systems are easy to control using general motor controllers [3]. Using this research, the team moved forward with generating possible solutions.

2.2 Concept Variants

The team decided to use the work from the previous capstone group in order to automate the pan axis movement for the satellite. In order to automate the tilt axis movement, the team had to brainstorm, develop concept variants, and then select a concept.

In order to brainstorm the team discussed multiple methods to articulate the tilt axis of the satellite dish. As a result of this, three separate ideas were considered as being viable. These solutions were the use of a pulley system to articulate the dish, the use of a linear actuator to tilt the dish, or the use of a highly geared motor to directly drive the dish at its point of tilting.

The pulley system would use a motor driving a winch in order to pull at the outer edge of the dish and tilt the system. This system would allow the use of the longest possible lever arm on the dish, which would result in a large mechanical advantage. However, this system would also be complex to make, manufacturer, and install.

The linear actuator system would use a pre-built industrial linear actuator in order to tilt the dish. This system would provide precise control over the tilt axis and be relatively simple to mount. The downside to this approach is the potential cost as well as high current draw from the system.

A direct drive gear system would involve fixing a gear to the portion of the satellite dish which tilts and driving that gear with a powerful motor connected to the shaft which does not tilt. This system would allow precise control of the tilt axis. However, this system would require complex set-up and have very low mechanical advantage.

In addition to mechanical methods to articulate the tilt axis, the team brainstormed different options for controlling the system. In order to track the sun three options were considered. These options included the use of light sensors, the use of tracking the sun based on known astronomical positions, and the use of a hybrid system involving both timing and sensing.

3 DESIGN PROPOSAL – First Term

The team's design solution will consist of the pan axis movement system, the tilt axis movement system, and the control system. The pan axis system will consist primarily of the work handed down from a prior capstone group, the tilt axis will use a linear actuator, and the control system will use an Arduino Nano working in conjunction with multiple sensors.

3.1 Pan Axis Design

The pan axis movement system will use the motor and mounting system passed down from the previous capstone team in order to move the satellite. This system will home by using the motor to turn the dish until it collides with a fixed in place obstacle. The current sensor in the system will detect a spike in the current and the control system will then have the known position of the dish. Once the dish position is known the control system will track further movement of the dish using the rotary encoder on the pan axis motor.

This design was improved upon over the duration of the project. The motor was to be mounted on a steel plate passed down from the prior capstone team. However, upon testing, this plate flexed and required strengthening. In order to improve this design, the capstone team considered welding steel support bars onto the plate. In order to verify that this would be sufficient to reduce the deflection of the plate, a simulation was conducted. Two CAD models of the motor plate were put through a static simulation in Solidworks. One plate had no support beams while the other had added angled supports. These plates were then loaded as they would be in the pan axis system – with a force of 200 lb on the end of the motor shaft. The deflection results of this study can be seen in Figure 2. This study showed that the addition of support beams would be enough to drastically reduce the deflection of the piece. The team implemented this design change and the result can be seen in Figure 3.

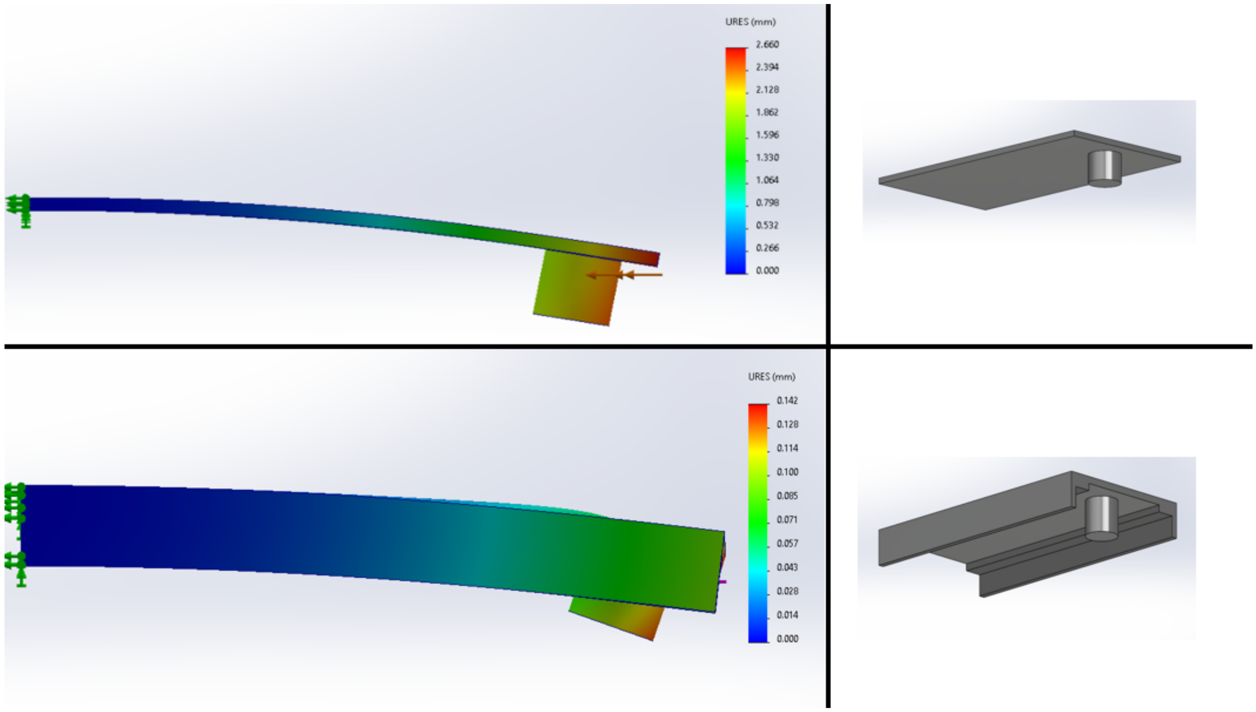
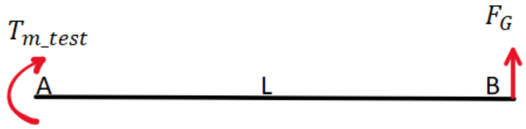


