The MARGE System

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Table of Contents

List of Figures

Background

Over the course of the last two semesters, we have worked on creating the Mobile and Autonomous Roadway Guardian Entity (MARGE) system. Overall, this system is battery powered with solar charging functionality. The MARGE device consists of two components - a mobile unit, the Rover (which prevents road access to specified cars) and a stationary unit, the Docking Station (which serves as a dock and charger). The MARGE system is intended to prevent unwanted vehicles from proceeding down residential driveways or cul-de-sacs. It achieves this through visual means, sending a rover from a docking station to a set location in the middle of the road. The MARGE device is equipped with a raisable traffic cone to identify that said location is supposed to remain unentered.

Requirements

The MARGE device is intended to provide an end user with a modular solution to unwanted traffic around their place of living. Primarily, the device is intended to be asynchronous and discriminate. It achieves this through three possible modes of operation:

- **Mode A**, or "**Normally Closed**" where the MARGE rover is positioned on the road and driveway access is only granted when a recognized vehicle is present. This is facilitated by a wireless key onboard the vehicle.
- **Mode B**, or "**Normally Open**" where the MARGE rover is positioned within the docking station and prevents access only when an unrecognized vehicle is present. This is facilitated by a wireless key onboard the vehicle as well as two radars positioned on the station.
- **Mode C**, or "**Scheduled**" where the end user specifies intervals over the course of the day where the MARGE rover is either active (on the road) or inactive (within the station).

User interface with the MARGE is intended to be easy and seamless, with minimal inputs occurring. This occurs through a screen mounted on the docking station as well as a separate remote control. These methods of control are simple, yet effective, allowing the end user to swap between operating modes as best suits their needs at the moment.

The MARGE system was designed following these specifications:

- The **Marge System Setback (MSSB)** is proposed to be 30m for the Normally Open mode.
    - When an unauthorized vehicle comes within 30m of the docking station, the rover will leave to obstruct it.
- The **Marge System Setback (MSSB)** is proposed to be 10m for the Normally Closed mode.

- When an authorized vehicle comes within 10m of the docking station, the rover will return from the and allow it to pass.
- The **Recognized Vehicle Sensing Distance (RVSD)** target will be 500m.
    - The docking station can sense and prepare for an authorized vehicle from 500m.
- The **Unrecognized Vehicle Sensing Distance (UVSD)** will be 120m.
    - The docking station can sense and prepare for an unauthorized vehicle from 120m.

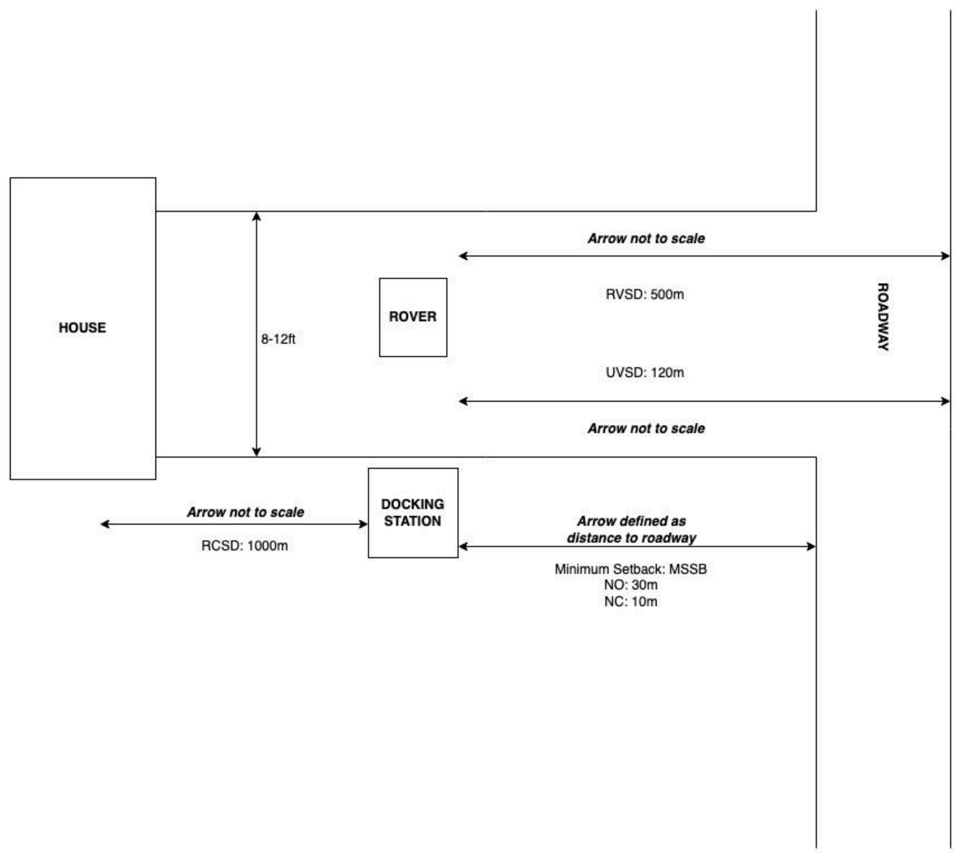


Figure 1: MARGE System Operation Diagram with Defined Distances

Mechanical Design

Rover

The mobile module for the MARGE device will act as a visual aid to deter vehicles from moving down a specified driveway. This rover is intended to be a passive indicator, and should not directly interact with a vehicle. While not within its charging station, the rover sits in the middle of a driveway awaiting instructions.

Without wheels, the chassis is 14 inches wide, 18 inches long, and 8 inches tall. Including wheels adds about 2 inches in height and 3.2 inches in width. For versatility and efficiency, it was decided to use different front and back wheels:

- **Front:** For movement, two 6 inch wheels are connected to drive motors and function as the way to and from the charging station. The rover is not intended to turn around. As such, the wheels will be front-wheel drive when exiting the station and rear-wheel drive when returning.
- **Back:** For guidance, two 4 inch omnidirectional wheels are left unconnected on the back of the rover. These allow the rover to pivot side-to-side without dragging on the ground, allowing for easier steering. Additionally, they serve as guidance wheels, fitting into the channels located on the floor of the station.

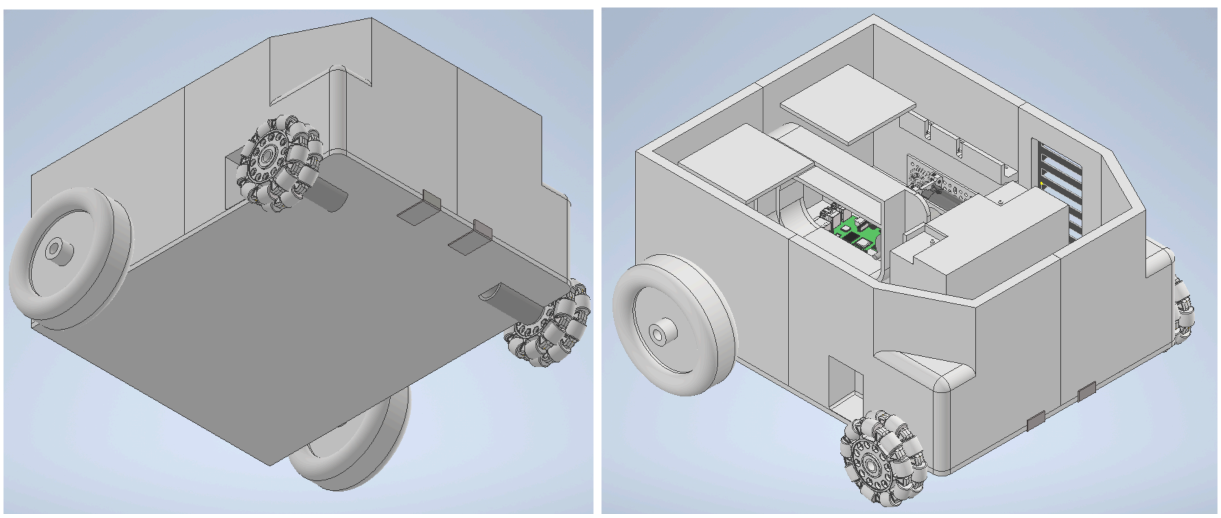


Figure 2a & 2b: Rover Bottom and Top View Without the Roof

The rover will consist of four 3d printed segments screwed into brackets connected to a base plate. Both the base and roof plate are constructed from polypropylene plastic. Located on the side wall is an air intake vent which will have a fan that provides cooling to the components within. On the back of the rover are metal female contacts intended to touch their male counterparts located on the bottom of the docking station. These facilitate charging of the rover.

