S.O.L.A.R.I.S.

Solar-**O**ptimized **L**and **A**utonomous **R**echarge & **I**ntelligence **S**ystem

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Chapter 2 - Project Description

2.1 Project Background and Motivation

In senior design, constraints define a project's limitations in terms of functionality and capabilities. Our project aims its sights on industry-relevant processes and standards, which serve as a learning opportunity. Solar-Optimized Land Autonomous Recharge & Intelligence System (SOLARIS), our project, can be split into two different categories. The main objectives of interest are solar optimization and autonomous intelligence systems. With these ideas in mind, we plan to tackle power-conscious design of a system intended to be self-sufficient. A major constraint yet to be stated for the team is cost. By splitting the cost between all team members, it remains important to find the balance between expenditure, low-power, and net positive charging capability. The key educational value remains an important portion as it relates heavily to our academic studies and our own personal interest as Electrical Engineer (EE) and Computer Engineering (CpE) majors. As we dive further into motivations for the project, we see software and hardware equally important to achieving this final goal.

Software design, firmware included, is one such interest that drives a large portion of the project. Embedded architecture has long since dominated consumer electronics markets and continues to prove itself valuable time and time again. An embedded system would be nothing without firmware or a software interface to connect it to the internet. That is why it is a motivation of ours to not only design a robust control system but also interact with it through a wireless connection. This not only provides an interesting learning experience but also adds valuable and relevant experience to the large toolkit expected from engineers. The combination provides an interaction between hardware constraints and software design in real-world applications. Integration of wireless communications reflects industry-relevant practices where modularity, scalability, and maintainability are essential. To emphasize, mobile and desktop applications for control and statistics serve as a valuable experience in developing a bridged embedded system. These embedded applications showcase engineering skills that are indicative of common workflows, frequent pairing with companion applications, and automated control systems.

Solar energy adoption continues to accelerate as improvements in battery storage and solar panel efficiency make renewable systems increasingly practical. This project offers hands-on experience designing and implementing a solar-powered system in a real-world context. At the same time, the growing fields of robotics and automation demand engineers who can effectively integrate electromechanical hardware with reliable control strategies. Through this project, the team will gain experience in motor and actuator selection, control system design and tuning, and system-level power management. By addressing efficiency, variable loading, and practical implementation constraints, the project will develop skills applicable to both energy systems and robotics and automation engineering roles.

2.2 Current Commercial Technologies and Existing Projects

2.2.1 Jackery Solar Mars Bot

Figure 2.1. *Jackery Solar Mars Bot*

Currently, there is no commercially realized product directly comparable to *SOLARIS*. This is primarily due to the high cost of solar panel technology, the reduced effectiveness of mobile robots burdened with large-area solar panels, and the greater efficiency of traditional stationary solar panel installations for battery charging. However, one company that specializes in clean, portable power solutions, Jackery, has proposed a concept for a future autonomous solar-farming mobile robot known as the “Solar Mars Bot” [1].

While the Solar Mars Bot has not yet been released as a consumer product, its existence as a concept is significant. Jackery describes the system as an autonomous robot capable of navigating toward regions of stronger sunlight and repositioning itself when light conditions deteriorate. The design integrates foldable photovoltaic panels with onboard energy storage, allowing the robot to both generate and manage its own power. When deployed, the panels are rated to deliver up to 600 W of charging power to the onboard 5 kWh battery.

Although technical details regarding its sensing, control algorithms, and navigation methods are not publicly available, the concept itself demonstrates a growing commercial interest in autonomous, mobile solar collection. This proposal reinforces the idea that *SOLARIS* occupies an emerging design space. The Solar Mars Bot suggests that industry is beginning to explore robotic platforms that can actively seek out optimal light conditions rather than relying on fixed installations. Even in its conceptual form, it validates the direction of this project and highlights the relevance of developing efficient, autonomous systems that can adapt their position in response to changing environmental conditions.

2.2.2 SolarX: DIY STEM Solar Powered Robot

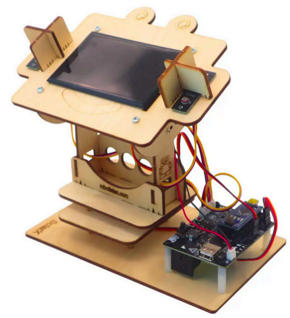


Figure 2.2. *DIY STEM Solar Powered Robot*

The SolarX: DIY STEM Solar Powered Robot is one of many consumer products designed as learning tools for directing a solar panel toward a light source, typically the sun, as effectively as possible. It uses photoresistive sensors to measure incoming light and determine how the panel should be oriented. Two servo motors, mounted on perpendicular axes, control the horizontal and vertical position of the solar panel, allowing it to continuously adjust until it is facing the brightest direction. [3]

Although this product represents only a small subset of what *SOLARIS* aims to accomplish, it felt important to include it as a design reference for that specific subpart of the project. A core goal of *SOLARIS* is to improve power generation by responding to changing light conditions, and this kit provides a concrete example of how sensor-driven solar alignment can be implemented in practice.

One major difference is in how motion will be achieved. The SolarX relies on servos, which require continuous power to hold their position. For *SOLARIS*, the intent is to explore a brushless motor actuator or similar mechanism that can reposition the panel without needing constant power to maintain its orientation. Since power efficiency is a primary constraint of the system, reducing energy draw is critical. While the actuation method will differ, the underlying design principle remains the same: use light feedback to determine how the panel should be oriented and adjust it accordingly to maximize available power.