Figure 2: Deflection simulation with no supports (Top) and added supports (bottom)

Figure 3: Angled steel bar welded onto motor plate

It was also determined that the strength of the motor system provided by the prior capstone group was insufficient. A torque test was performed on the output shaft of the motor. This was done by fixing a lever arm to the output shaft and measuring the force with a spring gauge. This gave the team the output torque of the motor. A site measurement of the force required to pan the dish was also performed. This was done by using a spring gauge on the outside rim of the dish. This gave the team the required motor output. These calculations can be seen in Figure 4.

Motor Torque Test:

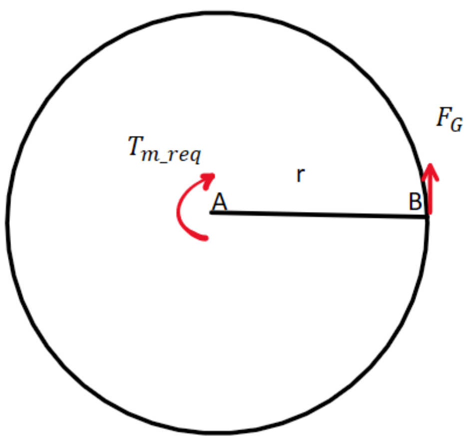


L = length of testing arm =20in.
F_G = Force measured on gauge = 25lb
T_{m_test} = motor torque obtained through testing.

Using the Sum of Moments about A:

$$\Sigma M_A = F_G * L + T_M$$
$$\Sigma M_A = 25\text{lb} * 20in + T_M$$
$$T_{m\_test} = 500\text{lb} * in$$

Motor Torque Required from Site Test:



r= Dish Track Radius= 41in.
F_G= Force measured on gauge = 25lb
T_{m_req}=Motor Torque required to move dish
Using the Sum of Moments about A:

$$\Sigma M_A = F_G * L + T_{m\_req}$$
$$\Sigma M_A = 25\text{lb} * 41\text{in} + T_{m\_req}$$
$$T_{m\_req} = 1025\text{lb} * in$$

Figure 4: Motor Torque output calculations (Top) and force required to turn dish (Bottom)

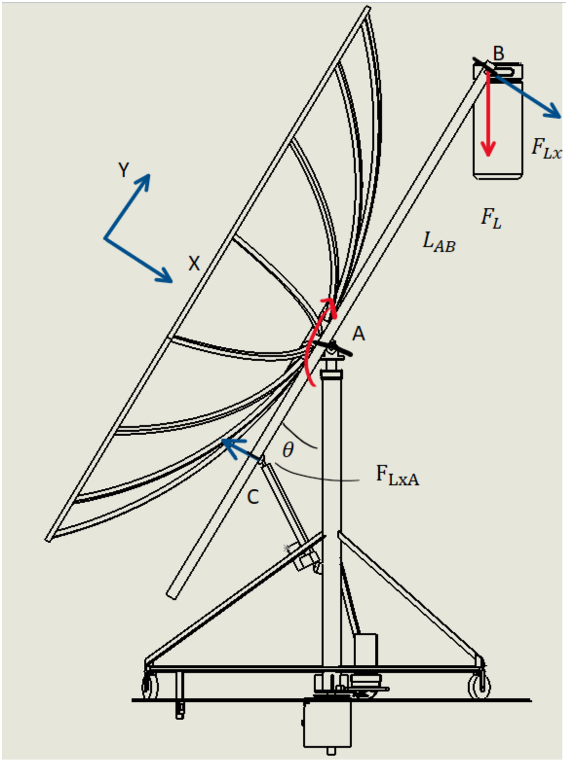
The system provided by the prior capstone group included a 2:1 gear ratio between the motor output and the dish itself through a chain and sprocket system. However, from the calculations it was found that the motor would not be able to provide enough torque to turn the dish even once its output was doubled.

In order to address this issue, the design of the pan motor system was changed to replace the provided motor output shaft sprocket with a sprocket of smaller diameter. The provided sprocket had 17 teeth, and was replaced with an 8 tooth sprocket. This doubles the gear ratio, which in turn doubles the output force of the motor. These sprockets can be seen in Figure 5. With these changes made, the pan axis system design was ready for final implementation.