Components located within include:

- A battery to power the many devices on the rover and ensure it has enough power to always return to the station.
- A main power switch located on the outside of the chassis in order to turn off all power to the Rover’s components.
- A Raspberry Pi camera utilized for navigating to and from an ArUco tag located within the docking station.
- An Arduino MEGA microcontroller serving as the main navigational control.
- Several circuit boards involving power distribution and motor control.

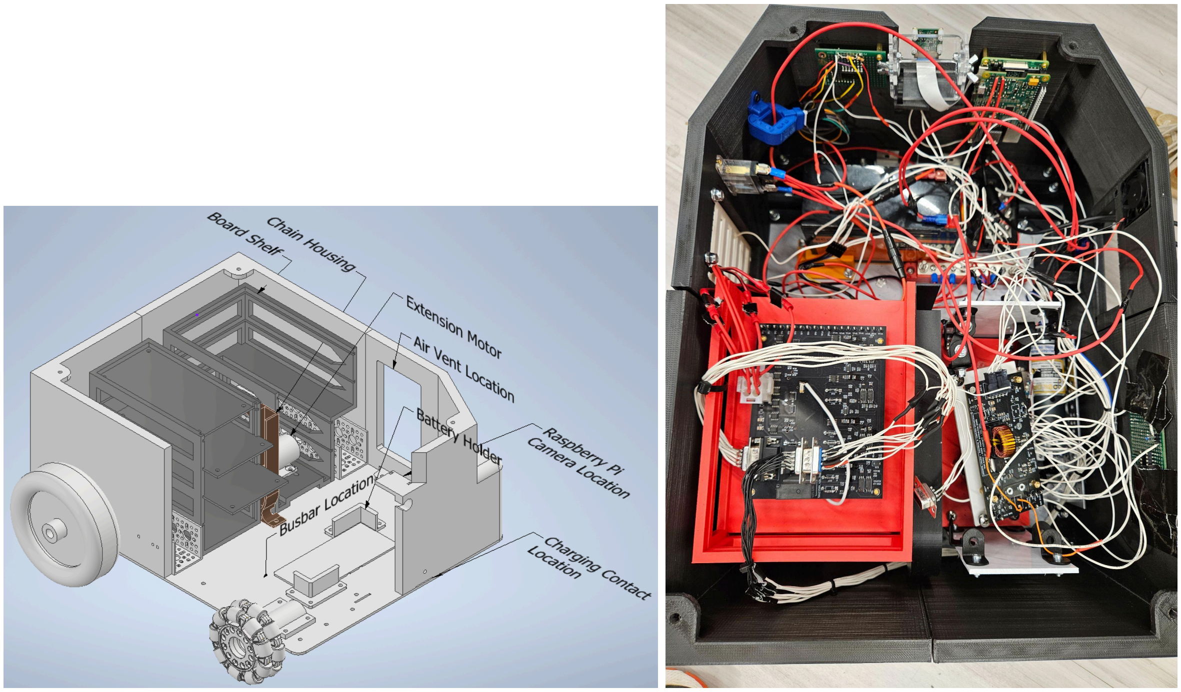


Figure 3a & 3b: Rover Internals

Additionally on the rover is a passive, visual aid to inform vehicles the driveway is not for use. This takes the form of an articulating cone which can raise and lower depending on the position of the rover. This cone is 3d printed in several interlocking segments and raised by a 3d printed chain system. This system is manipulated by a motor connected to its own controller board.