2.2.3 Summary

At this time, there is no consumer product that fully matches the scope of *SOLARIS*. However, existing concepts and educational devices show that the core ideas behind the project are both feasible and relevant. The Jackery Solar Mars Bot highlights a growing commercial interest in autonomous, mobile solar platforms that can reposition themselves in response to changing light conditions. Even as a concept, it supports the idea that mobile robots can be used to actively seek out better solar exposure rather than relying on fixed installations.

On a smaller scale, products such as the SolarX DIY STEM Solar Powered Robot demonstrate how light sensors and actuators can be used to orient a solar panel toward the brightest direction. While these systems are limited and primarily educational, they provide a clear and proven example of sensor-driven solar alignment, which directly aligns with one of *SOLARIS*' core goals.

SOLARIS takes these existing ideas and pushes them further by turning solar tracking into a fully autonomous, mobile behavior. Instead of only adjusting the angle of a panel, the system is designed to decide when orientation alone is no longer sufficient and physically move to a better location. Power efficiency is treated as a core constraint, so every action is driven by the goal of gaining more energy than it consumes. By combining light sensing, autonomous decision making, and low-power actuation, *SOLARIS* explores how a robot can actively respond to its environment to improve its own energy generation.

2.3 Goals and Objectives

2.3.1.1 Basic Goals

- Create a robot capable of autonomously moving out of shade on flat ground.
- Rotate the solar panel about two axes to orient itself in peak sunlight conditions.
- Energy gained from moving the robot must be greater than an equivalent, fixed solar panel over a full daylight cycle.
- Measure and report information to the end user such as distance traveled, energy used, energy gained, state of charge, etc.
- Create a phone app to serve as the primary means of communication between the user and the robot.

2.3.2.1 Advanced Goals

- Allow users to manually select between two different modes through the phone app, stationary, autonomous, and manual.
    - In stationary, the robot will not move, however it will still move the solar panel.
    - In autonomous mode, full control is given to the robot.
- The phone app should display all information we collect from the robot to the user.
- The Robot should be capable of avoiding collisions. In the event of a collision, it should be able to tell, back up and turn.

2.3.3.1 Stretch Goals

- Create a website that mimics the phone app's interface. It will not be capable of connecting to the robot, but if users want to see their data collected from the robot, they can sign in and see it.
- Use IR sensors to detect going onto a curb / road.
- Add GPS functionality to track position throughout the day, and use that information to have a more robust model of where good spots are at given times.

2.3.1.2 Basic Goals

At the project's core, our main goal is to create an autonomously moving robot capable of solar farming. The solar farming robot should be able to rotate and angle a solar panel for peak sunlight positioning. SOLARIS needs to be capable of operating in outdoor environments like flat yards or open fields, as opposed to traditional solar harvesting methods. As it moves, there will be a low-level obstacle avoidance protocol causing the robot to traverse non-ideal environments. With both basic goals in mind, we want to expand capabilities that support our broader goal, maximizing solar energy collection without requiring external intervention. The overarching goal is what supports the basic idea to design a new kind of solution that is more practical.

Another central goal that is explored in the senior design project is providing a net positive energy benefit when compared to stationary solar harvesting approaches. This robot will evaluate the tradeoffs seen between energy expended for movement and the additional energy gained by repositioning itself. It is without question that aiming the solar panel at the source of sunlight will increase electrical intake; however, it is yet unknown whether movement can also play a role in this collection process. Therefore, success is defined by achieving greater net energy generation over a full daylight cycle compared to an equivalently sized fixed solar panel.

Though autonomous in nature, our goals do not completely neglect human interaction with the project. For these reasons, we need observable data that gives us insight into efficiency and mobility. The robot should also serve as a platform for observing some of its most basic operating behaviors. Key metrics like battery life, charging rate, and distance traveled should be available to the user through a wireless connection. This system should also support safe operation, as it is meant to be autonomous in nature but observable by a user. The robot should be able to identify an event, such as a collision, and perform a maneuver to avoid the continuation of the event. These goals ensure autonomous operation, which can remain practical and robust for a real-world setting while also keeping the project innovative and fresh.

2.3.2.2 Advanced Goals

An advanced goal of the project is to ultimately enhance user interaction through the usage of a mobile application. The mobile application will serve as the primary interface between the user and the robot. With this platform, we can provide performance metrics, system behavior, and influence robot operation without touching the robot physically. In the mobile application, users should be able to select between one of two modes. These two modes exist transparently but functionally work the same. One mode allows the bot to become stationary, and the bot will function as a traditional solar harvesting setup with a rotating solar panel. The other mode would be default, as the robot’s full autonomous nature would allow it to navigate on its own and relocate if necessary.

This fully autonomous behavior highlights an advanced goal for this project as the robot is given complete control over its own decisions. The robot will be responsible for its energy management, navigation, and overall decision-making. In this mode, the robot will systematically evaluate conditions to determine if movement is necessary and then avoid obstacles on its way to a perceived optimal solution. All while a user can watch over system metrics via a wireless connection to the robot. This presents the last advanced goal of our project, which is to present relevant data to the user's device. On the device, metrics like distance traveled, temperature, and charging rate can all be displayed. Displaying this data allows a user to understand the robot's behavior while answering an important question about the robot's functionality.

