A.S.T.R.O.COM.

Advanced **S**olar **T**racking and **R**over **O**bservation **C**ommunication

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Chapter 2-Project Description

2.1 Project Background and Motivation

In the vast expanse of space exploration, where humanity's curiosity knows no bounds, our senior design project endeavors to tackle the intricate challenges surrounding rover communication systems and heliostat light reflection. As we venture into uncharted territories, we confront the fundamental hurdle of establishing robust and reliable communication networks between rovers and their human counterparts, bridging the vast distances that separate us. Simultaneously, we grapple with the complexities of harnessing the power of heliostat light reflection, leveraging this innovative technology to illuminate unexplored regions and unravel the mysteries hidden within. With unwavering determination and pioneering spirit, our project aims to revolutionize the way we explore and educate others, pushing the boundaries of engineering and innovation to forge a path towards the stars.

In our academia, the senior design project is a great way for undergraduate students to learn to work in teams to achieve a common goal. As a group, we must learn to overcome challenges to brainstorm, innovate, and design a functional project with multiple pieces of software and hardware. Using these factors, we decided that we wanted to pick a project that would not only challenge us but also motivate and inspire us to make change. Because of this, we decided that we wanted to think big for our project.

Our group was approached by a sponsor, Mike Conroy from Florida Space Institute (FSI) Student Design Projects. Mike is a well-respected mentor who has over 35 years of experience working with the National Aeronautics and Space Administration (NASA) as an engineer, team leader, and now senior design mentor. We knew we had an unbelievable opportunity to have a great mentor and idea for a project. A recommendation from our sponsor resulted in a project idea as we were brainstorming different topics and ideas to build an engaging and challenging senior design project. This recommendation was a project to build a mesh communication network with a set of rovers through a main communication tower along with a reflection system to give these rovers light when they might possibly be in a shadow behind a hill.

2.2 Current Commercial Technologies and Existing Projects

2.2.1 Heliostaat DIY Kit

The Heliostaat DIY kit is a commercially available product that uses a mirror to reflect sunlight at a specified location at all times. It does not use any light sensors to achieve this result. It uses a combination of GPS and calculations to determine its positioning. It uses two motors to move the mirror into position. The system is made to last for years even in the event of power failure. The Heliostaat can operate in two modes. The first mode of the product is to be a lamp that is on all day while reducing waste and space from a conventional lamp. The other mode is tracking the sun to maximize output for a solar panel.

The Heliostaat is meant to be low power and is controlled by a remote control. It uses a 12/24 V adapter to power and averages 430 mW. The remote control operates at 433 MHz with a maximum range of 50 meters when in an open area. It is unspecified what motors are used in the product but they are normally used for dish antennas. The software and hardware are both highly accurate with

0.01 degrees of accuracy for the software and 0.0125 degrees for the hardware. The internal processor runs at 48 MHz and the system has an LCD display with information on date, time and positioning on it. It's possible to modify the firmware if desired as well as use your own motors and add a wind sensor.

Heliostaat shares many similarities and differences with ASTROSCOPE. Both projects seek to track the sun and reflect sunlight using motors as the main idea. Both projects are controlled in some form with a remote control. The biggest differences lie within the use cases and how that end result will be achieved. For ASTROSCOPE the possibility using GPS does not exist as it will be used on the moon. This is the largest difference between the method of the two as ASTROSCOPE will require light sensors, Heliostaat does not. Both, naturally, will need to use calculations to determine any positioning but ASTROSCOPE cannot take can any action without the light sensors.

Another difference is the reliance on a mesh network hosted by a communications tower so that information can be transmitted between the reflector and one or more rovers that need light reflected to their location. Heliostaat doesn't handle changing positions on demand for moving objects. It does calculations by knowing its own position through GPS and everything else falls into place as that will reveal where the sun rises and where the sun sets for every day of the year. For ASTROSCOPE all positioning calculations are reliant on information being sent through the mesh network so that such calculations can be performed and light can be reflected to the given rover.

Overall, the very similar core ideas show that Heliostaat is one of the most similar products on the market to ASTROSCOPE. That said, it is only the reflector tower part of the project and doesn't involve anything to do with the moon or rovers. The integration of a scalable mesh network with a movable communications tower to coordinate sunlight positioning makes ASTROSCOPE more complex and wider in scope.