Figure 5: Old 17 tooth sprocket (left) and new 8 tooth sprocket (right)

3.2 Tilt Axis Design

The design includes a linear actuator to move the system in the tilt direction. In order to size this actuator, the team performed a static analysis based upon the measurements taken to move the dish. The team went on site and applied a vertical load at the end of the dish frame until the dish began to tilt. This allowed the team to calculate a specific torque required to tilt the dish. It was determined that the linear actuator would need to apply a force of 220 lb. These calculations can be seen in Figure 6. In order to ensure a large factor of safety, the team opted to use a linear actuator capable of moving 660 lb.



Calculating the torque to turn the dish:

$F_L = Force\ of\ Load = 180lb$

F_{Lx} = X component of load force = $F_L * \sin(\theta) = 93.3lb$

$L_{AB} = 59in.$

θ = Angle of dish

T_D=Torque required to tilt dish

Using the Sum of Moments about A:

$\Sigma M_A = F_{LX} * L_{AB} + T_D$

$\Sigma M_A = 93.3\text{lb} * 59in + T_D$

T_D =5504.7lb$*\ in$

Calculating the force for the linear actuator:

F_{LxA} = X component of actuator Force

$L_{AC} = 25in.$

$*F_L$ is not considered in actuator force calculation

Using the Sum of Moments about A:

$\Sigma M_A = F_{LXA} * L_{AC} + T_D$

$\Sigma M_A = F_{LXA} * 25\text{in} + 5504.7\text{lb} *\ in$

$F_{LXA} = 220.2lb$

Figure 6: Calculating the force required to tilt the dish and the force required for actuator

One end of the actuator will be mounted to the main post supporting the dish, and the other end will be connected to the frame under the dish. This can be seen in Figure 7. This positioning allows for the best possible leverage while still maximizing the tilt range of the dish. This point is 25 in. from the center of the dish frame. The chosen actuator has built-in limit switches for its maximum and minimum positions. This means that homing the tilt axis will make use of the linear actuator limit switch. In order to track the position of the tilt axis as it articulates, an accelerometer will be fixed to the dish. The accelerometer will be able to measure the angle of the sensor as it moves. Therefore the control system will be able to measure the angle when the system is homed, and then compare that angle to the measurements of the sensor as the dish is articulated in the tilt direction.

The team initially decided to machine and then weld a steel bar across part of the satellite dish in order for one end of the linear actuator to connect. In order to reduce cost, after a discussion with the client, a piece of scrap steel was used instead. This can be seen in Figure 7.

Figure 7: Linear actuator scrap steel beam

3.3 Control System Design

The control system will be an Arduino Nano. The team planned for this Arduino Nano to be connected to the pan axis motor controller, the tilt axis motor controller, the encoder, the current sensor, and the accelerometer. Once implemented these components would allow the system to automatically home itself and then follow the sun throughout the day based upon solar timing. Additionally, throughout the day the solar sensors will allow the dish to adjust its angle in order to optimize its collection of solar energy. The wiring diagram for this initial design can be found in Appendix C.

The current sensor was initially implemented into the design in order to act as a limit switch for the system to home itself. However, through testing it was determined that the resolution of the current sensor was insufficient for this purpose. A design update to the system replaced the current sensor with a homing limit switch.

An addition to the design was a solar charging module chip. The initial design would require unplugging the battery from the system and connecting it to a solar panel in order to trickle charge the system. However, with the addition of a solar charging module this process is automated. This chip connects to the battery, the solar panel, and the control system and regulates the battery charging and also regulates the draw of the control system to prevent overdraw. This solar module can be seen in Figure 8.

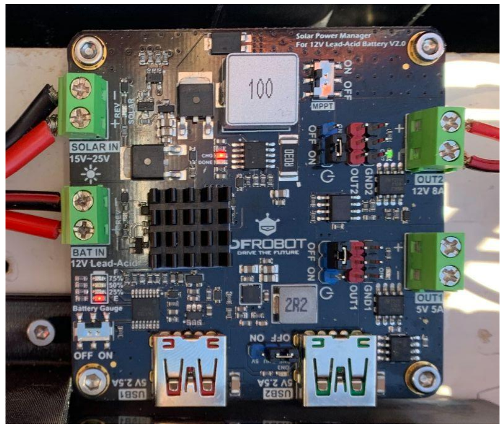


Figure 8: Solar Charging Module

The design was also changed from using a motor controller for each motor to using only one motor controller, capable of controlling two DC motors at once. This simplifies the overall electronics and reduces the number of wire connections. The wiring diagram with these changes can be seen in Appendix D.

4 Design Solution - Elizabeth

This section will give an overview of the team's solution for the solar tracking system and then focus on each of the customer requirements and how the resulting system meets these requirements.

4.1 Description of Solution

The team's system consists of pan movement and tilt movement functionality. It utilizes an Arduino Nano microcontroller chip as the controls for taking in sensor data and instructing the motors when and where to move. The movement of the motors orients the dish toward the sun throughout the day. This system can be broken up into four main parts: pan movement system, tilt movement system, controls system, and user interface.

