



LAFAYETTE COLLEGE

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

Senior Design Project

Samuel Filson, Sam Fowler, Michael Gadola, Erin Koczur, Trevor Lenig, Kristen O'Connor,
John Pogorelov, Liam Stewert, Jason Sonkin, Allen Wu

Mobile and Autonomous Roadway Guardian Entity
(M.A.R.G.E)
2023-2024

Final Project Proposal
November 10, 2023

M  **R G E**

Table of Contents

| | |
|--|-----------|
| Common Definitions and Terms | 3 |
| 1. Abstract | 4 |
| 2. Operation Overview | 4 |
| 3. Motivation | 6 |
| 4. Design Objectives | 7 |
| 4a. Power..... | 7 |
| 4b. Sensing..... | 11 |
| 4c. Microprocessor..... | 11 |
| 4d. Communication..... | 12 |
| 4e. Movement..... | 16 |
| 4f. Navigation..... | 16 |
| 4g. Structure..... | 17 |
| 5. Design Constraints | 21 |
| 6. Relevant Codes and Standards | 22 |
| 7. Operation Manual | 22 |
| 7a. Set Up..... | 22 |
| 7b. General..... | 22 |
| 7c. User Interface..... | 23 |
| 7d. Remote Control..... | 24 |
| 8. Safety Analysis | 27 |
| 8a. Battery Precautions..... | 27 |
| 8b. Weight Concerns..... | 27 |
| 8c. General Safety Concerns..... | 27 |
| 9. Calibration | 27 |
| 10. Estimated Cost | 28 |
| 11. Test Procedure | 28 |
| 11a. Acceptance Test..... | 28 |
| 12. Informational Website | 30 |
| Appendix | 31 |
| 1. Cart Battery Verifications..... | 31 |
| 2. Dock Battery Verifications..... | 32 |
| 3. Charging Duration..... | 33 |

Common Definitions and Terms

MARGE: Mobile and Autonomous Roadway Guardian Entity

Cart: Moveable part of the MARGE system that will control the flow of traffic along the driveway

Clicker: Remote used by allowed cars to move the cart into the dock to allow passage into the driveway.

Dock: A stationary part of the MARGE system that will serve several purposes including charging the cart, sensing vehicles, changing modes, etc.

Remote Control: Additional part of the system will have an override to the MARGE system and what mode it is and/or what position the cart is.

Open: The cart is located on the dock.

Closed: The cart is located on the driveway.

Processor: A microcontroller(s) that is used to control the actions and states of the system.

Normally Open Mode (NO mode): This mode indicates that the cart shall only enter the driveway from the dock when an unauthorized vehicle is present.

Normally Closed Mode (NC mode): This mode indicates that the cart shall only leave the driveway from the dock when an authorized vehicle is present.

Normally Open MARGE System Set Back (OMSSB): Minimum distance the MARGE system is set back from the entrance of the driveway when in normally open mode.

Normally Closed MARGE System Set Back (CMSSB): Minimum distance the MARGE system is set back from the entrance of the driveway when in normally closed mode.

Recognized Vehicle Sensing Distance (RVSD): Distance from the MARGE system that a recognized car will be sensed.

Unrecognized Vehicle Sensing Distance (UVSD): Distance from the MARGE system that an unrecognized car will be sensed.

Remote Control Sensing Distance (RCSD): Distance from the MARGE system that the remote control will be sensed.

1. Abstract

Lafayette College's Department of Electrical and Computer Engineering (ECE) split the ECE Class of 2024 into two groups requesting for each team to build a Mobile and Autonomous Roadway Guardian Entity (MARGE). The purpose of MARGE is to control the flow of traffic along a driveway. The MARGE system will consist of two pieces, the cart and the dock. The dock will be the housing and charging station for the cart, consisting of solar panels, a 12V battery used for solar charge storage, a charging mechanism, sensors for communication, sensors for identifying cars, a user interface (UI), and a processor. The cart will move into the driveway as a mechanism to stop traffic and will consist of a 12V battery, wheels, motors, a processor, and sensors to lead it to the dock. The MARGE shall be weatherproof and able to withstand multiple outdoor surfaces.

2. Operation Overview

The MARGE shall be easy to set up and user-friendly. Its main purpose is to limit vehicular access from the roadway to the driveway. The system shall sit at a user-designated distance away from the roadway depending on the mode that the system is in (at least 200 ft for normally opened and at least 20 ft for normally closed). The dock shall sit 3 ft away from the edge of the driveway's width to ensure no damage will occur should a car drive off the driveway and to ensure the ramp fits in between the driveway's edge and the dock.

The system shall operate in two different operating modes: normally-open and normally-closed. The remote control shall override the operating mode the cart is in and shall move the cart to the desired position. The remote control can override the operating mode and make the cart stay in the open or closed position without vehicle detection until instructed otherwise. It can also be used to temporarily override the operating mode allowing an unidentified vehicle to pass or block an identified vehicle. It can also be used to switch operating modes as well. The user will be notified in the user manual that the mode can not be changed if the user places the dock closer than 200 ft to the roadway. The attributes of each mode are listed below.

Normally-Closed Operating Mode

- The cart shall sit in the middle of the driveway's width.
- When a car enters the driveway a passenger in the car, if allowed access, can press the button on their given clicker which will move the cart to the dock allowing passage.
- The cart shall not move out of the way for unrecognized vehicles (cars without a clicker) unless the owner's remote control overrides the system.
- The cart shall move to the dock when the battery dwindles to the recharge limit (40% battery life remaining) and shall remain in normally-open mode until fully charged as determined by the charger. Then it shall move back to the center of the driveway and remain in normally-closed mode.
- The cart shall move to the dock at two designated times selected by the user during set-up to charge for 1 hour or until fully charged.

Normally-Open Operating Mode

- The cart shall remain in the dock.