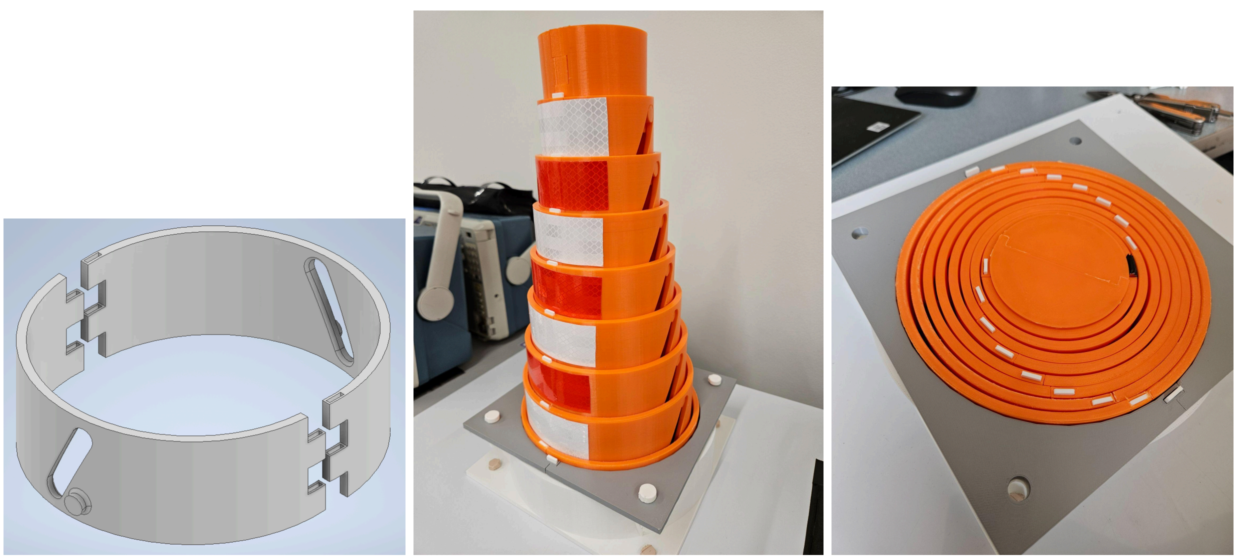


Figure 4a, 4b & 4c: Complete Cone System

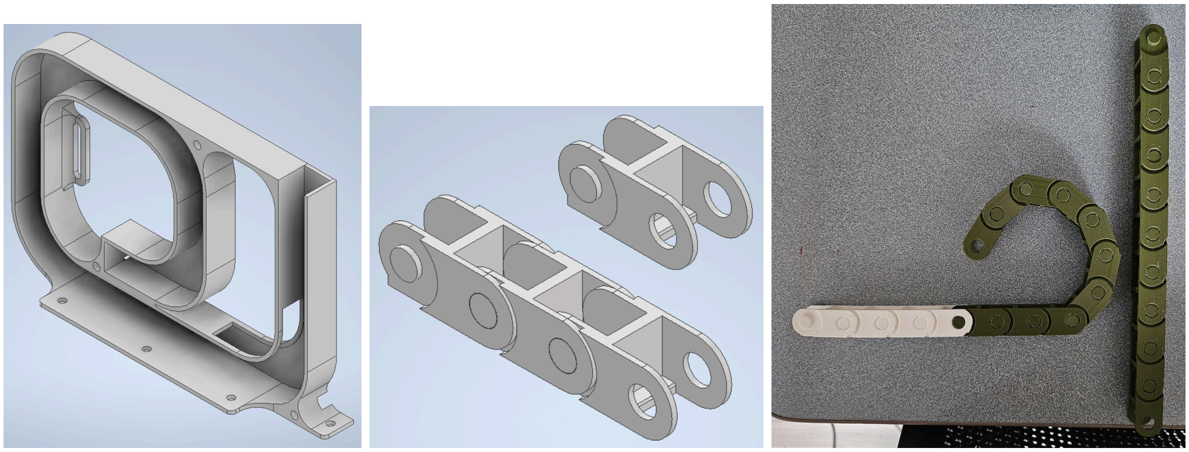


Figure 5a, 5b & 5c: Chain System

Docking Station

The stationary module for the MARGE device will act as a place to dock for the mobile portion. It provides a place to return to when not in use and provides the ability to charge, as well as cover from the elements. When the rover is not within the docking station, it will receive commands such as navigational aid or incoming vehicle notifications. This station is to be positioned on flat ground next to the patrolled roadway and must not be moved during operation. Overall, the station will be 22 inches wide, 30 inches long, and 20 inches tall, constructed from aluminum T Slot beams covered with polypropylene panels. The panels will be attached through M5 size screws for easy access to the different compartments within the station.

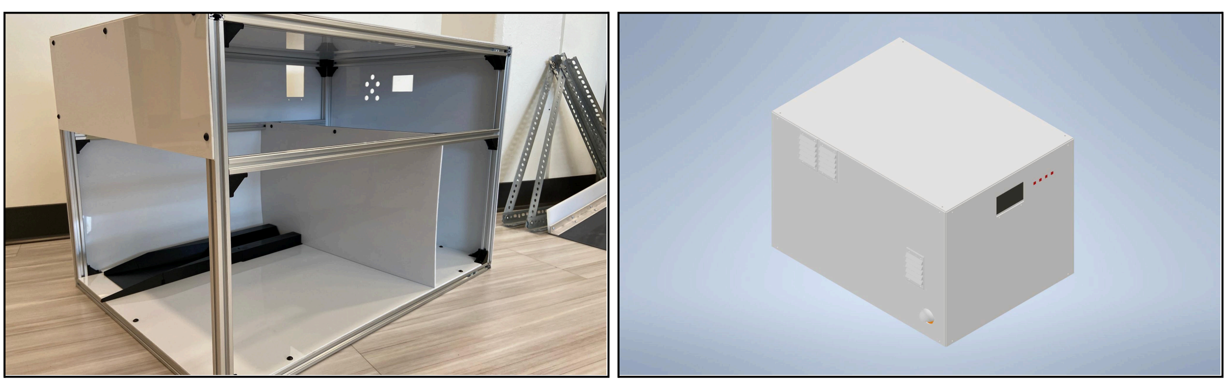


Figure 6a & 6b: Construction of Docking Station Front and Model of Back

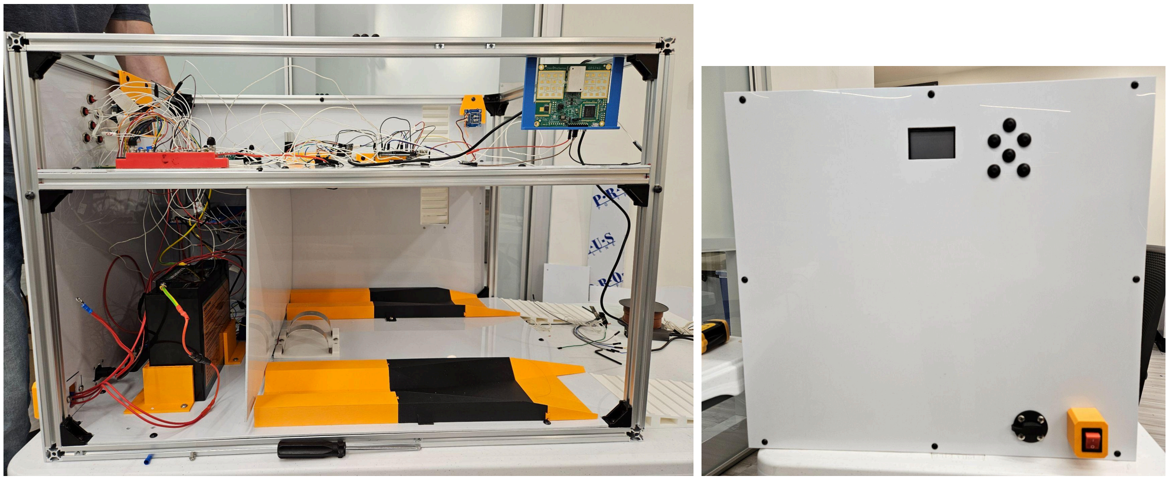


Figure 6c & 6d: Docking Station During Construction and Back of Docking Station

The internals of the station are divided into three compartments:

- **TOP:** This 30” x 22” x 6” section contains all peripherals and electronics utilized in the station. The microcontroller controlling the station resides here, alongside two radars (used for vehicle sensing), nRF transceivers. This section will also provide the board for an outer facing screen (and control buttons). Additionally, there are outward facing ventilation ports which prevent overheating within this chamber.
- **BACK:** This 10” x 22” x 14” section is utilized for energy storage and contains a battery alongside controllers and a connection to a solar panel located outside of the station.
- **BOTTOM:** This 20” x 22” x 14” section is where the rover will reside. On the floor of this chamber are wheel guides to ensure consistent positioning when the rover would enter or exit. Additionally there are tensioned contact leads within these wheel channels that allow the rover to charge while inside. On the back wall is an ArUco marker utilized when navigating to or from the station.