2.2.2 FSI Rover and App

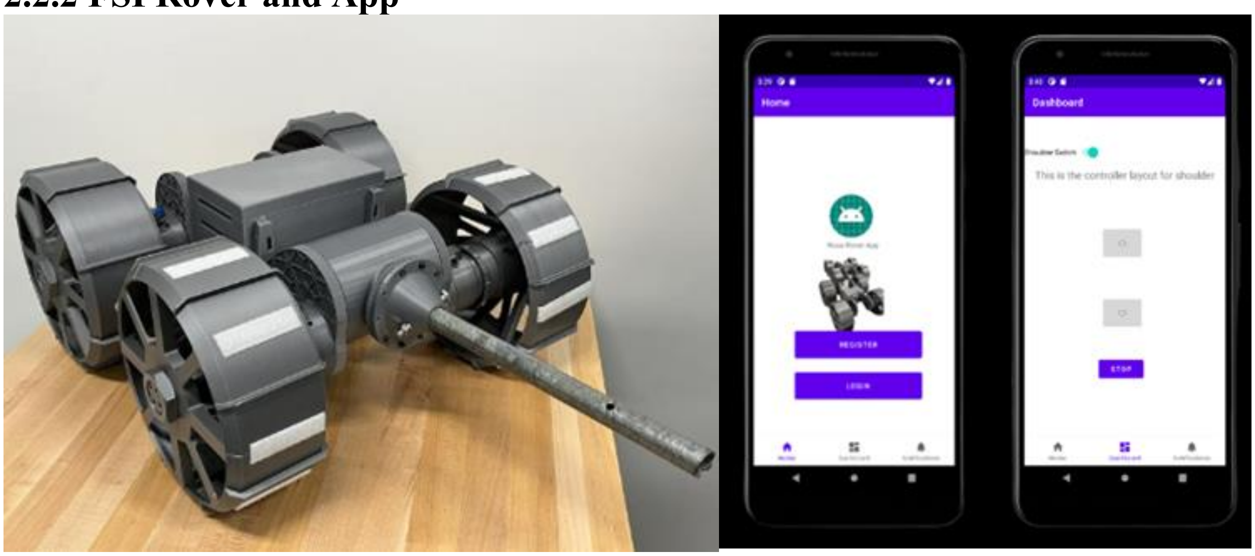


Figure 2.1. *FSI Rover and App from previous project.*

This was a congregation of previous projects that have been built for multiple years and universities, and we would be next in line to improve the rover project. Other schools had built this rover to be fully operational and able to be remotely operated through an app using Raspberry Pi Wi-Fi. Although the rover had been significantly upgraded, the communication aspect and the electrical components of the rover were lacking. This was a unique challenge for us to be the next group to take the rover project to the next step.

We decided to take this challenge head on. At the time, the group that was constructed had eight people total and we decided to split the groups into a “rover group” and a “tower group” to effectively break this project up into two senior design projects that coincide together. We picked our groups that gave us the best chance to build two successful projects that would work together using the advice and guidance from our mentor professor, Dr. Chan. We brainstormed ideas of the functionalities early on and got a head start on our project, beginning planning and constructing diagrams as early as Spring 2023.

For this project, the main goal of this would be an education source for elementary and middle school kids and a proof of concept to a company such as NASA that they could build off, rather than something that would be put on the moon. FSI would supply us with a budget that would allow little to no cost for this project if we stayed within the boundary of $750.00. This gave us an unbelievable opportunity to build an interesting senior design project that would be fully funded by a sponsor company while also being a contribution to children’s education in space exploration and communication systems.

As we started brainstorming how we wanted to attack this project, we did not think it would be feasible to have both communication and light reflection on the same tower since it would be too heavy and hard to balance the power draw from the microcontroller. We decided it would be best to break up the communication and mirror reflection into two separate towers to ease the power draw and make it simpler to divide the work among our group. The first tower, which will be the bulkier tower because of the motors and large mirror to reflect light to the rovers, is the “mirror tower”. The other tower is the “communication tower”, which will be light and compact, and theoretically can be picked up by the rover and placed somewhere else.