- The dock shall detect a vehicle from 200 ft away. When detected the cart shall move to the center of the driveway to block the vehicle’s entrance in enough time so as to not cause any immediate stops.
- The cart shall not move until the vehicle has either left the driveway or the clicker or remote has been pressed to allow entrance. Then the cart shall move to the dock and remain in its normally open position.

| | Normally-Open Operating Mode | Normally-Closed Operating Mode |
|-----------------------|---|---|
| Cart Location | Dock | Middle of the driveway’s width |
| Recognized Vehicles | Cart shall move to the middle of the driveway and only return to the dock once a passenger of the vehicle hits the clicker. | Cart shall remain in the middle of the driveway and only move to the dock once a passenger of the vehicle hits the clicker. |
| Unrecognized Vehicles | Cart shall move to the middle of the driveway and only return to the dock once the car has left the driveway or the remote overruns the system. | Cart shall remain in the middle of the driveway unless the remote overruns the system. |
| Charging Information | Cart shall plug into the charger whenever it returns to the dock. | Cart shall move to the dock when the battery dwindles to 50% and shall go into normally-open mode for a 30-minute period allowing for charging. Cart shall move to the dock during two designated times during the day, which are selected by the owner, to charge for 1 hour. Cart shall return to normally-closed mode after the charging period. |

Figure 2a. Operating Mode Information Table

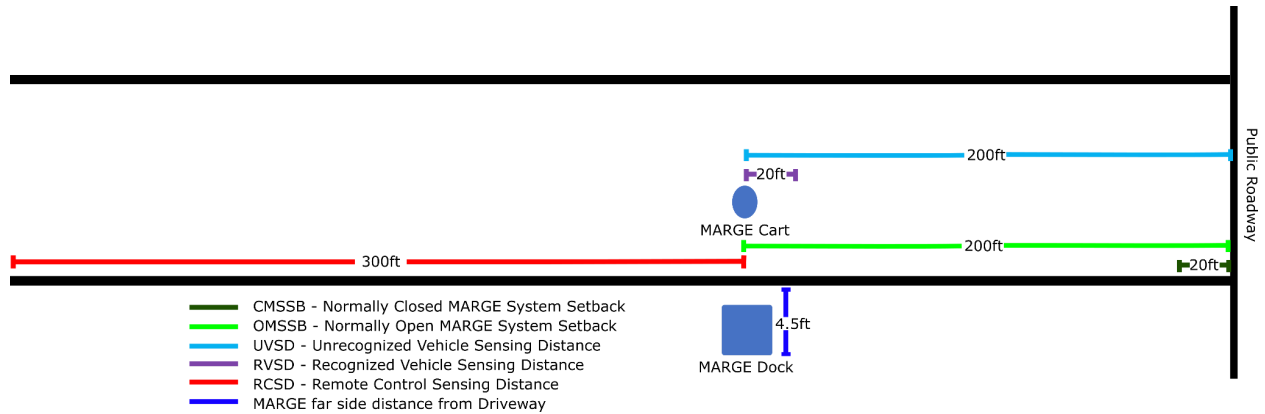


Figure 2b. Sensing Distance Diagram

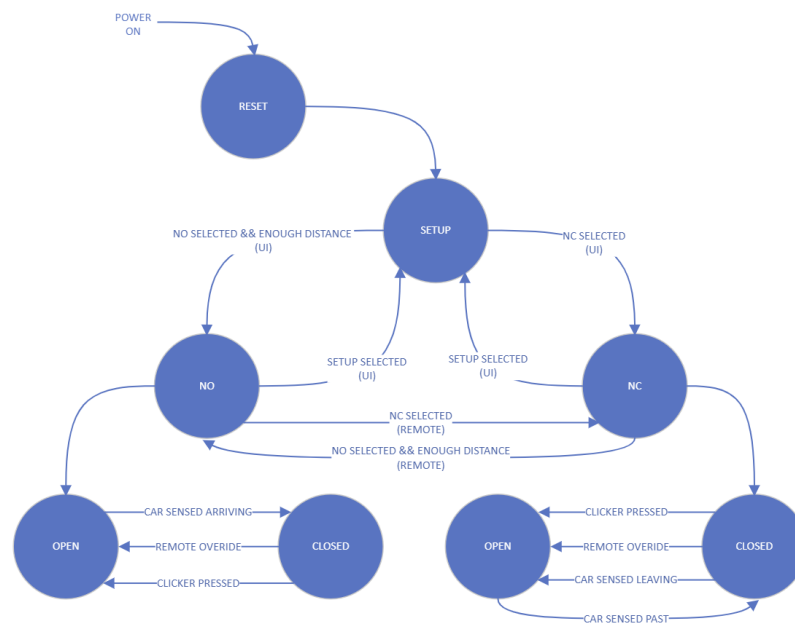


Figure 2c. Logic Diagram

3. Motivation

If you live in suburbia or out in the country, chances are you have a driveway. It is a part of life outside of cities where you need a car to get to work or school. Unfortunately for you, your driveway is accessible to all cars, not just your cars. These extra cars can block you in, from moving trucks pulling into the wrong spot to workman’s vans sitting in the middle of the driveway, to the late-night driver making a U-turn. If only you had a way to limit the cars that have access to your driveway.

A gate would fix this issue but a gate is expensive to install and maintain if you want something automatic, costing anywhere from \$2,500 to \$9,000, not including the cost of setting up the gate which must be done by outside contractors. This is not a realistic price for most homeowners and a gate can

sometimes look out of place on a person's property. The proposed product solves all problems by being easy to set up by the consumer, cost-effective, and does not take up much space at all.

4. Design Objectives

4a. Power

The system will run off of a 100W solar panel which will charge a 12V 50 Ah lithium iron phosphate (LiFePo4) battery in the dock. The battery in the dock will sustain all the equipment on the dock including the sensors, communication systems, and user interface. The battery in the dock will also charge a 12V 10 Ah LiFePo4 battery which will power the motors and communication systems in the cart. The system will run on all DC power with the help of step-ups, step-downs, and chargers.