4.1.1 Pan Movement System

For the pan movement of the dish, the DC motor was selected by the previous capstone team. The current capstone team selected a new motor controller so that it could be used for both the pan and the tilt systems.The purpose of the pan movement is to orient the dish toward the azimuth angle of the sun which is the angle of the sun along the horizon. In order to determine where the dish is pointed in the pan field, the system uses an absolute encoder which is attached to the motor shaft. The encoder communicates the position of the motor at all times with the Arduino Nano. Because the gear on the motor is smaller than the gear on the dish, the gear ratio is used to determine the actual dish degrees using the encoder degree. For example, when the gear on the motor rotates a full 360°, the dish rotates only 82.12°. This means the gear ratio is 8 to 35. Thus, the arduino keeps track of a rotation count when the encoder rolls over from 360° to 0° so that it always knows how far the dish has rotated from the home location. With this information, the Arduino Nano can instruct the motor to go to any degree. In a more practical sense, the current position of the system must vary from the current position of the sun by at least 4° so that the dish is not constantly moving and wasting energy.

4.1.2 Tilt Movement System

For the tilt movement of the dish, the team chose a linear actuator, which is a motor that moves objects in a straight line. The linear actuator is rated for 660 lb which is significantly greater than the weight of the dish with the keg on it. The team also designed a counterweight to hang off the back of the dish so that the dish is more balanced and less weight rests on the linear actuator. The purpose of the tilt movement is to orient the dish toward the elevation angle of the sun which is the angle of the sun above the horizon.

In order to determine the vertical tilt of the dish, the team has decided to use an accelerometer. An accelerometer is a computer chip that is mainly used to measure acceleration and vibrations, but it can also be used to determine angles based on its orientation. For this system, the accelerometer can measure the tilt angle of the dish using gravity pulling on the chip. The accelerometer is attached to the dish in a particular orientation so that when it communicates its y-axis angle, this angle aligns with the angle of the dish. With this information, the Arduino Nano can instruct the linear actuator to go any angle between 40° and 70°.

4.1.3 Controls System

For the controls, the brain of the system is the Arduino Nano which is a microcontroller, or integrated circuit used to govern specific operations in a system. The encoder and accelerometer from the pan and tilt systems are sensors that communicate with the Arduino Nano in order to determine where the dish is in real space. Everything that the Arduino Nano knows about the orientation of the dish comes from these sensors. This is called a closed loop system because when the Arduino Nano tells the dish to move to a specific position, the sensor can then check the position and confirm that the dish is actually in that location.
The Arduino Nano now needs to know where to tell the pan and tilt motors to go to face the sun. The system includes a GPS chip that the Arduino Nano communicates with any time the system is turned on. The GPS chip tells the Arduino Nano the time and date. The Arduino Nano then converts this from Coordinated Universal Time (UTC) into the local time and date, which is Pacific Standard Time (PST) for this system. The Arduino Nano uses this time, date, and the hard coded latitude to determine the azimuth and elevation angles of the sun.

4.1.4 User Interface

For the user interface, the team decided to simplify this piece as much as possible so that it would be easy for the client to use. The user interface consists of two buttons. One button turns the system on and off. This button is wired to connect the battery to the system. Once this button has been pressed, connecting power to the Arduino Nano, it runs the initialization sequence which homes the dish to a specific location. The team welded a stop point onto the dish and originally intended to use a current sensor to determine when the hard stop had been hit. After testing this option, the team found that this was not a viable solution for determining the home position. Instead, the team added a limit switch so that when the limit switch hits the hard stop, it sends a 'high' indicator to the Arduino Nano and the system knows that it is home. From here, the Arduino Nano calculates how much farther it must move to reach the azimuth and elevation angle and instructs the pan and tilt motors to turn the dish to those angles.
The second button is for loading a new keg on the dish. When this button is pressed, the Arduino Nano instructs the dish to move to the loading position. When the button is pressed again, the dish returns to tracking the sun.

4.2 Project Results

At the beginning of this project, the team and client decided on customer requirements for the system. These specifications with target and tolerance have overall remained the same throughout the duration of the project. There have been minor adaptations considering the winter months are not optimal months for solar energy. Thus, the team has calibrated the system so that it has optimal operation during the summer months. This section will discuss these customer requirements and how the resulting system meets these specifications.

4.2.1 Engineering Specification #1: Pan Movement Specification

The pan movement specification refers to the dish pointing at the azimuth angle of the sun. The dish is expected to be within 5° of the azimuth angle to be considered successfully meeting the specification. The pan movement uses a series of equations to determine this azimuth angle and points the dish to that specific location. The team used simplified equations, derived from the complex equations used by National Oceanic and Atmospheric Administration (NOAA). The equations are shown in Figure 9. These equations determine the azimuth and elevation angles of the sun. Using these equations, the team checked the output for the azimuth and elevation angles for different times throughout the year and a hundred years in the future. The team then compared these angles with the complex equations that NOAA uses. The angles were no more than the +/- 5° tolerance that is needed for this engineering specification. Figure 10 shows that the capstone team has moved the dish so that the focal point of the dish points directly at the keg hanging in front of the dish. You can see the shadow of the two posts are centered around the center of the dish. The encoder is used to determine where the dish is pointed. In order to calibrate the dish location, it is homed during the setup. The encoder and code calculation for the encoder degree can be seen in Figure 11.