From here we started picking team roles and areas we wanted to work with based on undergraduate majors and personal preferences. We have three computer engineers in our group and one electrical engineer, so we based our roles mostly on these parameters. Binh was selected to be the project manager and to be in charge of the motors and mirror reflection. He is a computer engineer studying the Digital VLSI Circuits track at UCF which focuses on hardware-software co-design, making him the right person for the job. Alex, the electrical engineer, would oversee the power supply unit (PSU) in both the mirror and communication tower for the project, as he has the most experience with this field. Rounding up the group working on the mirror tower is Stephen, who is managing the microcontroller and light sensing algorithm for the mirror tower. He is a computer engineer so creating this algorithm relies heavily on coding and computer science resources to do this. Lastly, the person captaining the communication tower is Pedro, who is the last computer engineer of the group, and will be using network protocols and computer science algorithms to create the mesh network communication system with the rovers through the antenna. From here, we started working on our research and project specifications that will be laid out in this project report.

As our main motivation for this project, it is to complete the senior design program, which serves as the capstone program for the College of Engineering and Computer Science at UCF, and to meet the needs of our sponsor, FSI, as they will be the ones funding the project. As we meet these necessary requirements, there are some internal motivations as well. Each group member wants to use this project as an opportunity to complete a team project with different roles to achieve a common goal, which will be incredibly prevalent as we enter the workforce in the industry after our graduation. On top of this being a great resume booster for any job application, this project will allow us to build necessary skills that will be used in the industry in the real world. These factors will be extremely important for early success by using these skills will allow us to make good first impressions and move up quickly with our respective companies.

Another piece of motivation for this project is to use this as a great opportunity to build a project full of innovative hardware and software to help with education for elementary and middle school students to teach and inspire them to learn about math and science to be the engineers of the future. On top of this, this could be an inspiration for an organization such as NASA to build upon this to create a more advanced system that could be used for future space exploration. This extra motivation keeps our group motivated, on pace, and thinking outside the box to inspire a future generation.

2.2.3 Summary

Overall, looking into currently available commercial technologies and past projects that relate to our current product gives a lot of insight into where we can take this project, how we can match what exists and build upon it in a new direction. Not only that but learning about real existing solutions that are related helps with setting down constraints and understanding practical requirements that must be met for a successful project.

In the special case of our sponsored project, we are actively building upon FSI's rovers with new ideas that will work with them. It's integral to our new project to understand the constraints placed on the rover's design off the bat. Our main concerns are the addition of a reflector tower and a communications tower that are both integrated with the rover through a mesh network.

The reflector tower is completely separate from the rover and the communications tower aside from their communication through the network. The communications tower needs to be small and light enough so that it could potentially be transported by the rover. The rover must also be modified to be able to communicate with our network design.

By looking at the DIY Heliostaat kit, there was a lot to learn about creating an effective reflector. While the context was completely different, locating the sun and reflecting its light to a given point is how both our project seeks to function and how Heliostaat functions. It evidenced how we could not use GPS when we are on the moon and must rely on sensors to get the desired result.

The commercially available kit also showcases price points that we would hope to match or go lower in comparison. Budgeting from our sponsor is a major concern for our project and having an idea of the cost for something similar helps to gauge expectations and goals, as well as understanding what parts are more expensive or what parts deserve more budget allocation.

In conclusion, this less formal and less technical part of researching for the project was important for many reasons. Seeing currently available and past complete projects affects where we want to take our decision making and goals. Special attention goes to the FSI rovers as they are an integral part of our intended complete system within our project.

2.3 Objective and Goals

The main idea of this project is to build a communication tower and mirror tower to supply the rovers with a mesh communication network and sunlight for solar charging. Some of the main goals and objectives are listed below.

Overall Goals

- Build a tower to handle rover communication.
- Build a tower to handle sunlight diversion to rovers.

These goals can be narrowed into the objectives of both the mirror and communication tower to successfully create the project.

Mirror Tower Objectives

- Identify optimal sun location based on lux value from sensor.
- Receive requests from communication tower using protocols.
- Create a heliostat algorithm to orient towards the target with motors.
- Create a self-sustainable power supply using solar and battery power.

Communication Tower Objectives

- Receive requests from rovers through mesh network protocols.
- Relay requests to mirror tower using communication protocols.
- Create a small and portable tower that can be moved by rovers.

Stretch Goals

- Peer to Peer Networking for communication and mirror tower with rovers.
- Wireless charging and/or docking station for communication tower.