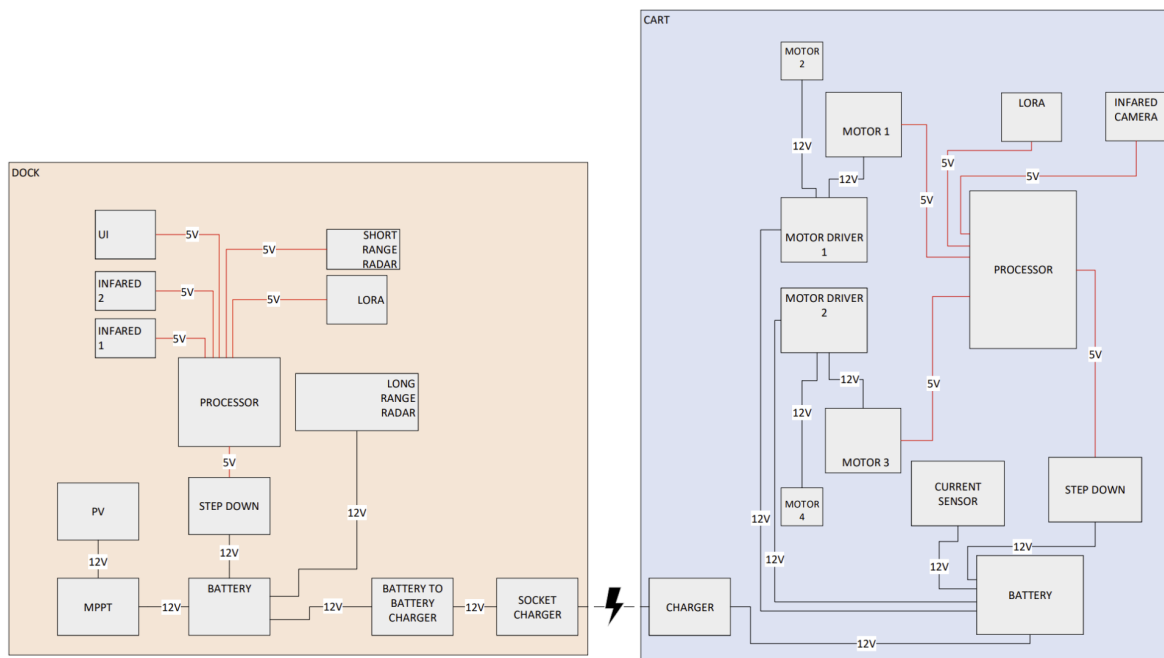


Figure 4a1. High-level diagram of power design for MARGE system.

4ai. Plug-In Charging

In the mechanical structure of the MARGE system, a pivotal component is the mating charger socket system, designed to facilitate seamless energy transfer and ensure operational safety. This system will be integrated with an off-the-shelf MPPT solar charge controller, a reliable unit responsible for managing the power supply from the solar panel to the battery. The core of this system comprises two substantial sets of metal contacts, directly connected to the battery outputs, functioning as conduits for power transmission.

To enhance the system's reliability and safety, an additional floating center sensing pin will be incorporated, constructed from a strip of metal. This innovative feature is designed to monitor the moisture levels within the socket continuously, acting as a safeguard against potential water-induced damages and other fault conditions. Through this mechanism, the MARGE system

ensures not only efficient energy utilization but also prioritizes the longevity and safety of the entire setup.

In the power segment of the project, a specialized PCB will be developed for the socketing system, central to MARGE's efficient operation. This PCB will feature a floating center pin in the contact assembly, a critical element designed to detect moisture and other fault conditions, enhancing the system's resilience against weather and potential tampering. It also includes current monitoring and communicates through a 3.3v i2c bus.

To ensure safety and energy efficiency, the system will not maintain a high nominal charging voltage on the contacts constantly. This prevents arcing and electrolysis of the contacts. Instead, it will employ a low standby communication mode, initiating a main power connection only through a secure handshake sequence with the cart. This approach not only conserves energy but also fortifies the system against unauthorized access and potential malfunctions, promising a secure and sustainable operation.

The dock-side component of the socket, which remains constantly energized, will be constructed using PETG via 3D printing, as illustrated in the accompanying diagrams. We will integrate a 1mm thick sheet made of either aluminum or stainless steel into this setup. The appropriate cable will be welded or crimped on the sheet metal contacts. This sheet will be precision-bent and tensioned within the mechanism to ensure a snug fit and reliable operation. The design currently displays only one of the two necessary sides for clarity. Additionally, for moisture detection, a slender strip of copper tape will be strategically placed along the socket's center, serving as a sensitive terminal for moisture presence.

The cart-side plug will consist of a mating 3d print and bent sheet metal, and will be designed similarly with the dock-side socket.