$$\alpha = \sin^{-1}\left[\sin\delta\sin\phi + \cos\delta\cos\phi\cos\gamma\right],$$

$$\beta = \begin{cases} \cos^{-1}\left[\frac{\sin\delta\cos\phi - \cos\delta\sin\phi\cos\gamma}{\cos\alpha}\right], & \text{if } \gamma < 0^\circ \\ 360^\circ - \cos^{-1}\left[\frac{\sin\delta\cos\phi - \cos\delta\sin\phi\cos\gamma}{\cos\alpha}\right], & \text{if } \gamma \geq 0^\circ \end{cases}$$

$$\delta = -23.45^\circ \times \cos\left[\frac{360}{365}(d+10)\right]$$

$$\gamma = 15^\circ \times (T - 12).$$

Figure 9: Solar equations for the azimuth and elevation angles

Figure 10: Dish Directly Pointed at the Sun


```
float oldDeg = encDegrees;
delay(10);
encDegrees = float(currentPosition)/4096.0*360.0*(8.0/35.0);
delay(10);
if (homing == 0){
  if (encDegrees < (oldDeg-50.0)){
    rotationCount++;
  }
  if (encDegrees > (oldDeg + 50.0)){
    rotationCount--;
  }
}
dishDegrees = encDegrees + (float(rotationCount)*(82.12)) - homePanOffset;
```

Figure 11: Encoder (left) and code for determining dish degree (right)

4.2.2 Engineering Specification #2:Tilt Movement Specification

The tilt movement specification requires that the dish point directly at the elevation angle of the sun. The elevation angle is the angle of the sun that is from the horizon up to its position in the sky. The tilt movement utilizes a linear actuator that can hold up to 660 lb. This measurement is well above the weights of the dish, which the team has estimated to be close to 400 lb at most. This weight was obtained using spring gauge testing, as well as by speaking with the client and the engineer who designed and manufactured the dish. The capstone team also fixed a counterweight to the back of the dish to take some of the load off of the linear actuator. Figure 12 shows the linear actuator at different spots, indicating that the linear actuator is moving the dish up and down.

Figure 12: Linear actuator positions

4.2.3 Engineering Specification #3: Weather Resistance

The client expects that all components will be weather resistant to the point that the device can withstand indefinite rainfall which corresponds to the IP04 or higher as the device will be outside and susceptible to the elements. Figure 13 shows the enclosure for the main electronics and battery in the upper right corner and the enclosure for the pan motor and encoder in the bottom left corner. The main electronics enclosure is rated for IP54 according to the spec sheet. The motor enclosure was 3D printed, coated in a sealant for any cracks, and spray painted. Figure 14 shows the enclosure for the limit switch on the left, which was 3D printed. It also shows the connectors for outer electronics like the accelerometer and encoder on the right. As shown in the image, the rating for these connections is IP68 which is well above the needed IP rating. The enclosures have survived through the rain, snow, and hail with the system working after these weather events.

Figure 13: Motor and electronics enclosure

Figure 14: Limit switch(left) and sensor connections(right)

4.2.4 Engineering Specification #4: Low Cost

The client expects that the total cost of materials for this project will not exceed $500. The client has left material choices up to the capstone team and will reimburse the team periodically. Appendix A shows exactly how much was spent on the project and the amount that the capstone team was reimbursed for. This total amount for the capstone team's additions was $353.16. This is about $140 under budget.

4.2.5 Engineering Specification #5: Solar Energy Powered

The client expects that the device will be powered by a solar panel that was purchased for the project. The client purchased a small solar panel that the capstone team fixed to the edge of the dish. The team also hooked up a chip to interface with the solar panel so that it could charge the battery when the battery is not being used. Figure 15 shows the panel mounted to the edge of the dish. Figure 16 shows the chip that interfaces with the panel, the battery, and system as a whole. The upper left corner of the chip is connected to the solar panel. The lower left corner is connected to the battery. The upper right corner connects to the rest of the system, supplying 12V of power. The light in the center of the chip indicates that the solar panel is currently charging the battery. Finally, the lights in the left bottom corner show how charged the battery is. In this photo, it is less than 25% charged.