2.3.1 Hardware

2.3.1.1 Reflector – Basic Goal:

The ASTROSCOPE's reflector tower's primary function is to redirect sunlight to a specific location as rovers or facilities requested when the elements are obstructed by shadow. The facilities use redirected sunlight as replacement energy directly from the sun. The reflector needs to be able to traverse through the range of the sun's path and find the highest amount of sunlight possible to reflect. The reflector tower utilized diode ambient light sensors to measure the amount of lumen. Lumen's data is fed to the microcontroller and calculated by an algorithm to get the light's direction vectors. A motor controls the whole tower from the vectors to get the maximum light for reflecting and charging the attached solar panel.

Various conditions cannot be tested due to environmental constraints such that the testing needs to be done in the earth's surface environment rather than the moon. Certain environmental constraints, such as high temperature, must be adjusted when fabricated for the space environment. The material used can be less durable because of the earth's atmosphere. Some parts used in the project must be considered in industrial form and alternative.

The moon has specific movement and hence has a different sun's path. Such a constraint needed to be placed. The tower position needed to be strategically placed for the sun to have the highest reflection and reduce the amount of overhead pross path. On the earth's surface, the tower needed to be placed on the North-South axis and at an elevation higher than the target rovers and facilities. This facilitates the most amount of light, and there is no overhead path.

The mountains and craters on the moon are significantly higher than any elevation on the earth's surface. Hence, the light path effectiveness must be scaled to appropriate intensity when fabricated for the space's environment. An offset can be accounted for due to the minimal atmosphere interference on the moon. The project needed to consider lumen loss and changes in the light path in the earth's atmosphere. The battery needs to be able to last two weeks without sun. This needs to be the case for maximum sustainability for the mirror tower. This will allow for less reliance on the solar panels for charging by having a larger battery.

2.3.1.2 Wireless Charging/Docking Station – Stretch Goal:

For power, the main stretch goal for the communication tower would be a wireless charging component possibly with a docking station to allow for easier charging of the rover on the smaller tower that might have less capabilities for self-sustainability in terms of power. This would be a big boost for the accessibility of the rovers so that it could be operated remotely to be able to pick up the tower and bring it to a charging station. With this goal, it would disregard the need for cables to be plugged in or just relying on solar panels.

2.3.2 Software

2.3.2.1 Basic Goals

ASTROSCOPE must carry out multiple goals that comprise of electrical and computer science components. The main goal of the project is to be able to effectively reflect sunlight to a rover that might need sunlight or extra light to charge. To be able to do this, ASTROSCOPE must be able to communicate with these rovers using communication protocols to relay the message to the sensor and microcontroller to start this process. Our other main goal is to keep these two features, which are the mirror tower and the communication tower, separate from each other for functionality and mobility.

The main point of these two components being separate is so that the communication tower can be picked up and moved by a rover. This means that another one of our main goals is to have the communication tower be compact to the point that one of the rovers can theoretically pick it up and move it to a new location. Because of this, the communication tower must be able to relay the message to the mirror tower to using communication protocols to send the rover requests over. This can only be done by hosting a network, which is the primary goal of the communication tower.

In terms of light reflection, the first of the main goals for ASTROSCOPE are to identify the sun's location by using algorithms with the light sensor and microcontroller to determine the optimal location for most light intensity. From here, ASTROSCOPE needs to calculate a vector for light trajectory to provide to the hardware's movements with the motors. This movement of the motors will have to correspond with the specific coordinates of the rover in need of light.

For power, the main goals of ASTROSCOPE are to be sustainable and self-sufficient so that the towers can run on battery and solar power. From here, the towers will need to effectively deliver power to each component using a calculation software to determine which components are most important or in need of power on the towers. These power goals are critical for the functionality of ASTROSCOPE.

2.3.2.2 Peer to Peer Networking – Stretch Goal:

In the communication tower, there is a main stretch goal that is on the table if time permits. For the networking aspect, having a peer-to-peer network for each of the towers and to the rovers would be ideal to create a seamless communication system. The peer-to-peer networking system would allow for complete decentralization so there is no single point of failure between the rovers and communication tower. This would also allow for easy scalability for future additions to this project. Lastly, the peer-to-peer networking would add some extra security with no need for intermediary nodes.