2.3.3.2 Stretch Goals

To expand upon our advanced goals, we would like to introduce additional functionality that can enhance user control, system intelligence, and long-term data analysis. With these features, we could apply a more sophisticated system to explore decision-making capabilities that expand upon the original core system requirements for functionality. One such stretch goal is to expand upon a manual control system from the user interface of the application. This could include finer control over movements, adjustments for speed, and the ability to directly interact with solar panel orientation. Ultimately, these adjustments would provide users with greater flexibility in their own use of the platform. Similarly, this would require a much more robust design, allowing for a much more fine-tuned system entirely.

In addition to mobile application enhancements, there could be an integration of higher-level control logic or the mounting of an artificial intelligence to improve autonomous behavior. This next level of autonomy could enhance decision-making behavior capable of strategizing navigation. The robot would also be capable of a higher level battery management with adaptive battery level thresholds and movement statistics. These upgrades would allow the system to better respond to changing environmental conditions, which could produce increased performance over time. To expand on connectivity, the robot could alternatively connect to a web-based interface where the structure of the app would be mirrored, but would apply a more practical interaction. The website would not provide direct communication with the robot, but would alternatively allow for more detailed logging of events and statistics for later consumption. All stretch goals mentioned support a long-term analysis and provide a more accessible platform for interaction with the robot.

2.3.4 Basic Objectives

- Design and fabricate a mobile robotic platform driven by DC motors and a motor driver capable of traversing flat outdoor terrain such as yards or open fields.
- Implement a mechanically actuated solar panel mounting system using a motorized joint to enable controlled rotation and tilt for sunlight alignment.
- Integrate obstacle detection sensors (ultrasonic sensors) and low-level motor control logic to support autonomous avoidance of environmental obstacles.
- Incorporate onboard energy storage, charge regulation, and efficient power distribution circuitry to support simultaneous solar charging and system operation.
- Develop embedded control firmware on a microcontroller to manage motion control, sensor input, and autonomous decision-making.

- Measure and record battery voltage, charging current, and power consumption using onboard sensing circuitry.
- Implement wireless communication hardware to transmit system metrics and operational status to an external user device.
- Detect collision or near-collision events using physical or proximity sensors and trigger corrective motor commands to prevent sustained contact.
- Ensure the system can operate autonomously without external power or physical user input after deployment.

2.3.5 Advanced Objectives

- Support multiple operational modes selectable via wireless communication, including:
    - A stationary mode where only the solar panel actuation hardware is active.
    - A fully autonomous mode where the drive motors and sensors are continuously engaged.
- Integrate wheel encoders or equivalent motion sensing to quantify distance traveled during autonomous operation.
- Design the electronics and firmware architecture to allow modular expansion of sensors or actuators without redesigning core subsystems.

2.3.6 Stretch Objectives

- Implement manual motor and panel control through the application by directly commanding motor drivers and actuators.
- Develop a web-based interface to visualize logged system data independent of direct robot communication.
- Use hall effect sensors to detect collisions as a bumper instead of checking if an axle has difficulty moving through the encoder.

2.4 Required Specifications

2.4.1 Overall System Specifications

Table 2.4.1 *Energy Specifications*

Energy Specifications		
Specification	**Description**	**Target Value and Unit(s)**
Energy for User	After a sunny, optimal day, the system shall provide the end user with at least 15 watt-hours (Wh) of usable energy from the battery.	≥15 Wh/day
Energy Generated	After a sunny, optimal day, the system shall generate at least 75 watt-hours (Wh) of electrical energy through solar harvesting.	75 Wh/day
Power Output Connection	A USB-C Power Delivery (PD) connection shall be provided for user energy extraction from the system.	USB-C Power Delivery (PD)
Power Input Connection	A USB-C Power Delivery (PD) connection shall be used to charge the system battery.	USB-C Power Delivery (PD)

Table 2.4.2 *Mobility Specifications*

Mobility Specifications		
Specification	**Description**	**Target Value and Unit(s)**
Max Forward Robot Speed	Maximum designed robot speed (forward).	0.3 m/s
Average Robot Speed	Normal forward robot speed.	0.1 m/s
Max Reverse Robot Speed	Maximum designed robot speed (reverse).	0.3 m/s
Weight		<30 lbs
Solar Panel Rotation	Pan axis range of motion.	360 Degrees

Mobility Specifications		
Solar Panel Tilt	Tilt axis range of motion.	45 Degrees

2.4.2 Component System Specifications

Table 2.4.3 *Component Specifications*

Component	Parameter	Subsystem and Description	Target Value and Unit(s)
Geared BDC Motor w/ Planetary Gearbox	Torque	4 Motors that provide the means of rotating the wheels for movement.	24V, 48W, 23RPM
Solar Panel	Power	Primary source of energy for battery charging.	20 Watts
Solar Panel	Voltage	Voltage level that solar panel operates at.	12 V
Battery	Capacity	Powers all devices on the robot system.	128 Wh
Pneumatic Knobby Tires	Size	Wheels that each motor will be linked to via a shaft.	4”
High Torque Worm Gear BDC Motor w/ Self Locking	Torque	Motor for pan-axis rotation of solar panel.	24V or 12V 5RPM
Bluetooth Low Energy (BLE)	Wireless Communication Range	Communication subsystem. Used to send data from the robot to a mobile app.	1-6 meters
Linear Actuator	Torque	Tilt-axis motion for solar panel	200 N-M, 4” Stroke
PWM H-Bridge Motor Drive	Amps	3 boards for driving the motors and linear actuator	10 A
5V Regulator	Volts	Regulator for sensors (ultra-sonic sensor)	5 V
3.3 V Regulator	Volts	Regulator for photoresistors	3.3 V