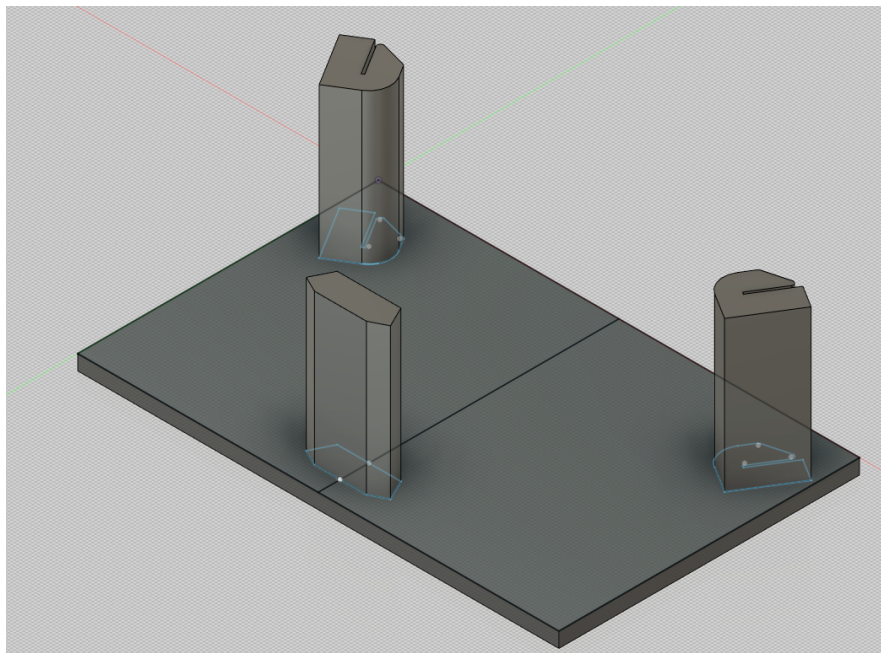


Figure 3d1. Preliminary Mechanical Design for Socket Side 3D Print

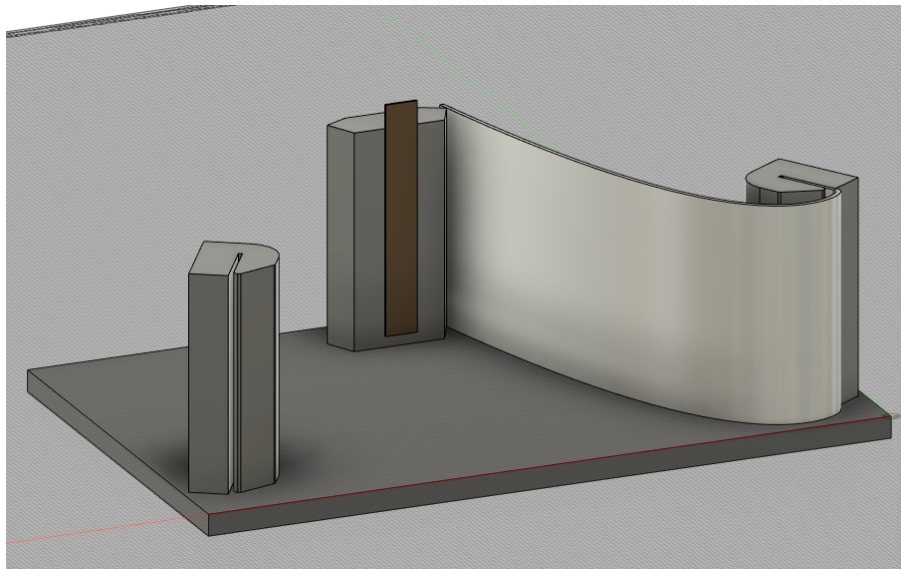


Figure 3d2. Setup Illustration for Socket Side 3D Print (One side)

For the dock-side, which is always energized, significant precautions will be taken to prevent the high-current charger wires from shorting or arcing. Main charging power will be supplied to the primary contacts only when the moisture-detecting floating third terminal (central copper tape) indicates dry conditions and confirms the cart side is securely docked. This is verified by testing the resistance across the main contacts with an always-on 3.3V test voltage.

Once the main contact plus is switched from the nominal 3.3v test voltage to the charging voltage supplied by the commercial Lifepo4 charger, a floating hall effect sensor will constantly monitor the charging current estimate the charge delivered, and cut off the power in case of significant overcurrent events.

For the cart side, the relay will be replaced by a MOSFET circuit that functions as a diode, allowing current only to flow into the cart battery with minimal loss. A floating hall effect sensor will oversee the charging current and approximate the amount of charge the battery receives, enabling estimation of the battery's state of charge.

It should be noted that the system's design emphasizes energy conservation; thus, the current sensor will not actively monitor the system's energy use. This means that precise charge percentage estimation will be unavailable during regular operation. Reliable charge estimates will be feasible primarily when the battery undergoes significant voltage shifts indicative of full discharge or recharge cycles.

In the event that the cart's battery is fully depleted and the system is unpowered, a backup circuit will activate the cart-side microcontroller using a 3.3V test voltage from the dock, restoring the system. This will be hardware designed to be done passively without any communication.

4a.iii. Energy Collection and Storage in Dock

The main source of energy collection in the MARGE system is the 100W solar panel. The solar panel will be south-facing, getting around 5 peak hours of sunlight per day. The energy collected by this solar panel will run through an MPPT solar charge controller into a 12V 50Ah battery with a maximum of 20A. This 12V battery will be used as our energy storage unit in the dock. Through a DC-DC charger and the socket system, this 12V battery will charge the 12V battery on the cart supplying a constant 8A to charge the battery.

4a.iii. Normally Closed Charging

When the cart is in the normally closed option, it sits in the center of the driveway until a recognized vehicle comes into range. In normally closed mode the cart will have to travel back to the dock to charge its battery. During setup, the owner of MARGE will be given options and decide a charging cycle for their cart. During this charging cycle, MARGE will leave the driveway to enter into the dock to be charged for 1 hour. In the case MARGE goes below 40% battery life before its scheduled charging, MARGE will leave the driveway to enter into the dock to be fully charged, staying in the dock for 1 hour. If an unrecognized vehicle appears during this charging time, MARGE will act as if it is in a normally open state and move to the center of the driveway.

The battery in the cart will have a current sensor which will detect its battery life. There will also be a current sensor in the dock charger. When the current sensor in the cart detects the cart battery to be at 40% or lower, it will have the cart be sent back to the dock to charge. When the current sensor in the dock charger detects the dock battery to be 100%, the dock battery will stop charging the cart battery. The current sensor chosen is a Hall effect current sensor. This was chosen because it is the least invasive, the most accurate, and consumes the least amount of power compared to other types of current sensors. The current sensor will output a voltage based on the input current. The input-to-output ratio is 100 mA to 1 mV.

4a.iv. Normally Open Charging

When the cart is in the normally open option, it sits in the dock until an unrecognized vehicle comes into range. While the cart is sitting in the dock, it will be charging. The cart's resting position in the dock will have it positioned on the charger. The cart battery will stop charging when it reaches full to optimize battery life.

4a.v. Scheduled Charging

When the cart is in the scheduled option, it sits in the driveway for a set amount of time, moving when a recognized vehicle comes into range. During setup, the owner of MARGE will decide on a schedule for their cart. This schedule must account for the time MARGE needs to charge. During this charging time, MARGE will leave the driveway to enter into the dock to be charged for 1 hour or until fully charged. If an unrecognized vehicle appears during this charging time, MARGE will act as if it is in a normally open state and move to the center of the driveway.

Same as the normally closed mode, if the current sensor detects the cart battery to be at 40% or lower, the cart will be sent back to the dock to charge.

4b. Sensing

To support Navigation as described in section 4f, the cart will be able to sense IR Beacons at a range of 10ft via the implementation of an IR Camera

To facilitate the function of detecting incoming and outgoing unrecognized vehicles radar sensors will be implemented. The two radar sensors that have been selected are the OmniPreSense OPS243-A Doppler Radar Sensor, and the InnoSenT GmbH 80.00000062. They will perform the function of detecting a vehicle entering or leaving the roadway, these sensors have been selected to perform one role each.