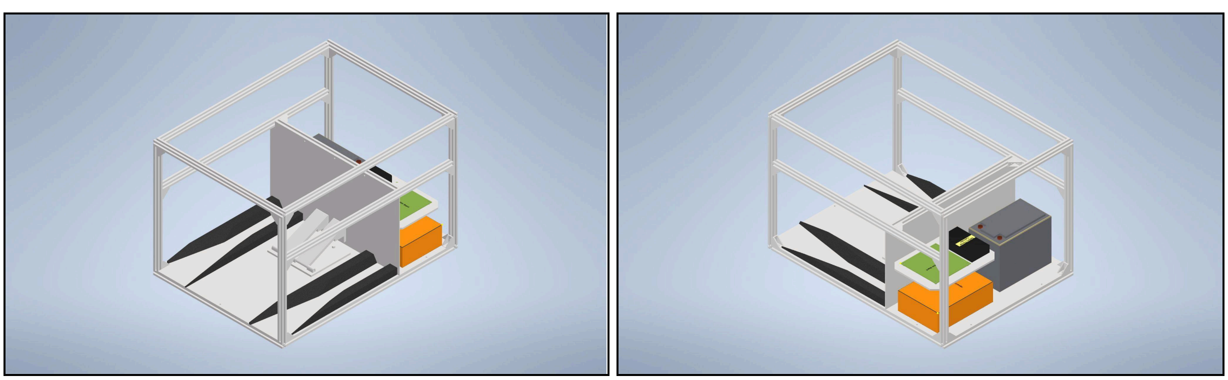


Figure 7a & 7b: Model of Lower Compartments of the Docking Station

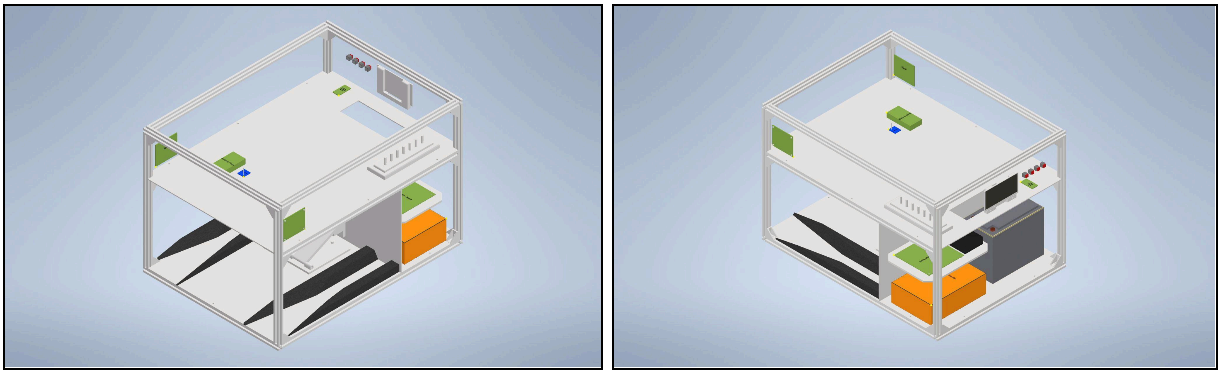


Figure 8a & 8b: Model of Upper Compartments of the Docking Station

Electrical Design

Power Distribution

Required for the MARGE system is solar charging functionality. As such, both the docking station and rover portions feature individual accumulator systems. Each will be equipped with a lithium iron phosphate battery (50Ah and 10Ah respectively). These batteries are in a 4-series configuration, providing a nominal voltage of 12.8V. Each portion also contains a hall effect sensor acting as a coulomb counter. This allows the system to detect its overall power consumption, whether it the rover is charging, as well as a state of charge for each battery.