2.4.3 Hardware and Software Diagrams + Prototype illustration

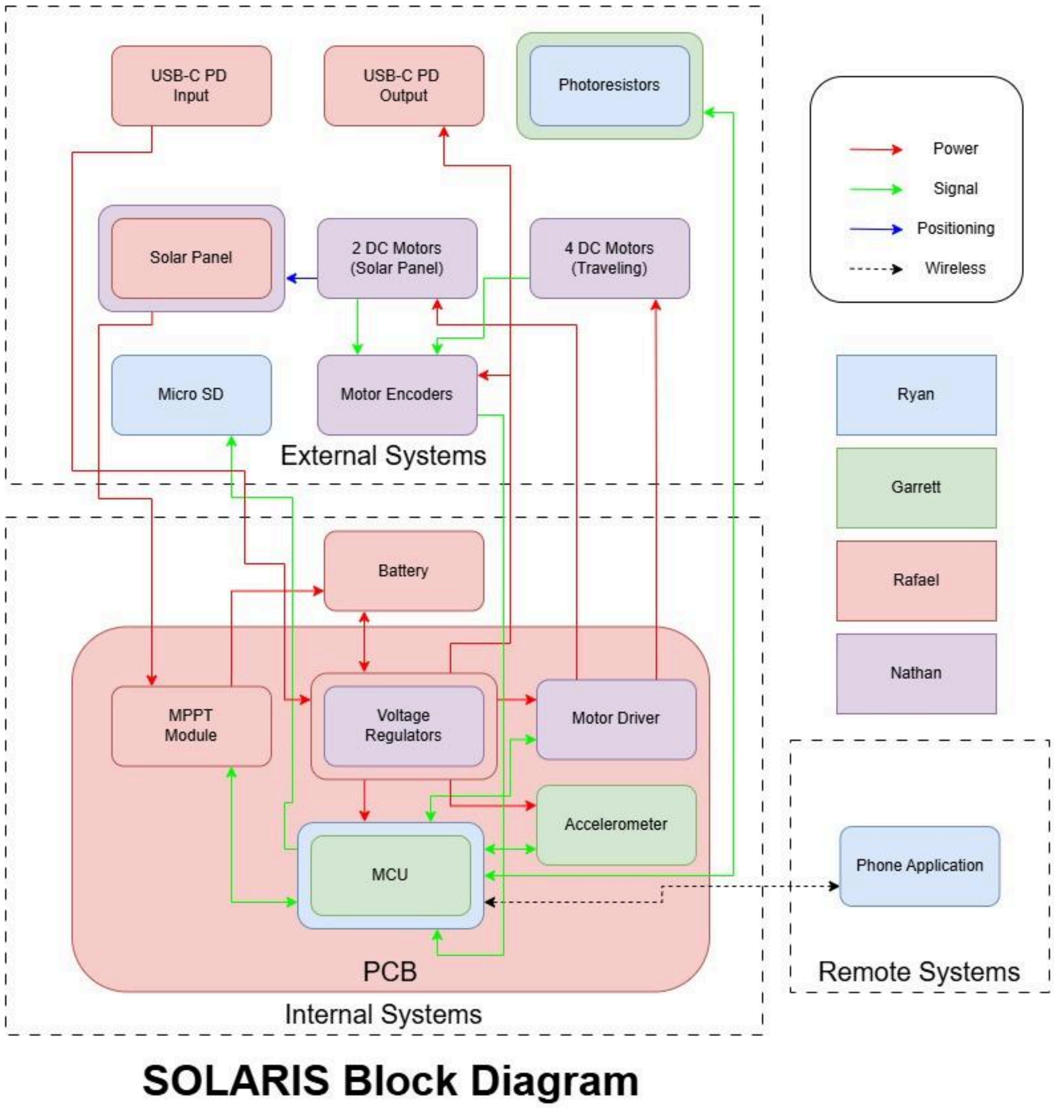