Figure 15: Solar panel mounted to dish

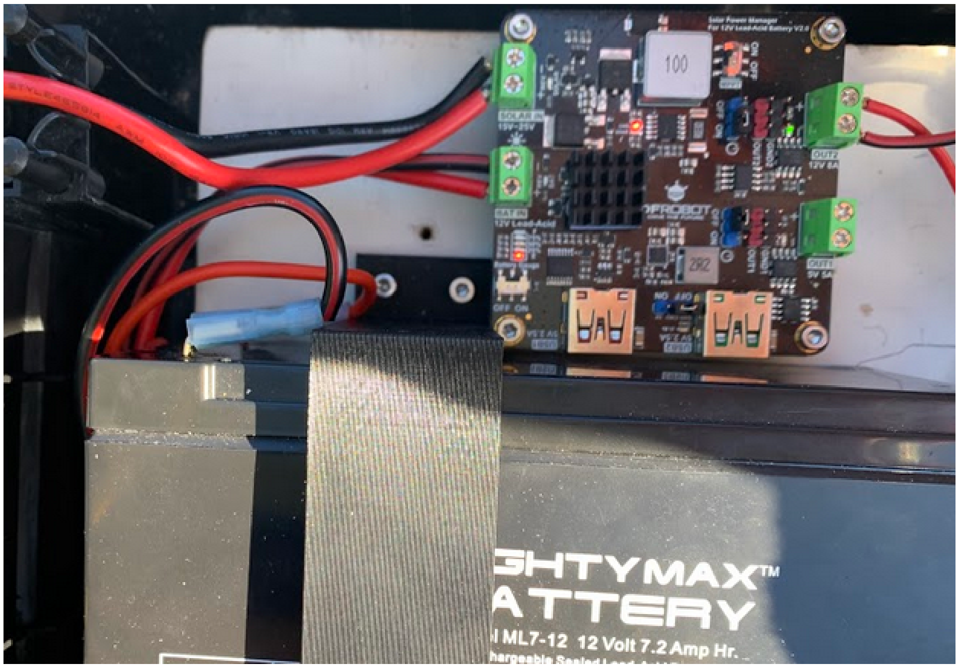


Figure 16: Solar power module

4.2.6 Engineering Specification #6: Easily Accessible Components

All components will be easily accessible and removable from the device within reason. All electronic components can be accessed by opening the enclosure which has four clasps, seen in Figure 13, above. The linear actuator can be removed by releasing the pins, which can be seen in Figure 12, above. The pan motor can be accessed by removing four screws on the bottom of the enclosure. All components are easily accessed by removing screws using a screwdriver or by releasing clasps or pins by hand. Further, the different sections can be removed from the others. The box with the electronics can be completely separated from the accelerometer, the linear actuator, and the pan motor and encoder enclosure.

4.2.7 Engineering Specification #7: Easy to Use

The client expects that the device will be easy to use and intuitive. The client will not need assistance when operating the machine. The client will only need to know how to use the two buttons in Figure 17 to operate the system. The button on the right side is an on/off switch. This disconnects the system from the battery. The battery can still charge when the system is powered down. The button on the left will put the dish in the loading position so that the client can remove or change out the keg that is at the focal point. Pressing the on button will start the system, go through the homing loop and then go to the azimuth and elevation angles of the sun. At the end of the day, the user will need to turn off the system by pressing the on/off button again.

Figure 17: Electronic enclosure with two button inputs

5 LOOKING FORWARD

In terms of the requirements laid out by the client, the current OSU capstone team has met all corresponding engineering specifications. The team has provided a system that pans and tilts toward the sun throughout the day. The system is weather resistant, low cost, solar energy powered, and easy to use. Further, the system has easily accessible components so that if any problems do occur, the chips and motors can be replaced without difficulty. Although the system has met the expectations of the client, there is always room for improvements to be made in each section.

In the pan movement system, there are several improvements that could help with longevity and overall functionality. The first suggestion would be to switch out the sprocket and chain. Currently, the motor is attached close to the center of the dish. This solution was inherited from the previous capstone project and was implemented by the current team. Because the motor is close to the center point, it takes a significant amount of torque to move the dish. Thus, a more robust sprocket and chain may make this specific solution last longer. The current capstone team has mitigated the problems from this centralized motor by strengthening the plate that the motor is attached to, which was explained in previous sections. If the client wanted to overhaul the pan movement system, the current team would recommend placing the motor on the outside ring. This motor could then move one of the wheels to turn the dish. This movement would require less torque and less power. This would make it easier for the motor to move the dish and there would be less drain on the battery. It also has less parts that have fail points, like the chain. However, this would mean an increase in the use of long wires which could lead to different fail points.

In the tilt movement system, there are also improvements that could be made to help with functionality. Currently, the dish can move as low as 40° but is stopped by the linear actuator length. Another team could swap out for a different sized linear actuator, but this might lead to a higher expense or compromising the robustness. In the winter, the sun barely reaches 40°, so the current system is not optimized in the elevation angle plane during this season. Fortunately, there are far less solar hours in the winter, so the client does not plan on using the dish as much during these times of the year. Lowering this angle should be approached with caution, however, as the dish can be a serious fire hazard if pointing at the tree line. The counterweight could also be reengineered so that it can change weights a bit easier. Currently, the counterweight is a keg filled with water. A future team could attach a keg with a spout that can empty the water easily and still refill with the hose if needed.

In the controls system, there are optimizations and checks that could improve the overall functionality of the system and orient the dish more precisely. The team used more simplified equations for the solar tracking system. If a future team or the client wanted more precision in the orientation of the dish, a future team could use the more complex equations that NOAA provides. These equations rely on time, date, and latitude, like the simpler ones, but they also rely on the day of the year from the millennium, the curve of the earth, and the route of orbit. A future team could also do further testing on the thresholds that the current team put in place for the dish. The dish has a specific homing position and does not go further than 270° from the north direction. Because the current team was testing in the winter, it was difficult to verify all thresholds. It would be beneficial to have testing at different points throughout the year to make sure that the thresholds match up with all degree possibilities for the sun. The capstone team also considered utilizing the low power mode option that is present in many Arduino chips so that it is not using the battery more than it needs to if it is left on all night. At this time, the system needs to be turned off at night and turned back on in the morning. A team could code this so that the system could stay on all night and start tracking the sun again in the morning.