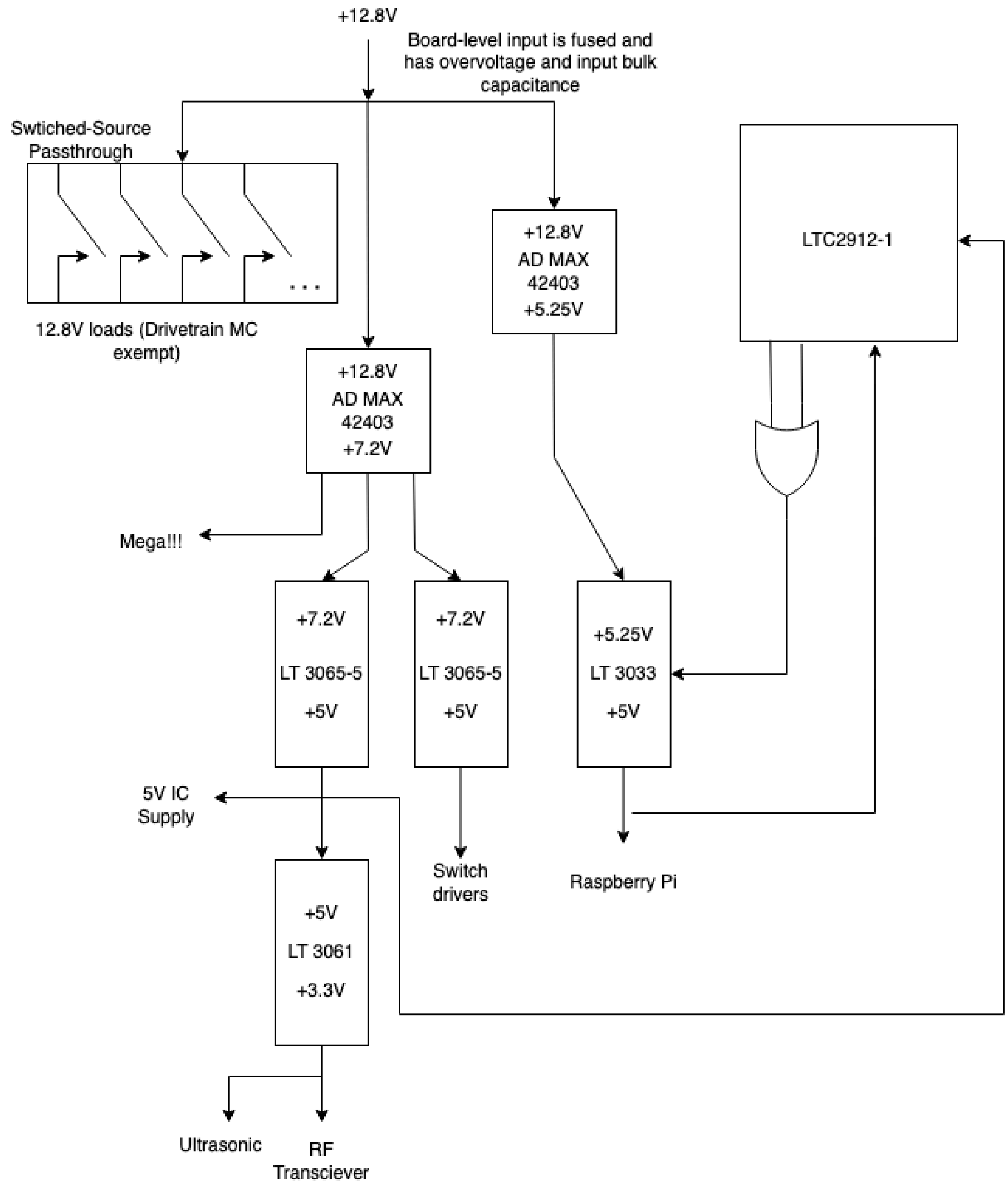


Figure 9 - Rover Power Distribution Top Level

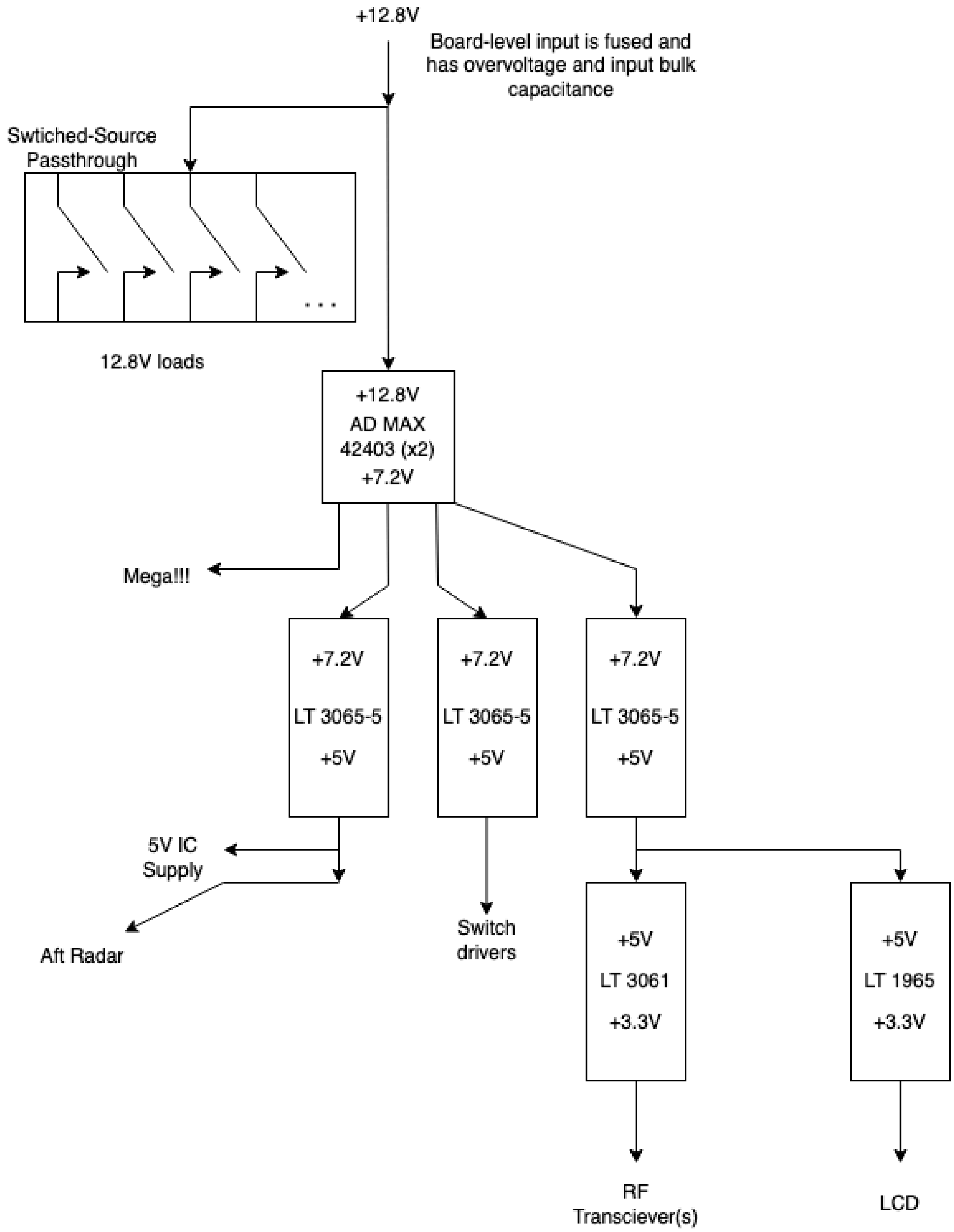


Figure 10 - Docking Station Power Distribution Top Level

Top-Level Electrical Design: Rover

The rover will contain several circuit boards each with a unique function:

- **Power Distribution:** This board contains six voltage regulators which provide 4 different levels of output voltage. These voltages are utilized throughout the rover for non-switching applications including a Raspberry Pi camera, RF transceivers, and an Arduino MEGA microcontroller.
- **Drivetrain Motor Controller:** This board is intended to run a pair of 12V brushed DC motors which will propel the rover. On the board is a pair of all N-Channel MOSFET H-Bridge drivers with an included fuse, relay, and opto-isolation (for microcontroller signal protection). Gate drivers receive a PWM in conjunction with an always on (when conduction through the motor is desired) signal from the Arduino for operation.
- **Barrier Actuator Motor Driver:** This board controls the raising and lowering of the visual cone. It achieves this through an H-Bridge controller by a PWM signal. Similar protections to the drivetrain board are taken.
- **Sleepy Pi:** This board is directly compatible with the onboard Raspberry PI camera. It manages power by putting the camera into a low consumption sleep mode under specific conditions.

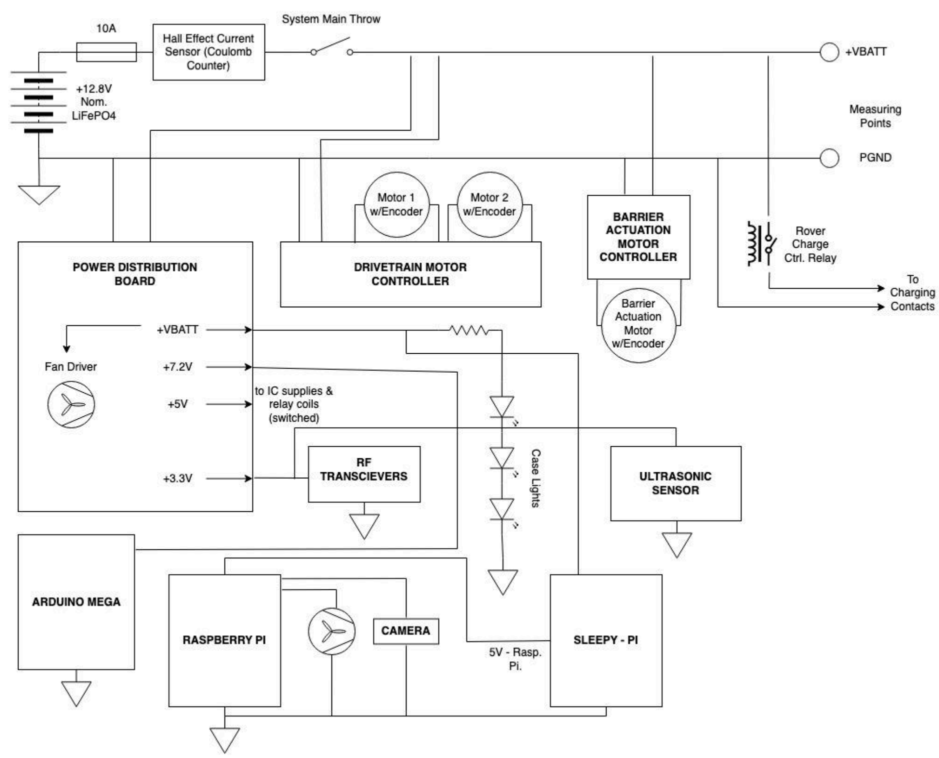


Figure 11: Top-Level Electrical Design - Rover

Top Level Electrical Design: Docking Station

The docking station will contain several circuit boards each with a unique function:

- **Power Distribution:** This board is very similar to the power distribution board on the rover, but with a few differences. This was done to increase simplicity in the design process. Chiefly among the differences is the need to power different peripherals. Being powered are both radars, RF transceivers, a fan, a projector LED (for visibility of the ArUco tag), and an Arduino MEGA microcontroller.
- **User Interface Controller:** This board (receiving some inputs from the microcontroller) interacts with outwards facing buttons and a screen and features a built in microcontroller and SRAM extension. It allows the user to visualize certain information and data pertaining to the MARGE system, as well as setting and modifying particular variables to their liking.