Figure 2.3. *Hardware Block Diagram*

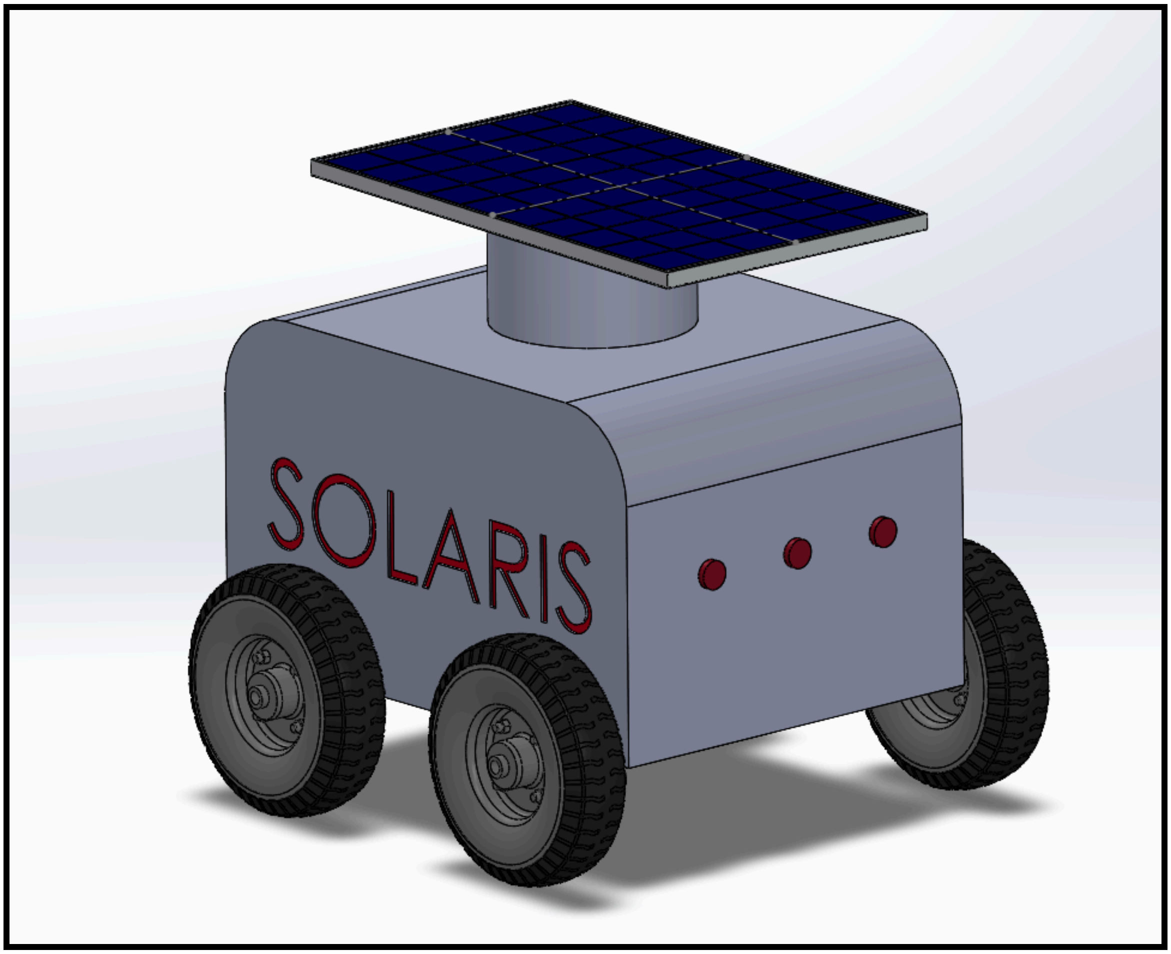
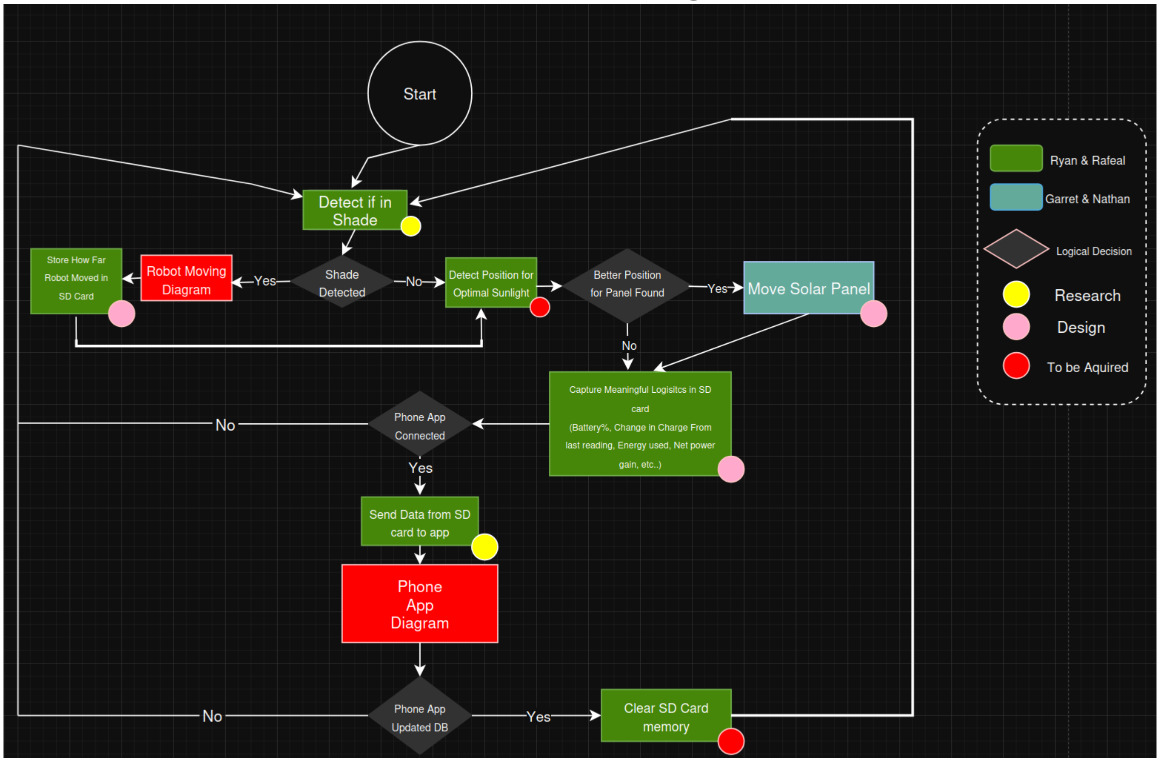