Overall, the team has completed all requirements set by the client and delivered a system that optimizes the solar energy throughout the day. The client has expressed interest in progressing this project so that it generates energy that can be harnessed for the farm. The team would recommend that this project be offered in the winter and spring. Testing the final system in the winter was difficult because there were not many sun days to choose from. If the project completes in the spring, it will be easier for the team to complete final testing and optimization especially if the project turns into an energy generation system.

6 CONCLUSIONS

In order to apply design principles to the design of this project, the capstone team considered the needs of the client, the needs of the system, and then did research in order to find solutions which would meet those needs. During this design process the team focused on the safety of the project. Safety considerations included: high factors of safety, an easy to stop system, and restraining the movement of the dish to reduce fire risk. Additionally, the team focused on the environmental aspects of their solar energy project by ensuring the system would not draw from grid power.

Longevity was at the forefront of the design process. Longevity ties in with the environmental impact of the design, as well as with its overall safety. If the project has a long life cycle then its components will not go to waste. In order to ensure that the parts in this project will last for an extended period of time, large factors of safety were used wherever possible. These factors of safety also ensured that the client would not be in danger from any parts failing. For example, the tilt axis motor is rated for nearly three times the required load. Additionally, all of the electronic components will be well protected in their enclosure in order to ensure a long life.
In addition to focusing on the longevity of components, in order to reduce the environmental impact of the project, recycled materials were used wherever possible. For example, scrap steel was used in order to strengthen the pan motor mounting plate. Additionally, in order to join the linear actuator to the dish a piece of scrap steel was used. Using these recycled materials meant that the team did not need to purchase new steel- which in turn meant that the environmental impact of manufacturing that steel was not incurred.

Additionally, this system is a renewable energy project, and having this project on display at the upcoming OSU Engineering Expo can further expose the public to renewable energy projects. The more visibility renewable energy projects have the more viable they will seem to society as a whole. So, even if this project is only a small component of that overall representation it does still contribute to the public presence of renewable energy.

This parabolic solar dish generates enough heat to boil an entire keg of water using just the sun. This means that there is a responsibility to ensure that energy is safely managed. This solar furnace is located on a christmas tree farm, and the client has noted that in the past the solar furnace has burnt one of the nearby christmas trees. In order to ensure that no fires will be started due to this dish, the capstone team designed the tilt axis to have a minimum angle which would direct the focal point of the dish above the tree line so that no energy is directed towards where it may cause a fire.

Ass this is a mechatronics project which involves actuating heavy loads, such as 100 lb kegs of water, the team designed the project to be easy to shut off should something go wrong. The power switch cuts power to the system immediately, functioning both as the main on/off switch and also as an emergency stop.

Overall, this project was designed with the users solar tracking needs in mind, while focusing on safety and longevity. This solar energy project also has implications which stretch beyond the client's christmas tree farm, as it serves as an example to show that even small scale solar energy projects have their place in society.

7 REFERENCE

[1] "Solar Tracking Sensor." Sunto. State-of-the-art Professional Solar Technologies. <https://www.sunto.technology/sensing/solar-tracking-sensor>(10/15/2022)

[2] "12-Inch Qarl-3612 Heavy-Duty Linear SuperJack Actuator." <https://www.sadoun.com/product/12-inch-qarl-heavy-duty-linear-superjack-actuator> (10/15/2022)

[3] "Linear Actuators 101 - Everything You Need to Know about Linear Actuators." Firgelli Automations. <https://www.firgelliauto.com/blogs/actuators/linear-actuators-101>(10/15/2022)