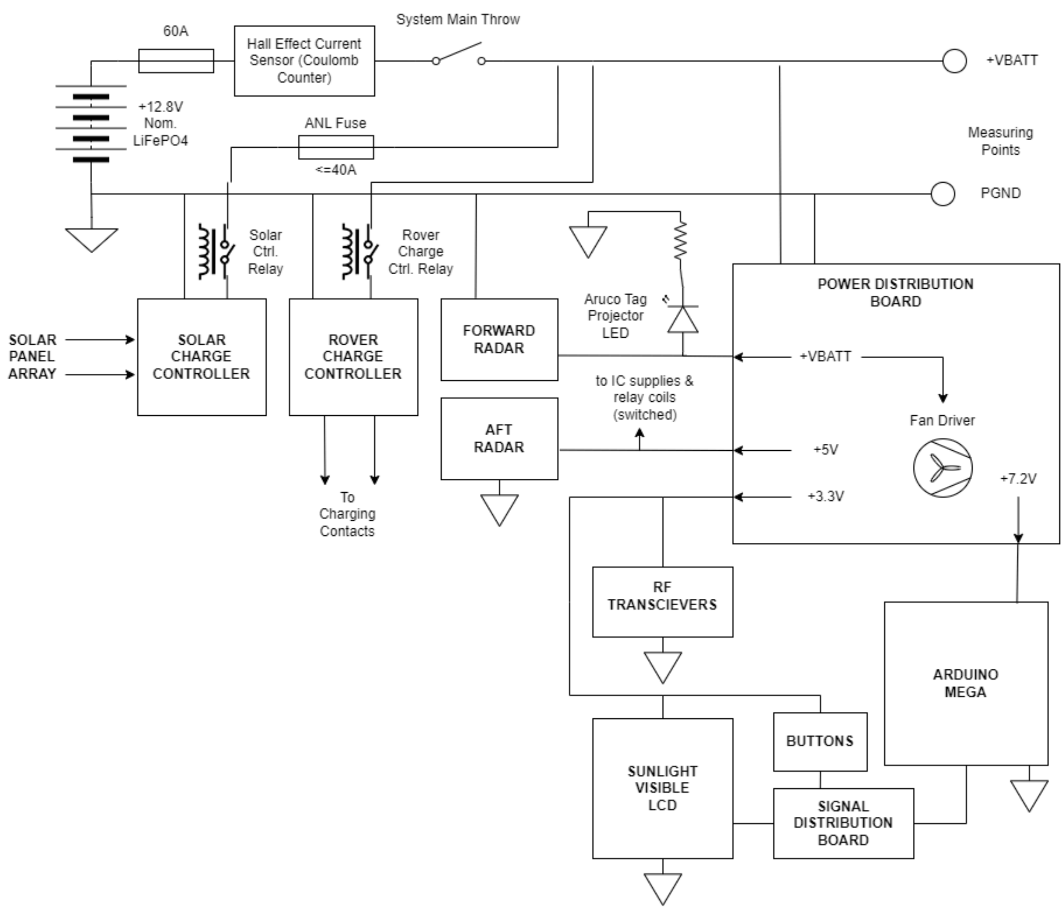


Figure 12 - Top-Level Electrical Design - Docking Station

Firmware Design

MARGE System Control/Functionality

In order to control the behavior of the rover, a finite state machine (FSM) will be implemented on an Arduino Mega that takes input signals from the remote, the beacon in the authorized vehicle, and the docking station. The rover will transition between states depending on these inputs and the mode that is set by the remote or the GUI. The variables utilized by the FSM include radar signals used in vehicle detection, navigation signals to communicate the rover's location, internal battery signals to track the device's charge, and signals from a user-controlled remote control to change modes from a distance.

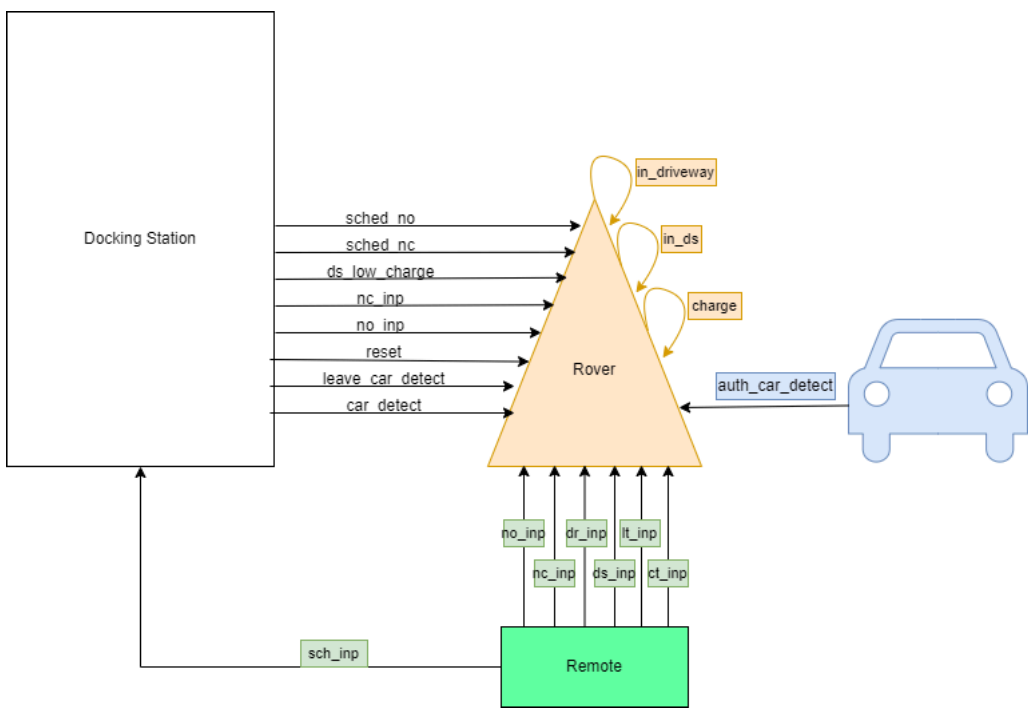


Figure 13: Signal diagram for the rover and the docking station

There are 15 states that are in the rover's FSM. The connections of the states are displayed in the state transition diagram below. The following list describes the detail of each mode as it transitions through the FSM:

- **NORMALLY OPEN:** The device will stay in the IDLE state until a "normally open" input comes from the docking station, the remote, or the scheduler. The device will then transition to the NO_IDLE state, where it will remain in the docking station until an unauthorized car is detected or a signal is sent for the device to switch modes. It then moves to the NO_TO_DRIVEWAY state where it remains until the navigation code signals that the rover is in the proper pose. The device then moves to the NO_DRIVEWAY state until the unauthorized vehicle is no longer detected. At this point, it will move to the NO_TO_STATION state and return to the docking station, unless the device is signaled to change modes. Once in the station, the device transitions back to the NO_IDLE state.

- **NORMALLY CLOSED:** The device will stay in the IDLE state until a "normally closed" input comes from the docking station, the remote, or the scheduler. As the rover moves to the center of the driveway, the FSM remains in the NC_MOVE state. Once it is in position, the device will transition to the NC_IDLE state, where it will remain in the driveway until an authorized car is detected or a signal is sent for the device to switch modes. It then moves to the NC_TO_STATION state where it remains until the navigation code signals that the rover is in the docking station. The device then moves to the NC_STATION state until the authorized vehicle is no longer detected. At this point, it will move to the NC_TO_DRIVEWAY state and return to the driveway, unless the device is signaled to change modes. Once in the station, the device transitions back to the NC_IDLE state.
- **SCHEDULED:** A scheduling encoder determines the desired state of the scheduled mode based on the time detected from a DS1307 chip that connects to the Arduino via an I^2C setup. If "sched_no" is asserted high, the device will follow the states for the Normally Open mode. If "sched_nc" is asserted low, the device will follow the states for the Normally Closed mode. If "sched_dw" or "sched_idle" are asserted high, the rover will remain in the driveway or docking station, respectively, until a signal is sent to change the scheduled mode or unless the "ds_inp" or "dw_input" signals are sent from the remote.
- **Battery Conservation:** In each state without active rover navigation, there is a check to ensure that the battery of the rover is greater than specified thresholds of 60% when leaving the docking station or 15% when in the driveway. If at any point the battery is below the appropriate threshold while in the driveway, the device will transition to the DRIVEWAY TO CHARGE mode, where it will move back to the docking station and transition back to the IDLE state. If the battery is below the 60% threshold while in the docking station, the device will transition back to the IDLE state. While in the IDLE state, the device will stay in a low-power mode where no signals will affect the mode change until the battery is charged.

Though not crucial to the device's behavior, the user also has the option to toggle the lights and the cone on the rover with the remote control. In all non-moving states except for IDLE, a function will be created that will toggle the lights or the cone depending on the signal it receives.