Figure 2.4. *SOLARIS Prototype Illustration*

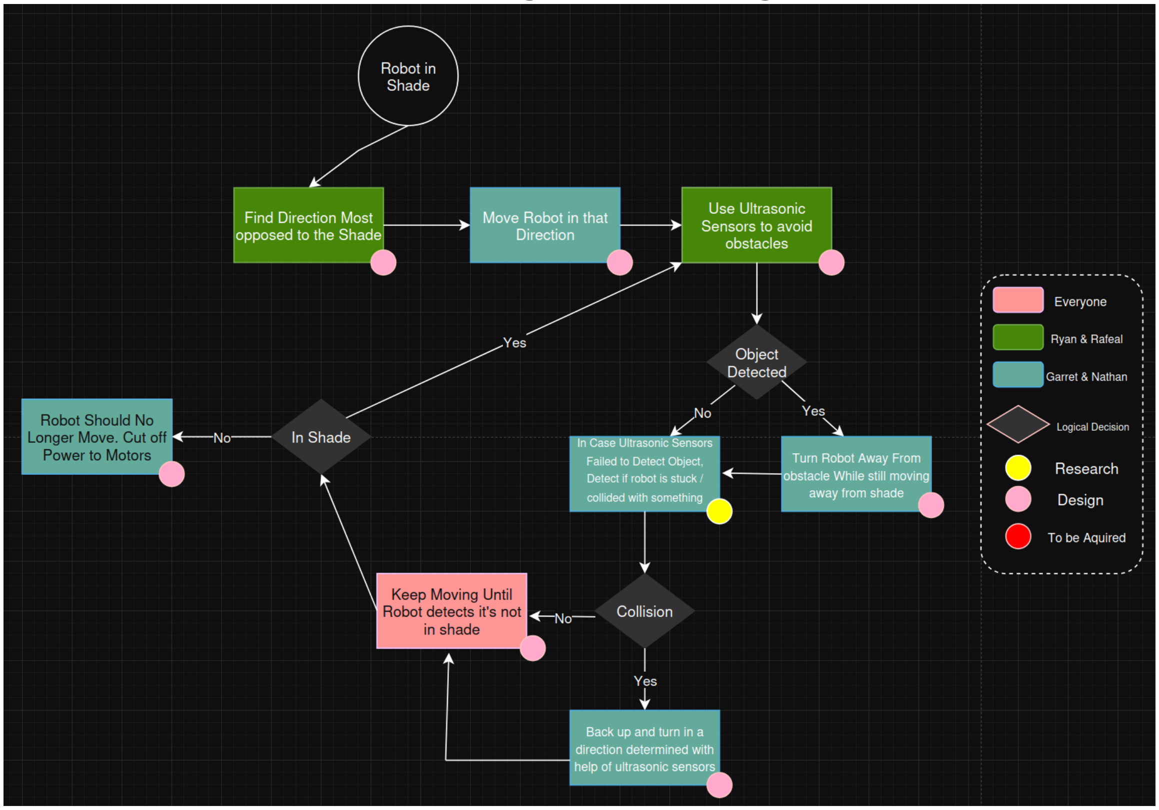
Main Function Diagram



Above is the software diagram for the main control of SOLARIS. It mainly goes over what happens when shade is detected and when to move solar panels, and log statistics.

Figure 2.5. *SOLARIS Main Function Software Diagram*

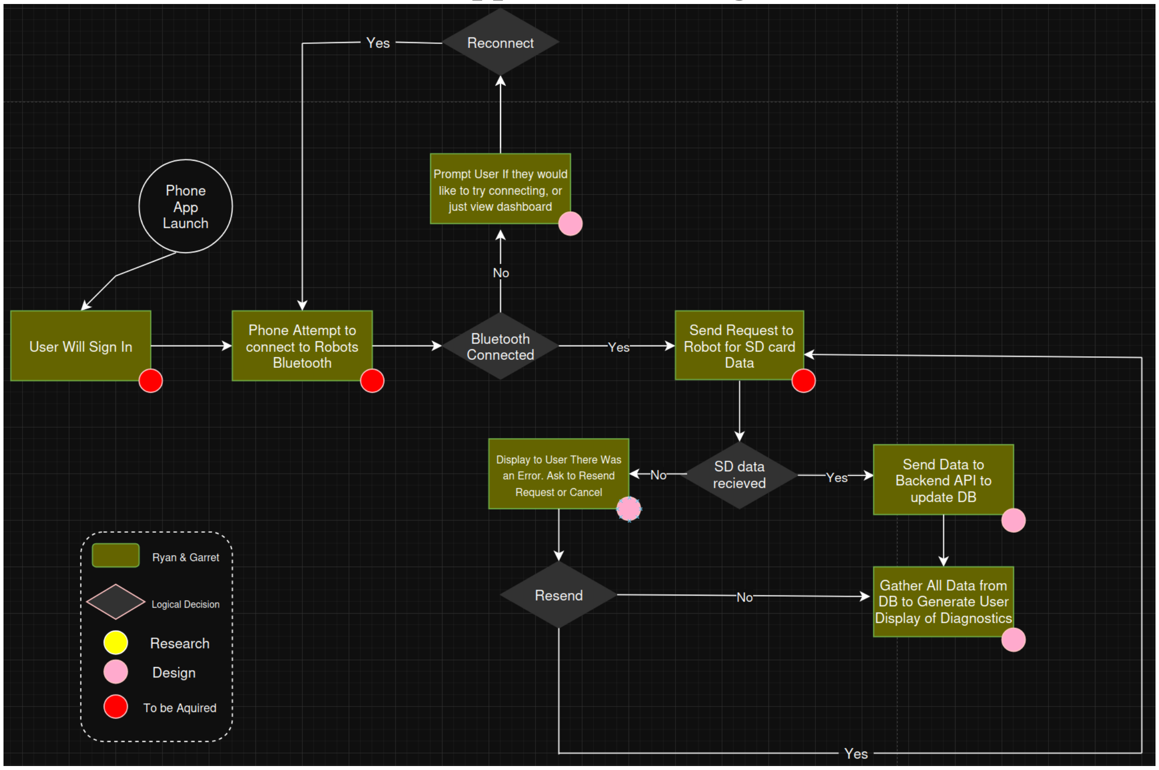
Robot Driving Software Diagram



Above is the software diagram for the robots driving functionality. It describes how the robot moves to the sunlight while avoiding objects and handling collisions