The OPS243-A Doppler Radar Sensor has a detection range of over 300ft which facilitates the designated set back distance for normally open mode in order to detect incoming vehicles. Considering the entering vehicle is expected to be moving at 10 miles per hour, it will take 20 seconds to reach the marge system. Within said 20 seconds, the Cart, which is moving at a little over a foot per second, will be able to reach its closed position. This sensor ensures that the Cart will have enough time to move.

The InnoSenT GmbH 80.00000062 fulfills the shorter-range role of detecting an outgoing vehicle. Considering the less demanding task the InnoSenT GmbH 80.00000062 has been selected for its lower range, to reduce false positives, and its lower price, to lower the cost of the MARGE system as a whole.

4c. Microprocessor

In order to facilitate the logical control of the MARGE system several Raspberry Pico H's will be implemented. The Raspberry Pico H was chosen as the microcontroller within the Dock, Cart, Clicker, and Remote control. The Pico H operates on a real-time operating system, which facilitates faster interrupt times, which will be crucial for the MARGE system to react to environmental interrupts such as LoRa Communications or Radar detections. In addition, the Pico can address all the wired communication that the MARGE system will use: UART, I2C, GPIO Digital ports, and GPIO Analog ports.

4d. Communication

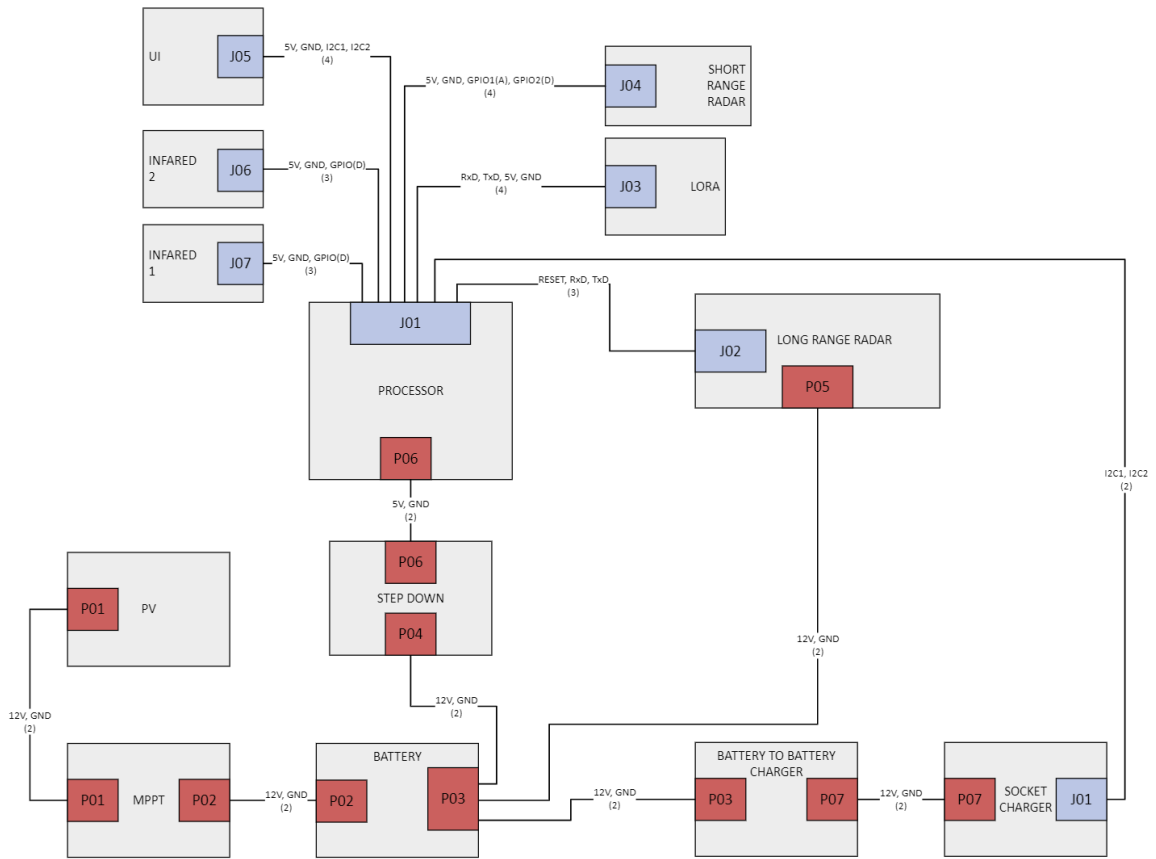


Figure 4d1. High-level diagram of Connection design for Dock

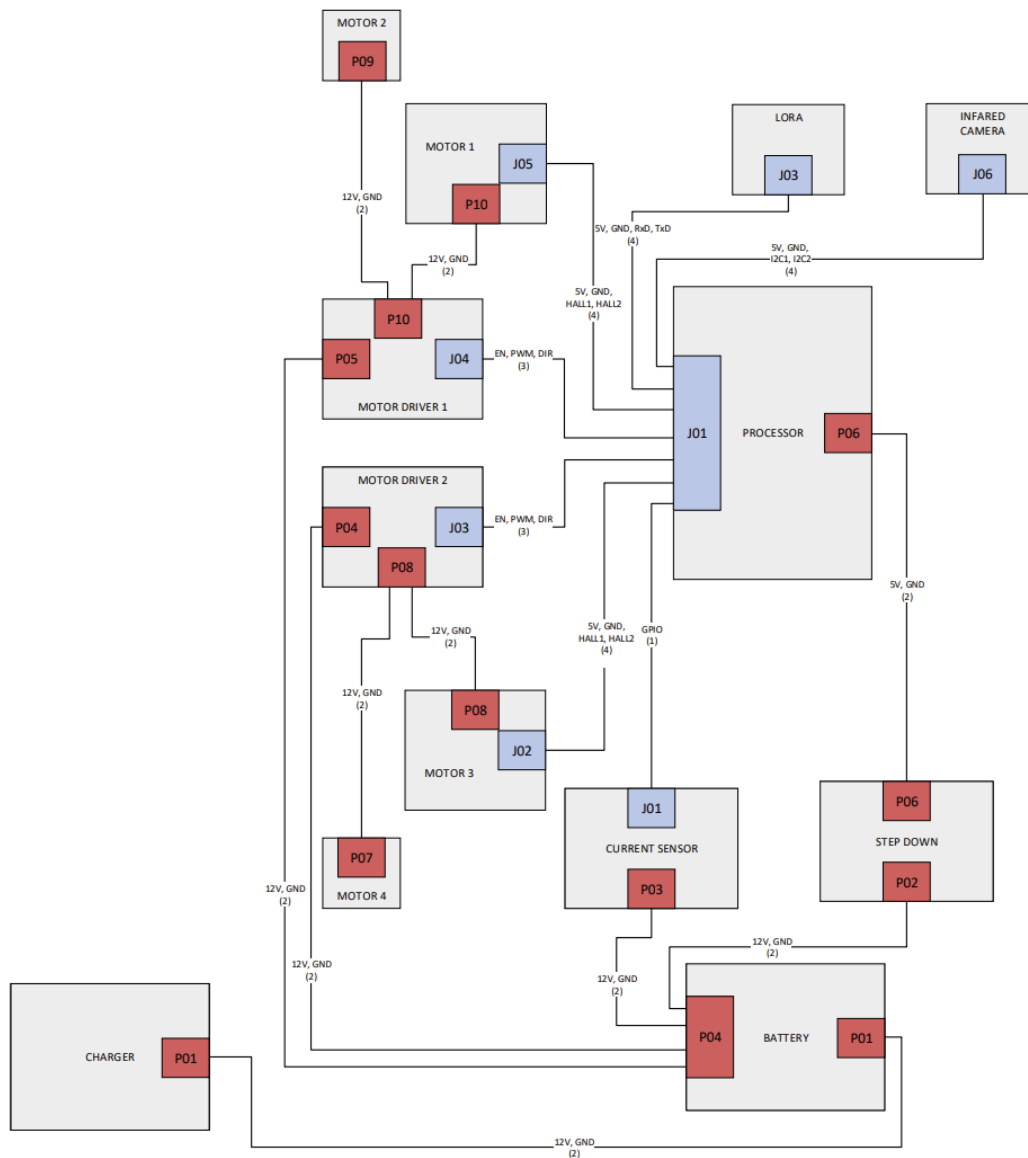


Figure 4d2. High-level diagram of Connection design for Cart

Lora is a chirp spread spectrum (CSS) modulation technique optimized for low power while providing functionality for trade-offs between data rate and sensitivity. These tradeoffs are determined by: bandwidth, spreading factor, and coding rate. Bandwidth specifies the size of each frequency band which can improve data rate but decrease sensitivity. The spreading factor controls how many symbols each bit of payload data is spread across a sampling period. Higher spreading factors decrease data rate but increase sensitivity. The coding rate is the number of error-correcting bits added to each payload which can prevent packages from being dropped in high noise environments but decreases data rate.