2.4 Required Specifications

In consideration of objectives and constraints, specifications are required:

Table 0.1. *Specification of Towers*

Heliostat Tower	
Minimum Temperature	-40°C
Reflector	
Minimum size	1ft diameter
Maximum size	5ft diameter
Maximum Weight	9kgs
Minimum Reflectivity	98%
Response Time	3 minutes
Tower Frame	
Maximum total weight	27kgs
Minimum Weight Capacity	10kgs
Solar Panel	
Minimum Power	30W during sunlight hours
Maximum Voltage	24V
Battery	
Minimum Lifespan	2 weeks without sun
Communication Tower	
Minimum Enclosure Volume	6.5"x6.5"x5"

Maximum Weight	2kg
Minimum Network Range	20m
Communication Rate	2400MHz
Voltage input	3.3V or 5V
Maximum Current Draw	500mA
Minimum Temperature	-40°C
Latency	1 second
Maximum Power	5W

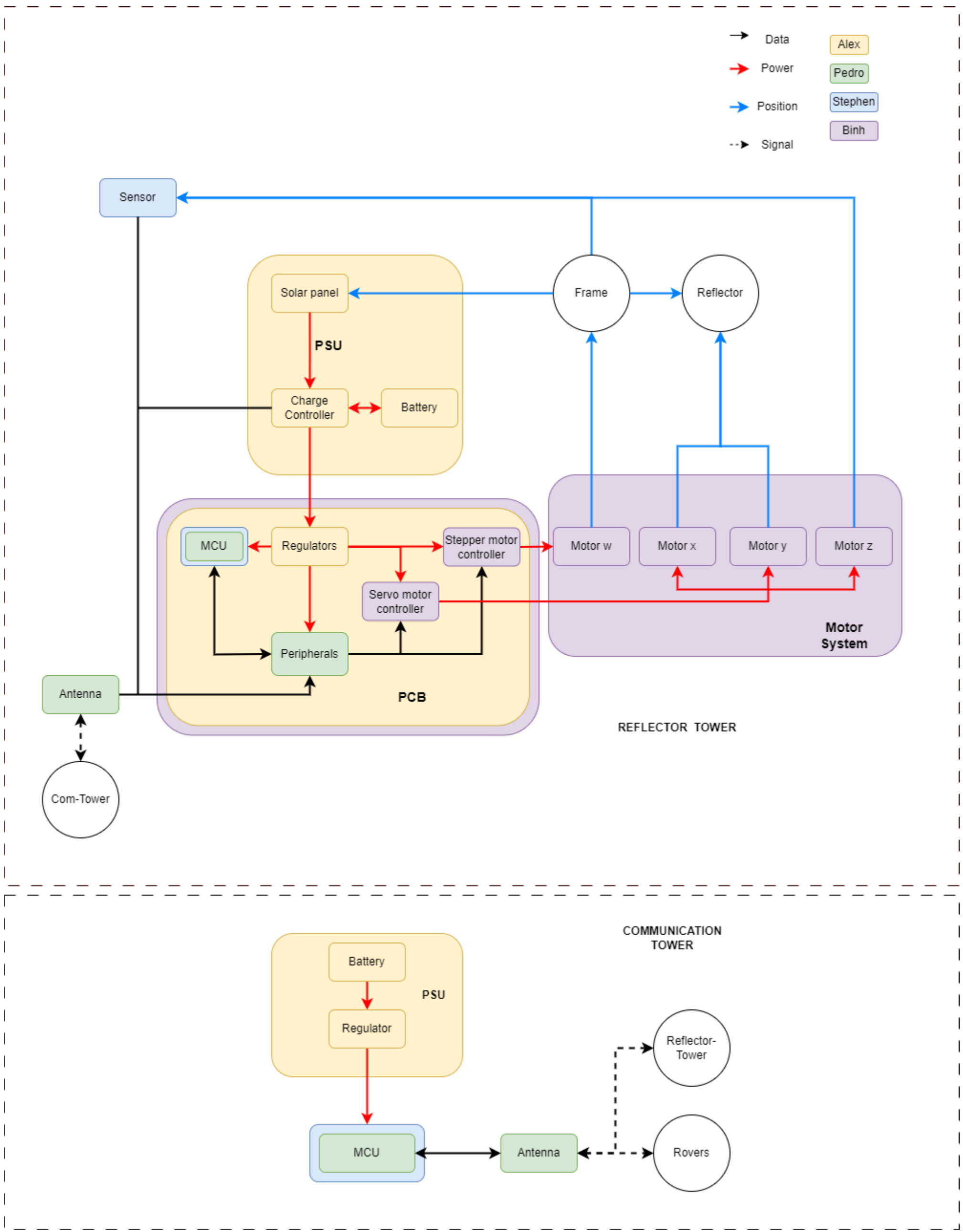


Figure 2.2. *Hardware Diagram by Authors*

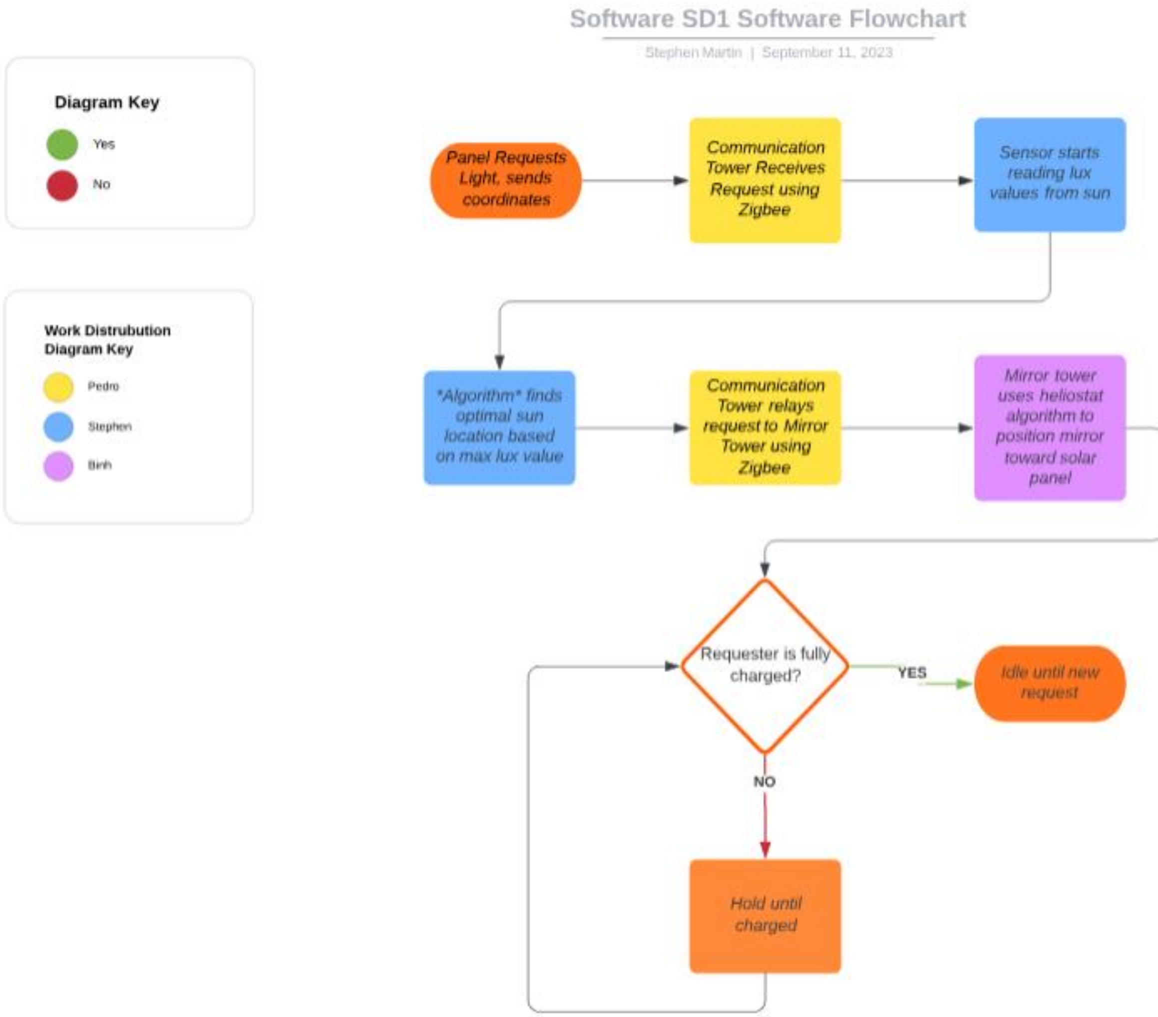


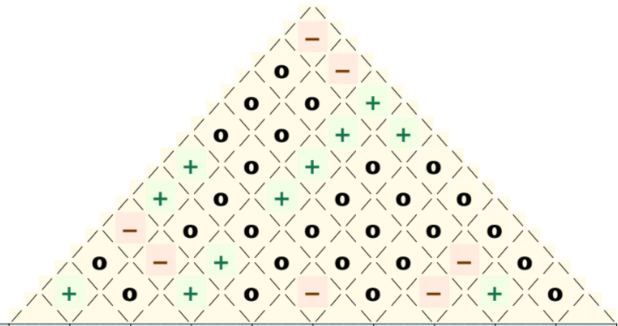
Figure 2.2. *Software Flowchart by Authors*