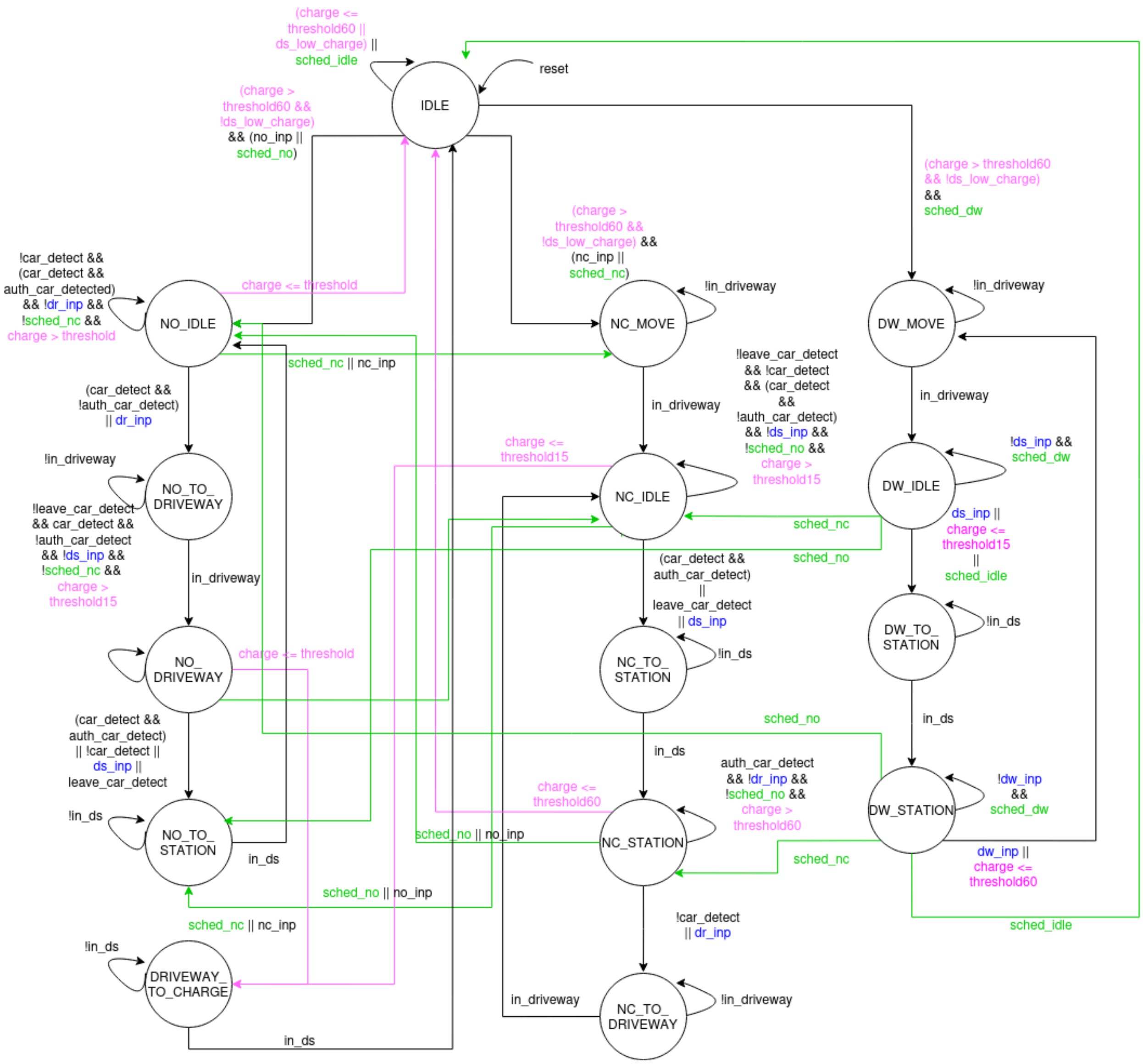


Figure 14: State transition diagram for the rover

Navigation

The mobile unit (rover) will drive to and from the stationary unit (docking station) to a specified position (most often the center of the user's driveway). This is facilitated by a custom drivetrain motor controller board linked to motors in the front of the rover. This board is operated through four PWM inputs derived from the Arduino MEGA microcontroller. These PWM are based on two onboard odometry calculations techniques. The first depends on openCV video data from a Raspberry Pi 4 camera. This camera will always be looking at an ArUco tag located within the docking station. Additionally, encoder data from the motors will be utilized as a backup in the case the openCV navigation fails.

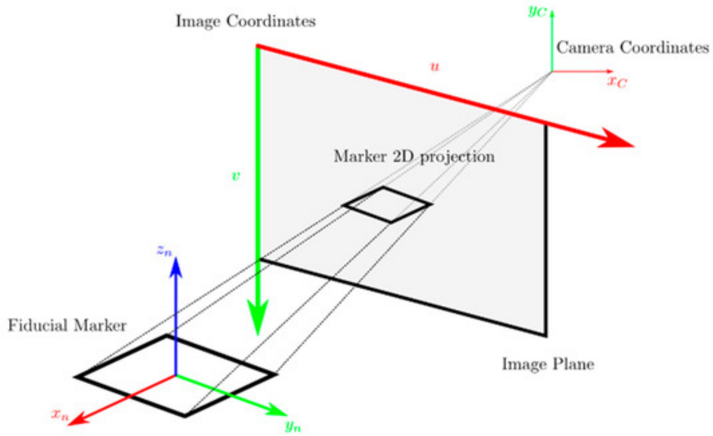


Figure 15 - Camera and Aruco frame representation w/ translation and rotation vectors.

Vehicle Sensing

In order to detect and authenticate vehicles, the system will employ two separate systems. For detecting authorized vehicles, a solution akin to a garage door 'clicker' will be used. After the user presses a button, the beacon sends a 24GHz radio signal to a RF transceiver onboard the docking station.

To detect unauthenticated vehicles, a passive system is utilized. This takes the form of a pair of radars (forward and backward facing) located on the docking station. The forward radar sees a vehicle, reports its velocity, and sends the rover to the center of the driveway to obstruct its path. The backwards radar will see a vehicle attempting to leave the drive and signals the rover to leave the road.

User Interaction

To make the device operate as needed, user control methods are integral. As such, multiple forms are provided to make operation as intuitive as possible.

Mainly, user input will take place through a sunlight visible LCD screen attached to the docking station. This screen will provide several options to the user, accessible through buttons attached underneath it. Foremost, this allows the user to change operating modes of the MARGE system. Additionally, it will allow specific settings to be manipulated so the devices function exactly as desired.

Additionally, a handheld remote is included to determine the operating mode of the MARGE system from a convenient distance. In addition to changing modes, the remote will have additional functionality including the manual raising and lowering of the visual aid cone, as well as turning on and off lights on the rover.