Figure 2.6. *SOLARIS Robot Driving Software Diagram*

Phone App Software Diagram



Above is the software diagram for the phone app functionality. It shows what happens when data is collected from the robot, how connectivity issues are handled, and ultimately how statistics from the robot are displayed

Figure 2.7. *SOLARIS phone app Software Diagram*

2.5 Design Requirements

2.5.1 Marketing & Engineering Requirements

Table 2.5 *Justification Chart for Requirements*

Marketing Requirements	Engineering Requirements		Justification
1, 2	1.	Rover should reposition itself autonomously toward higher light intensity using sensors and the control system.	The ability to autonomously reposition corrects inefficiencies in fixed solar harvesting systems while reducing the need for manual intervention.
1, 2, 4	2.	The system should operate in low-power sleep mode while charging, consuming <300mW in the idle state.	Low-power operation lets the system maximize energy gain while extending operational lifetime; the bot can outlast suboptimal weather conditions entirely.

1, 2, 3	3.	The rover should detect obstacles within a minimum range of 20-50 cm accurately using ultrasonic sensors to avoid collision.	Automated obstacle avoidance ensures reliability in dynamic real-world environments, whether outdoors or indoors.
2, 3	4.	The system should provide real-time battery voltage, charging current, and charge state data.	Being able to monitor energy metrics allows users to evaluate system performance like distance traveled, battery level, and charging statistics.
2, 3, 4	5.	The rover should communicate wirelessly with a smartphone via Bluetooth Low Energy (BLE).	Bluetooth Low Energy (BLE) enables low-power communication with user devices, making it suitable for field deployment and demonstrations.
1, 3	6.	Rover should have four wheels with encoders to estimate distance traveled and improve distance traveled accuracy.	Feedback from encoders provides improved navigational efficiency while allowing precise movements to be made for travel.
3	7.	The system should require no external infrastructure for normal operation.	An independent infrastructure makes deployability a priority, allowing for remote or agricultural environments.
4	8.	Total system hardware cost shall not exceed $1000	Cost constraints enable feasibility for deployment while also aligning with the competitive market for low-cost energy monitoring.
3, 4	9.	The system should be implemented on a single custom PCB with modular sensor connections.	Custom PCB demonstrates design project integrity, while the modularity of sensors allows for an easier debugging process.
4, 5	10.	The charging system for solar-battery should exceed an efficiency of >50% under nominal operating conditions.	An efficient charging system is achievable using commercial MPPT-based Li-ion charging ICs and demonstrates the balance between complexity, cost, and performance.
5	11.	The System should operate reliably in outdoor lighting and temperature without user intervention.	The reliability of an unattended rover in a working environment increases the number of practical applications.

1, 2, 4	12.	The rover should operate for a minimum of 72 hours without solar input under normal conditions.	Ensuring continued operation even during sub-optimal conditions demonstrates robust power design and applicability in differing environments.
Marketing Requirements **1. The system should maximize solar energy harvesting through autonomous behavior** **2. The system should operate reliably with minimal human intervention** **3. The system should be easy to deploy and monitor** **4. The system should be low-cost and energy-efficient** **5. The system should be reliable in a real-world operating condition**			