In this project, Lora will be utilized to provide long-range radio communication between the different components of our project. Each of these components: The Dock, Cart, Remote, and Clicker will contain a uniform board that will provide long-range radio functionality. Our network model will follow a star topology with the Dock at the center and every device shall relay packets through the Dock to maintain the system state. The specific data that will be flowing through the system is yet to be determined.

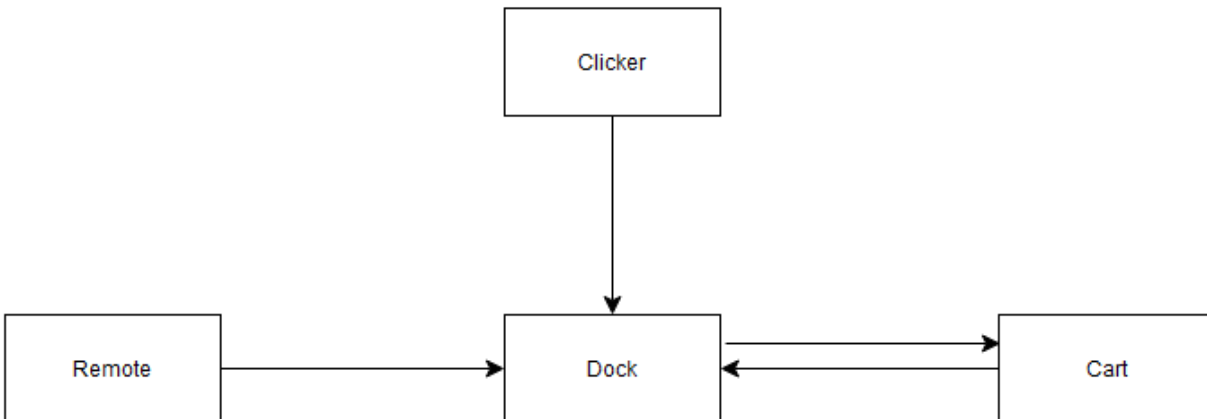


Figure 4d3: Network topology to be implemented

The board we will be designing will contain several components including a SX1276 LoRa Connect Transceiver from Semtech, a linear voltage regulator, a crystal oscillator with its resonant frequency at 32 Mhz, a Raspberry Pi Pico, and an RF switch linking the transceiver module and the SMA connector for an antenna.

The first component on the board is the SX1276 transceiver chip. This chip performs the LoRa modulation through a component called a modem and communicates with the onboard MCU through 6 GPIO ports and an SPI interface which needs 4 ports to operate. The transceiver has several different modes of operation, however, for this project, we will be implementing the chip in Packet Mode. In Packet Mode, the 6 GPIO ports will be used to give status information to the MCU, while the SPI interface will be used to change configurations on the device and transmit/receive data from the transceiver FIFO. The onboard MCU shall have firmware implementing an SPI driver and 6 open GPIO ports to decode and encode messages to the LoRa modem and shall communicate with the higher-level microcontroller through a UART port. The communication through the UART port shall be done through an API. Publicly available source code will be used as a guide for developing this API.