2.5 House of Quality

Correlation	
Positive	+
Negative	–
Nocorrelation	o

Relationship	
Strongly Positive	↑↑
Weakly Positive	↑
No Relation	○
Weakly Negative	↓
Strongly Negative	↓↓

Direction of Desirability	
High	▲
Low	▼



Column #		1	2	3	4	5	6	7	8	9	10
Functional Requirements / Customer Requirements (Explicit and Implicit)	Direction of Desirability	Size	Weight	Power Transmission Efficiency	Power Utilization Efficiency	Accuracy of Reflection	Illumination Range	Communication Rate	Communication Range Between R-C towers	Communication Range Between C tower and Rovers	Battery life
Direction of Desirability		▼	▼	▲	▲	▲	▲	▲	▲	▲	▲
Affordability	▲	↓↓	↓↓	↓↓	↓	↓	↓	↓	↓	↓	↓↓
Portability	▲	↓↓	↓↓	↓	↓	○	↓	○	↓	↓	↓
Energy Efficiency	▲	○	○	○	↑	○	↓	↓	↓↓	↓↓	↑↑
Power Delivery	▲	↑↑	↑↑	↑↑	○	↑↑	↑	○	○	○	↓
Reliability	▲	↑	↑	↓	↓	↑	○	○	○	○	↑↑
Ease of Use	▲	○	○	○	○	↑	↑	↑	↑	↑	↑
Communication Range	▲	↑↑	↑↑	○	↓	○	○	↓	↑↑	↑↑	○
Compatibility	▲	○	○	↓	↓	○	○	○	○	○	↓
Connectivity	▲	○	○	○	○	○	○	↑↑	↑↑	↑↑	○
Time-Saving	▲	↓	↓	↑	↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑
Ease of Mantainence	▲	↓↓	↓↓	○	○	○	○	○	○	○	↑↑
Upgradability	▲	↓	↓	↑	↑	↑	↑	↑↑	↑	↑	↑
Product Efficiency	▲	↑	↓	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑
Product Targets (Reflector/Communication)		Approx. 2x1x1 m^3 / Aprox. 30x30x30 cm^3	<50lbs / <5lbs	>250W / N/A	>90% / >95%	<1 degree / N/A	100 m Diagonal / N/A	>50kB/s / >50kB/s	500 meter / 500 meter	500 meter / 500 meter	5 years / 2 years

Figure 2.4. *House of Quality*

Chapter 10 - Administrative Content

10.1 Budget

The budget provided for this project is limited to $750. This limit is set by FSI and not by UCF or self-imposed. The goal of this project is to keep all costs within the $750 provided by FSI to minimize personal costs from group members.

Higher cost items, such as motors, microcontrollers, the frame, batteries, and solar panels, have been allocated a larger portion of the budget. Lower cost items such as regulators and sensors are allocated a smaller portion of the budget. Note the $750 budget includes multiple iterations, meaning the Bill of Materials must include room for spending on replacement or exchanged parts.

Table 10.1. *The Budget allocation for the various parts of the project*

Sub-System	Budget
PSU and Solar	$ 150.00
Frame/Reflector	$ 200.00
PCBs and Electrical	$ 100.00
Total	**$ 450.00**

Seen from the table above, this project is underbudget. This enables more margin for error, such as part replacement, and the iterative design process to take place without significant financial repercussions.