2.5.2 House of Quality

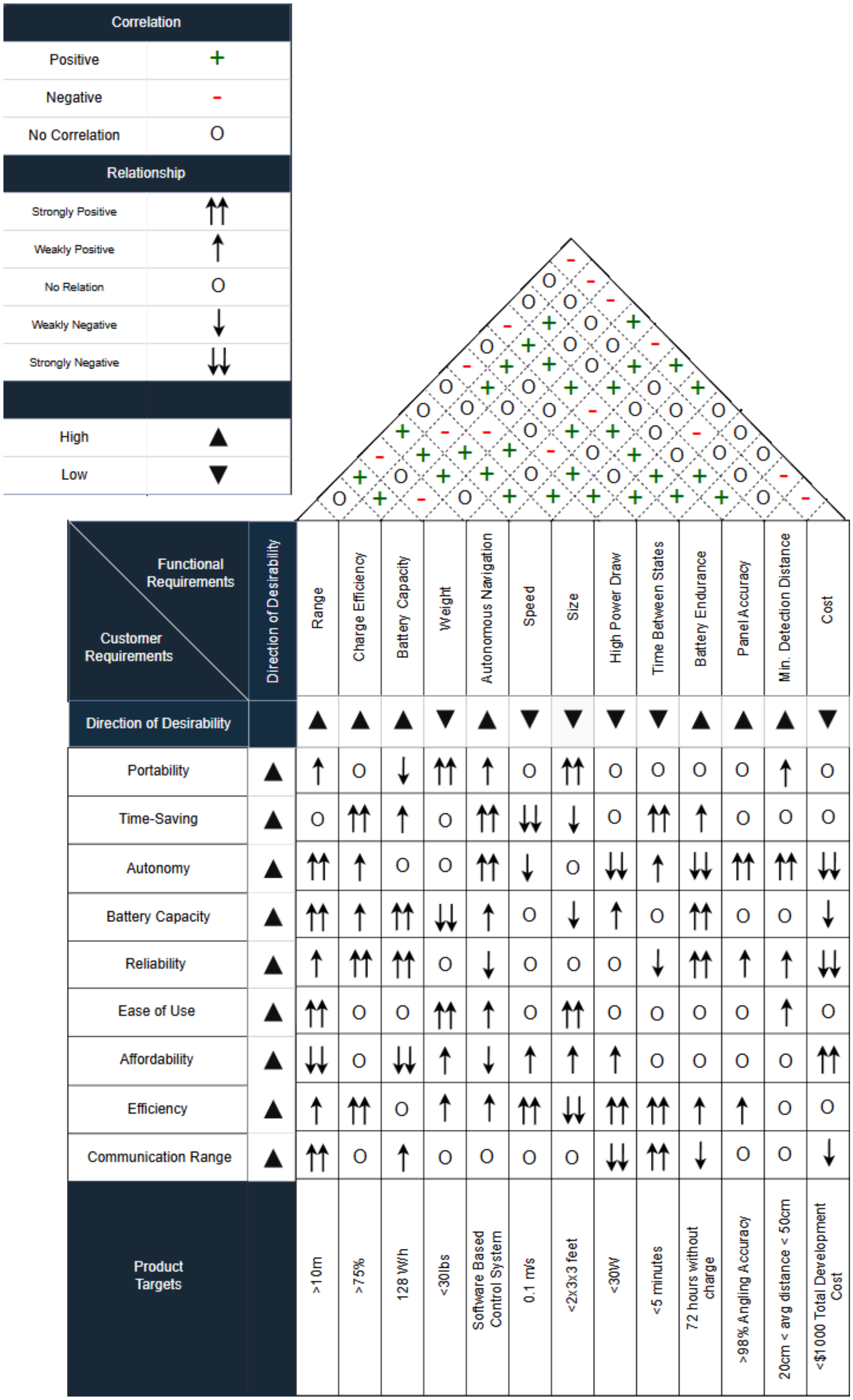


Figure 2.8. *House of Qualities*

Chapter 10 - Administrative Content

10.1 Budget

The total budget allocated for the SOLARIS project is approximately $1,000. This budget is intended to cover all major system components, including mechanical hardware, electronic components, sensing and actuation devices, power management hardware, and prototyping materials. Funds are also reserved for iterative development and testing, allowing for component replacement or redesign as needed throughout the project lifecycle. Establishing a defined budget constraint ensures that design decisions remain practical and encourage cost-effective engineering tradeoffs while still meeting the project's functional and performance objectives.

10.2 Bill of Materials

Table 10.2 *Itemized Bill of Materials*

Component	*Part Name*	*Quantity*	*Unit Price*	*Total Price*
Ultrasonic Sensor	HC-SR04	1 pack of 5	$8.99	$8.99
Photoresistors	GL5528	8	$0.5	$4.00
MCU	ESP32-S3	1	$1.85	$1.85
Magnetic Encoders	AS5600	2 packs of 3	$8.99	$17.98
MCU dev kit	ESP32-S3-Dev Board	1 Pack of 5	$32.99	$32.99
Solar Panel	ACOPOWER 20W Mono Solar Panel	1	$39.50	$39.50
Battery	NERMARK 12V 10Ah LiFePO4	1	$31.99	$31.99
Wheel	am-2256_blk	4	$9.60	$38.40
Wheel Motor	M42B30-24P-30S/G 42-99.5S1	4	$39.90	$159.60
Pan Motor	5840WG-555PM-522-EN 24V	1	$27.50	$27.50
Tilt Linear Actuator	OK648	1	$32.99	$32.99
SD Card	TS4GUSDHC10	1	$6.50	$6.50

SD Socket	MEM2061-01-188-00-A	1	$1.06	$1.06

10.3 Distribution of Work

Table 10.3 *Distribution of Work*

Electrical Engineering	Responsibilities
Rafael Puig	Input and output port configuration from the user
	Battery safety and power system design
	Lead PCB design
Electrical Engineering	**Responsibilities**
Nathan Hammond	Servo and motor technology
	Design of the power delivery system
	Co-Lead PCB design for drivetrain control
Computer Engineering	**Responsibilities**
Ryan Markowitz	Phone app design for interface with the MCU
	Software lead for IoT connection
	Co MCU firmware design
Computer Engineering	**Responsibilities**
Garrett Fortier	Lead MCU firmware design and debug
	Automation for the self-driving algorithm and modularity
	Hardware/Software integration

10.4 Milestones

Table 10.4 *Milestone Progress*

Milestone Number	***Milestone Description***	***Start Date***	***Anticipated End Date***	***Dependencies & Requirements***
#1	Recruitment	01/12/2026	01/16/2026	Scout for potential team members interested in working together
#2	Brainstorming	01/16/2026	01/22/2026	Talk with one another briefly

				over a week to discuss ideas
#3	D&C Document	01/22/2026	01/30/2026	Divide up the task and work independently to add relevant information
#4	Mentor Meeting	02/04/2026	02/04/2026	Meet with Dr. Suboh for D&C revision
#5	60-Page Milestone	02/06/2026	03/27/2026	Work will be divided up, and then relevant portions of the paper will be written
#6	Final Document	03/01/2026	04/28/2026	All group written portions will be formatted onto one document

Appendices

Appendix A – Reference

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