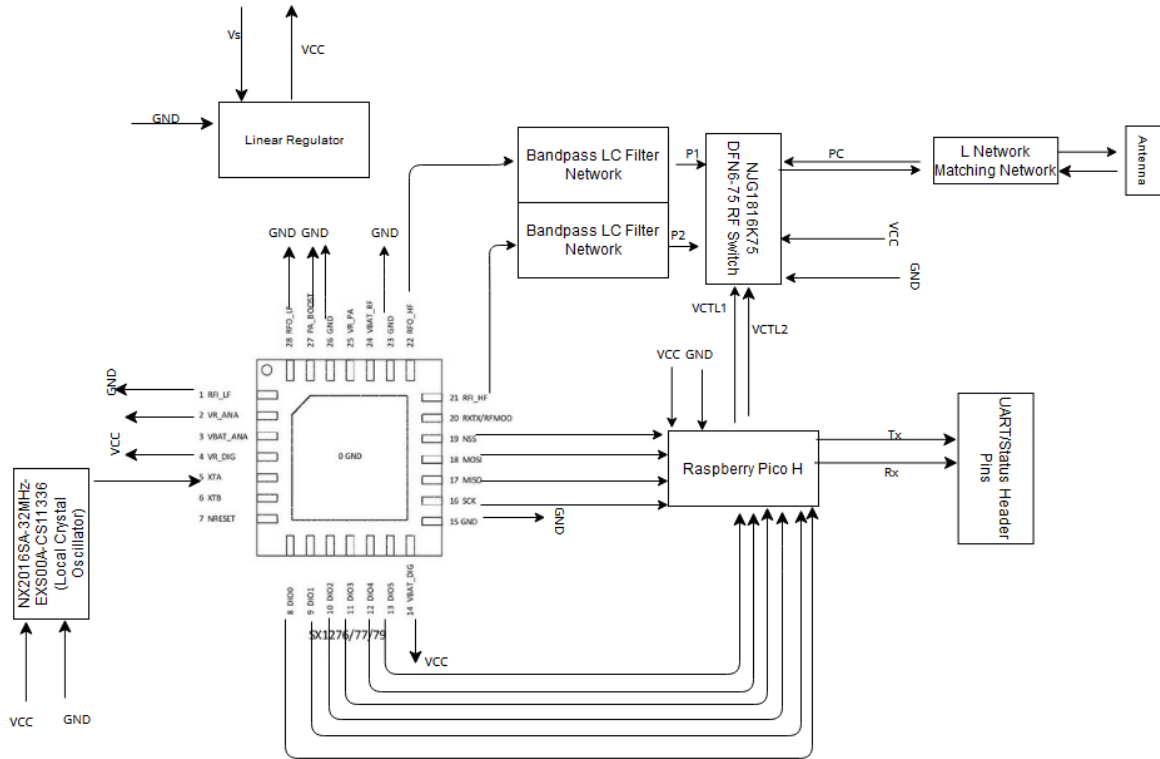


Figure 4d4: Proposed Circuit Block Diagram

The bandpass filter between the transceiver and the RF switch shall be designed in MATLAB and implemented as an LC network centered at the transceiver's center frequency of 915 MHz. Between the RF switch and the antenna will be an L network to provide additional matching if necessary. The RF switch will be enabled and disabled by the MCU for improved power conservation.

Inter-board Wired communications utilize I2C and UART. UART is a serial communication protocol that was studied in the embedded systems course. It enables full duplex communication, i.e. two devices connected via UART can send data in both directions simultaneously. UART will connect the three LoRa chips to their respective microcontroller. I2C will be utilized to connect the remaining sensors to their respective microcontrollers. IC is chosen for these connections as it functions via a bus, which permits several sensors to communicate with the microcontroller on shared GPIO ports. In this way, I2C limits the potential risk of an insufficient quantity of GPIO ports. The remaining analog and digital GPIO ports will be used to communicate with devices that do not require serial communication, such as MOSFETs or current sensors.

In order to facilitate communication between the MARGE system and the user, a user interface has been developed. The status of MARGE will be communicated to the user via a 4x20 character transfective screen. The screen will concisely describe the current status of the MARGE system and display the options a user has to work through. A transfective display was

selected because it will be visible under direct sunlight and MARGE will operate outside. The user will be able to communicate with the MARGE system through five buttons associated with the user interface; these five weather-proof push buttons will navigate through the user interface as described in the preliminary operation manual.

4e. Movement

The cart will utilize four motors, two on the front wheels and two on the back wheels, allowing for more precise turning. The motors that will be used are the DFRobot FIT0186 12 Volt DC Motor. The wheels will be 6 inches in diameter and will add around 3 inches to the total height. The motors have an RPM of 251 and the wheels have an RPM of 41.8 which can be found through the drivetrain transmission ratio of 6. With 6-inch wheels, the cart can move with a load of 6 pounds per motor at 0.747 miles per hour or 1.1 feet per second with a torque of 12.5-foot pounds.

A set of two motor driver boards will be used to drive the four motors. Each motor driver board will have two H-bridges which will drive one side of the cart (ie. left or right). The driver will take one PWM signal and one direction signal from the processor to drive the motors accordingly via the H-bridges. Each pair of motors on a side will turn in the same direction and speed. This will allow the cart to move in the necessary direction to go either to the center of the driveway or back to the dock.

4f. Navigation

For cart navigation, there are two aspects, the infrared tracking camera and the movement and orientation of the motors themselves.

The motors are set up in two pairs, the right and the left. The difference between the two pairs is their motor inputs. The different inputs on each side of the cart will allow for a combination of regenerative steering where both pairs of motors move in the same direction, and neutral steering where one pair stops or rotates in the opposite direction of the other pair. The cart will know whether or not to activate neutral steering based on the reading of the infrared tracking camera.

The motors will catalog the distance traveled through the use of encoders embedded in the motor itself. The integrated encoder is a quadrature hall encoder that has 64 counts per revolution of the motor shaft. That is equal to around 2797 counts per revolution of the gearbox. This will allow the cart to know where it is on the driveway based on revolutions of the encoders.

The infrared camera we will use in our design is the IR Tracking Camera model, RB-Dfr-553. The camera frame ratio is 128 x 96; Its onboard image processing analyzes the IR image data to track the X and Y positions of the four brightest IR sources in the camera's field of view. The camera communicates via I2C, so it can easily receive updates, like altering sensitivity settings, and transmit the position of detected IR sources. By transmitting the positional information of IR sources instead of the full array of IR image data, computational load is significantly reduced for the microcontroller that the IR Camera is connected to. The IR sources that will be used along with an IR camera, are IR 940nm LED beacons. These LEDs have been

selected because the camera is designed to filter to 940nm light. The wavelength filtering in combination with signal modulation filtering will ensure the IR Camera/Beacon system will work outdoors.