8 APPENDICES

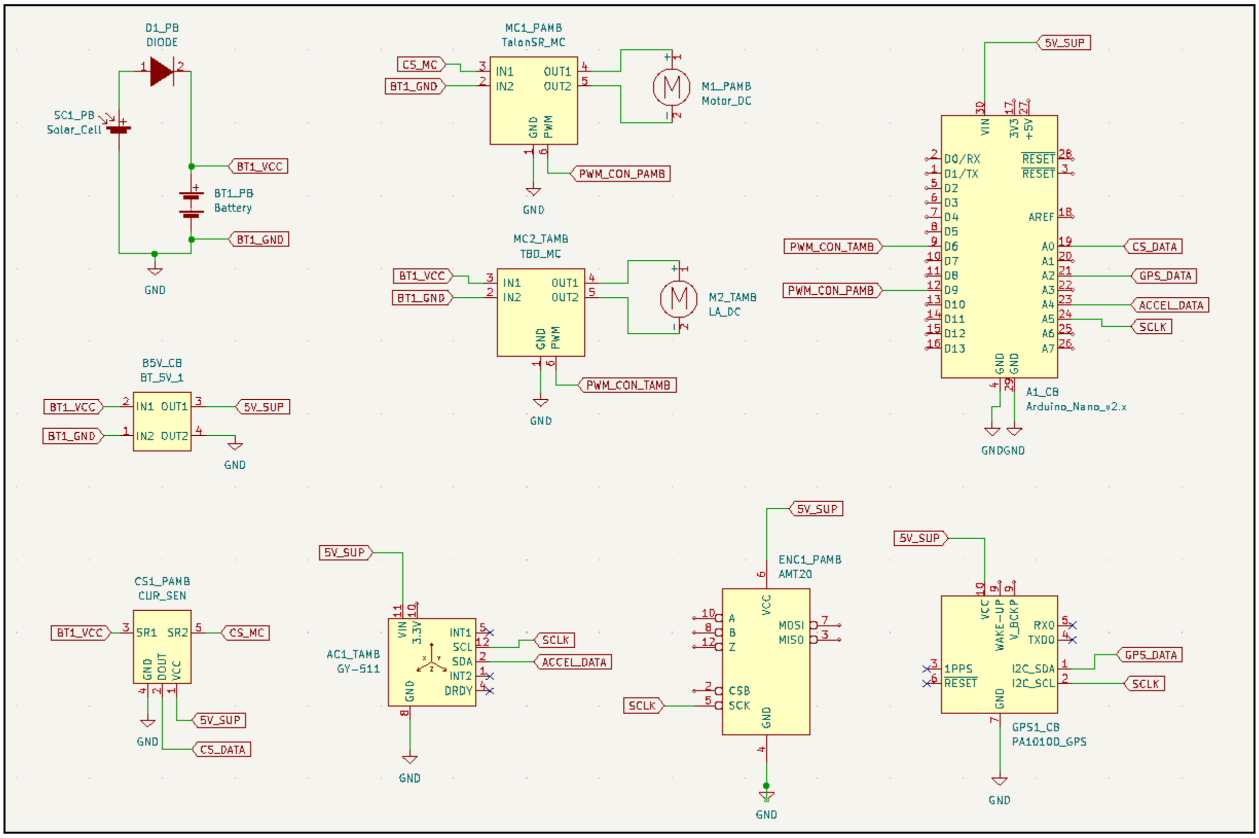
8.1 Appendix A: Bill of Materials Table

No.	Project Block	Old vs. New Capstone	Item Name	Qty	Vendor	Link	Price per Unit	Total Cost
1	Tilt	New	Linear Actuator	1	Amazon	Recoil Link	66	66
2	Tilt	New	Actuator controller	1	Amazon	LA Controller	17	17
3	Power	Old	Battery	1	N/A	N/A		0
4	Comp	New	Accelerometer	1	Amazon	Accel Link	9.99	9.99
5	Comp	New	Arduino	1	AliExpress	Arduino Link	35	35
6	Comp	New	Current Sensor	1	Amazon	Curr Dev Link	7.39	7.39
7	Testing	New	Multimeter	1	Amazon	Multimeter Link	12.99	12.99
8	Tilt/Pan	New	Dual Motor Controller	1	Amazon	MC Link	15.78	15.78
9	Power	New	Self-Resetting Fuse	1	Amazon	Fuse Link	10.97	10.97
10	Power	New	Toggle Switch	1	Amazon	Toggle Link	8.99	8.99
11	Comp	New	Push Button	1	Amazon	Push Button Link	7.99	7.99
12	Pan	Old	Motor	1	N/A	N/A		0
13	Pan	Old	Motor Controller	1	N/A	N/A		0
14	Power	Old	Voltage Regulator	1	N/A	N/A		0
15	Comp	Old	GPS chip	1	N/A	N/A		0
16	Comp	Old	Data Storage chip	1	N/A	N/A		0
17	Pan	Old	Encoder	1	N/A	N/A		0
18	Pan	New	small gear	1	Mcmaster	Link	22.7	22.7
19	Power	New	Enclosure	1	Amazon	Link	26.99	26.99
20	Power	New	Ethernet Coupler	1	Amazon	Link	13.99	13.99
21	Power	New	Ethernet Cord	1	Amazon	Link	8.99	8.99
22	Power	New	Solar Module	1	Amazon	Link	33.5	33.5
23	Power	New	wire nut	1	home depot	-	3.98	3.98
24	Power	New	5/8 drill bit	1	home depot	-	9.97	9.97
25	Pan	New	PETG filament	1	Amazon	Link	24.99	24.99
26	Misc	New	wires	1	Amazon	Link	14.99	14.99
27	Power	New	Trickle Charger	1	Amazon	Link	17.96	17.96
							Total	353.16

8.2 Appendix B: House of Quality Table

Customer Requirements (CRs)					
CR#	CR description	Weight	Matching Engineering Specification	Targets with Tolerances	Test Procedure Number
1	Develop device that can pan to point towards the sun	50	Device will point center of dish directly at the sun	+/- 5°	1
2	Develop device that can tilt to point towards the sun	50	Device will point center of dish directly at the sun	+/- 5°	2
3	Develop a device that is weather resistant	50	Device will protect electronics from rainfall, not submersion	Survives indefinite rainfall	3
4	Low Cost	30	Sum of component prices is less than target	Under $500	4
5	Develop a device with a rechargeable power source dependent on solar charger	50	Device battery is recharged by solar panel	Yes/No	5
6	Develop a device with easy maintenance	10	Battery and other components are easily accessible	Less than 5 steps to replace any part	6
7	User-friendly operation of system	10	Does client need assistance to operate/calibrate	Yes/No	7
	Sum	250			

8.3 Appendix C: Old Electronics Wiring Diagram



8.4 Appendix D: Final Electronics Wiring Diagram