10.2 Bill of Materials

Table 10.2. *An Itemized Bill of Materials*

Component	Name	Price	Quantity
Mechanical			
Mirror	0.032" x 24" x 24", 3003-H14 Aluminum Sheet	$28.86	1
Mirror Coating	Mylar	$25.99	1
Frame	ADJ LTS-6 T-Bar Tripod Lightweight Lighting Stand	$54.99	1
Misc.		~$50	
Electrical			
Battery	Howell Energy hw-4f7	32.99	1
Motor w	Nema 23	$30.73	1
Motor x-y-z	9.5-11kg*cm Servo Motor	$0.00	0
Charge Controller/BMS	Smaraad SR11004	$39.99	1
Mirror Coating	Mylar	$25.99	1
Solar Panel	RNG-50D-SS	$49.99	1
Microcontroller	ESP32-C6-DEVKITC-1-N8	$9.00	1
External Antenna	PC140.07.0100A	$20.96	2
MicroSD card	5251	$4.50	2

MicroSD card breakout board+	254	$7.50	1
PCB			
Microcontroller for PCB	ESP32-C6-WROOM-1U	$3.48	1
Stepper Motor Controller	DRV8833PW	$2.84	1
Servos Motor Controller	PCA9685PW,112	$2.64	1
3.3V Regulator	TPS54JA20	$1.50	1
5V Regulator	TPS54JA20	$1.50	1
USB-A Connector	2057-USB-AP-S-RA-SMT-ND	$0.55	3
Sensor-MUX	TCA9548APWR	$1.78	1
Sensor	VEML7700	$1.88	5
USB-to-UART Bridge Controller	CP2102N-A02-GQFN28	$4.07	1
MicroSD Socket	1660	$1.95	1
Misc.		~$20.00	
Total		**$423.68**	

10.3 Distribution of Worktable

Below is the distribution of worktable detailing the assigned tasks to the group members. The responsibility of each system is distributed to specific members; however, each system relies on other member's systems. Collaboration is present among the group members at every level of this project to ensure these systems are designed in a manner that they fit other system's requirements. This ensures that all members are aware of and involved in the design and implementation of systems, regardless of if they are directly responsible for it or not.

Table 10.3. *The distribution of worktable.*

Electrical Engineering	**Responsibilities**
Alexandre Fiset	PSU Design and Implementation
	PCB Design
	MPPT Tracking Implementation
	Administrative Documentation
Computer Engineering	**Responsibilities**
Binh Pham	Reflector Technology and Design
	Motor and Motor Controls
	Vectoring Technology
	Project Lead
	Positioning and Vectoring Algorithm
Computer Engineering	**Responsibilities**
Pedro Kasprzykowski	MCU Selection and Implementation
	Software Design and Implementation

	Antenna and Communications
	Website Design and Management
Computer Engineering	**Responsibilities**
Stephen Martin	Sensor Selection and Implementation
	MCU Selection and Implementation
	Positioning and Vectoring Algorithm
	Software Design and Implementation

10.4 Milestones

Multiple events and meeting are required to create a good dynamic between members and a successful project. First, new members are recruited, and project's topics discussion held in the first week of senior design I to kick start the project with sufficient information:

Table 10.4. *Project Initialization Milestone*

Project Initialization				
Start Date	**Planed Date**	**Required End Date**	**Task**	**Description**
08/21/2023	08/21/2023	08/21/2023	Recruiting	Members recruited: Alexandre Fiset (EE), Pedro Kasprzykowski (CpE), Stephen Martin (CpE), Binh Pham (CPE)
08/22/2023	08/29/2023	08/29/2023	Brainstorming	Meeting in person to go over various ideas and pick one for the project.
08/30/2023	08/30/2023	08/30/2023	Sponsor Meeting	Discuss idea with sponsor.
08/28/2023	09/04/2023	09/15/2023	Initial Document	First 10 pages of Divide and Conquer
08/28/2023	10/28/2023	11/03/2023	60-Page Milestone	First have of the Document
08/28/2023	12/01/2023	12/05/2023	Final Document	Final Document of SD I

Table 10.5. *Project Fabrication Milestone*

Project Fabrication				
Start Date	**Planed Date**	**Required End Date**	**Task**	**Description**
08/28/2023	09/28/2023	09/28/2023	Components Selection	Making a tentative BOM with core component
09/13/2023	10/29/2023	12/05/2023	System Design	Making overall schematic for the project

10/29/2023	12/01/2023	12/05/2023	System Testing	Testing individual component and compatibility
10/29/2023	11/15/2023	TBD-SDII	PCB Design	Discuss idea with sponsor.
TBD-SDII	TBD-SDII	TBD-SDII	PCB Testing	First have of the Document
TBD-SDII	TBD-SDII	TBD-SDII	Prototype Completion	Final Document of SD I

Various tasks are overlap as expecting due to the nature of the project and some tasks are TBD. This milestone is a guideline for reference as a successful project.