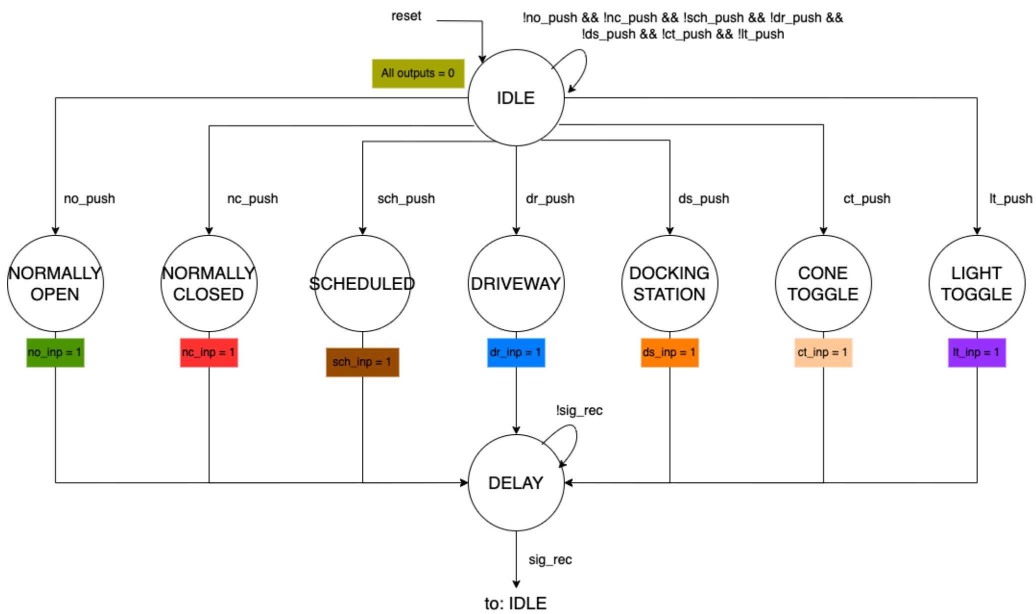


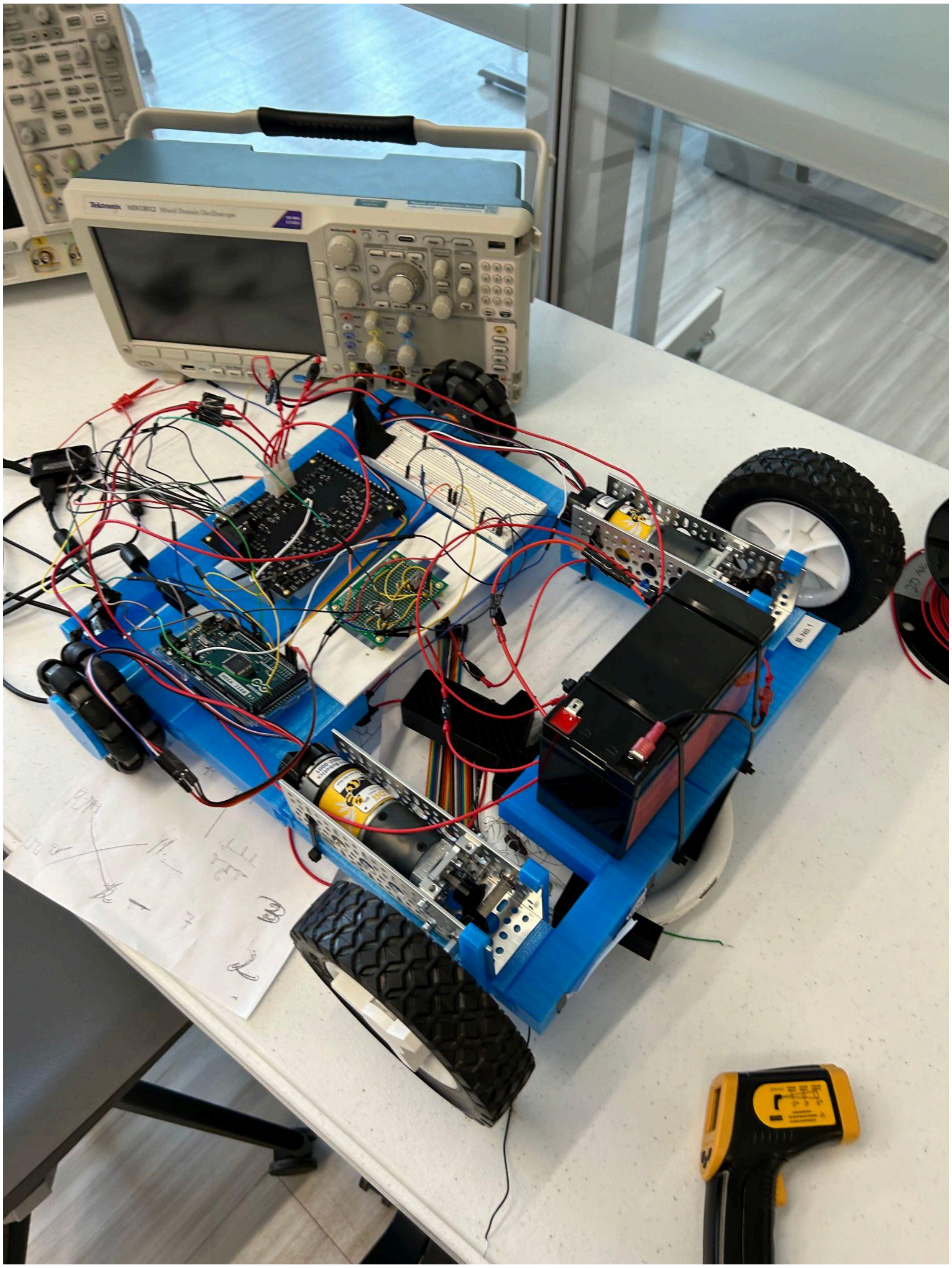
Figure 16 - State Diagram for the Remote Control

Conclusion

Fundamentally, the MARGE System serves as an easily configurable solution to keep unwanted vehicles away from a specific location. It institutes solid practices allowing for seamlessness and consistency of function. With solar charging features, the system provides users a way to keep cars away without installing another (more permanent, invasive, or expensive) solution. Overall, the MARGE system uses complex parts to create simple peace of mind for any end user.

Appendices

Appendix A - Rover Drivetrain Validation Platform:



Appendix B: Table of Performance & Functionality Metrics/Targets

PERFORMANCE METRIC/ FUNCTIONALITY REQUIREMENT	TEAM EFFORT TO MEET METRIC	OUTCOME	CATEGORY OF DESIGN	NOTES
1.Design the major components of the MARGE with battery capacity and consumption in mind, and perform calculations for appropriate battery capacities. 2.Demonstrate that these design choices yielded the desired effect.	Team selected battery capacity by preliminary proposal based on anticipated behavior, desired tolerances, and a 3-page calculation on motor consumption based on travel.		Hardware	From RFPP
Design and implement the necessary hardware for minimal power consumption and low power modes as applicable.	Team designed and tested two distinct power distribution boards with high efficiency and controlled output in mind. Included on these boards are load controls and MCU interfacing. Team selected components purposefully with power consumption in mind.	Successful	Hardware	From RFPP
1.Design for use of Operational Mode A as outlined in the RFPP. 2.Demonstrate this mode as functional.	Team developed this mode functionality into the greater system FSM		Firmware	From RFPP
1.Design for use of Operational Mode B as outlined in the RFPP. 2.Demonstrate this mode as functional.	Team developed this mode functionality into the greater system FSM		Firmware	From RFPP
1.Design for use of	Team developed this mode		Firmware	From RFPP

Operational Mode C as outlined in the RFPP. 2.Demonstrate this mode as functional.	functionality into the greater system FSM			
Provide functionality for remote override as described in the RFPP.	Team developed this mode functionality into the greater system FSM. Additionally, a remote controller was designed for use by the end operator.		Firmware, Hardware	From RFPP
Provide a hardwired local system display as described in the RFPP.	Team designed and developed a display control system and programmed a user display system.		Firmware, Hardware, Mechanical	From RFPP
Calculation of system defined operating distances based on functionality and capability of the MARGE system.	Team calculated a system operational diagram and submitted it for approval in both the preliminary and final proposals.	Successful	N/a	From RFPP
The rover successfully navigates out of the docking station to the center of the pathway, and returns to the docking station, unaided.	Team designed a locomotion and navigational control system dedicated to navigating the rover through its operational space autonomously.		Firmware, Hardware, Mechanical	From RFPP
The barrier actuation system can activate properly and does so only when desired.	Team designed a barrier actuation control system and visual indicator to be actuated.		Firmware, Hardware, Mechanical	From team
The rover successfully charges from the docking station and does not create a situation where the rover fails due to battery exhaustion in the pathway.	Team designed a coulomb counting solution for calculating an SOC for both the rover and docking station and includes decision making based on this SOC in the FSM.		Firmware, Hardware	From team
The rover and docking station	Team integrated a commercial		Firmware	From RFPP

can successfully communicate with one another wirelessly.	RF solution with the FSM for use in communication between remote units.			