The two functions that the IR Camera/Beacon system will fulfill are to align the car with the dock for returning to it and to calculate the current distance between the cart and the dock. In order to calculate the cart-to-dock distance, the perceived distance between the two IR Beacons will be used. For example, when the cart and dock are ten feet apart the beacons will be ~22 pixels apart from the camera's reading. When the cart-to-dock distance is shorter, four feet, the camera will perceive the beacons as ~55 pixels apart. Based on the pixel difference between the two beacons, the system will know how far approximately the cart is from the dock. In order to ensure that the Cart remains aligned with the Dock, the Cart will be instructed to rotate to ensure that the two beacons are equidistant from the center of the camera's field of view. For example, if the beacons are 50 pixels apart, the cart will adjust to make sure both beacons are 25 pixels from the center of the camera's field of view.

4g. Structure

The MARGE system will be made up of four separate units, the dock, the ramp, the cart, and a solar panel mount. The cart, dock, and ramp will both be made of a lightweight, durable, and weather-resistant material. Both the dock and the cart will have internal structures to allow for a multi-leveled stack design to efficiently store all of the internal components. The dock's dimensions will be 1.5 ft x 1.5 ft x 3 ft, weigh less than fifty pounds, and will have the ramp lying down next to it to allow the cart to easily traverse over the difference in height between the dock and the driveway. The ramp will be made of two 1 ft x 1.5 ft PVC sheets, and walls that will guide the cart to the charging port on the dock. The cart's dimensions will be 1 ft x 1 ft x 2 ft and have a pyramid-like shape that will add a 3" of height onto the cart which will make it more noticeable to cars attempting to enter the driveway. The cart will be approximately 20 lbs. The solar panel mount will be a lightweight, easy-to-move set of angle brackets with a punched hole bar. The mount will allow for the solar panel to be angled at whichever degree the user chooses and will be light enough to allow the user to pick it up and move it to where they need it.

Below are two sets of Fusion drawings showing the design for both the cart and the dock. The first set of drawings shows the different views of the design of the cart. The second set of drawings details the look and measurements of the design of the dock.

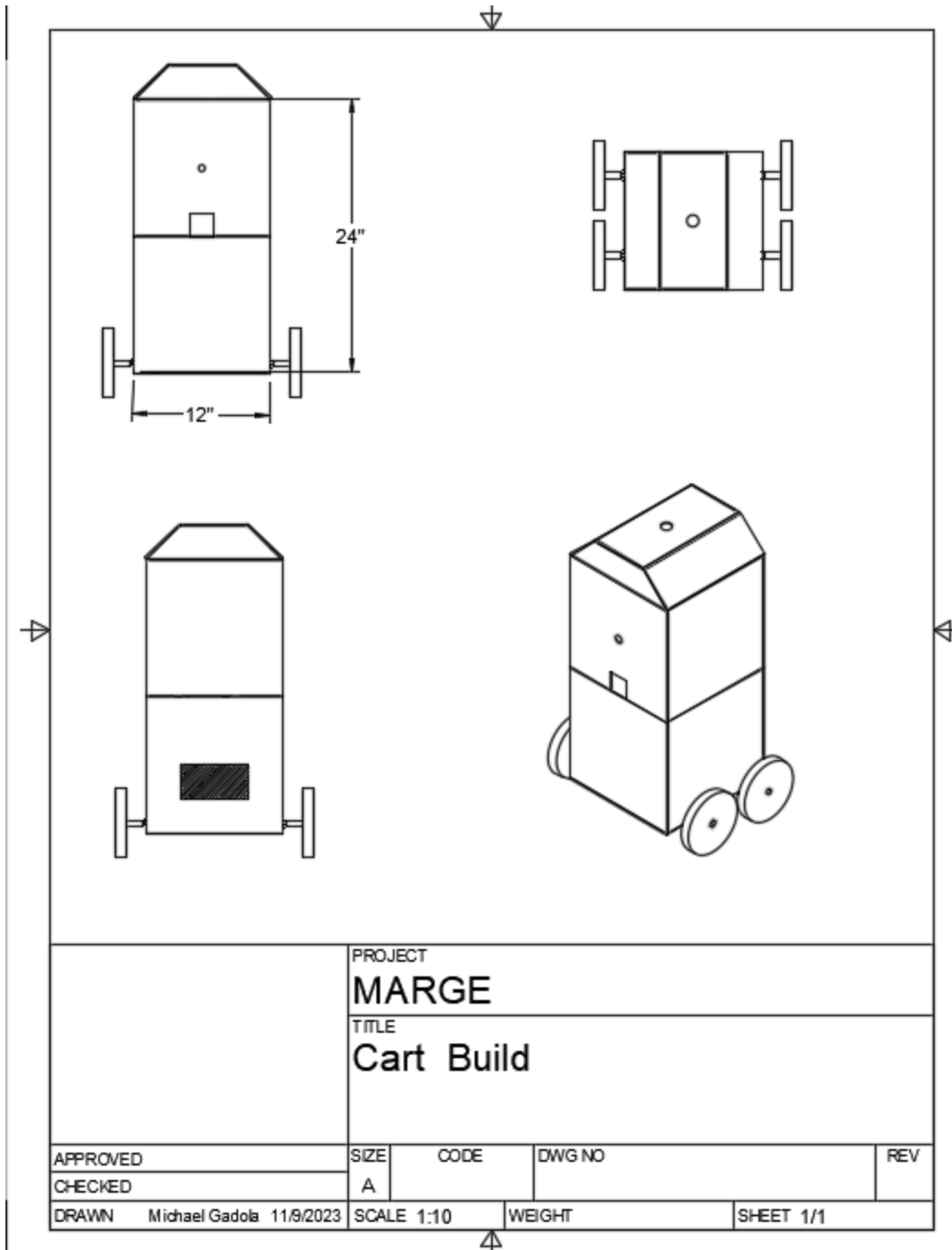


Figure 4g1: Initial cart design

Our cart design is a 12" x 12" x 24" rectangle that has a pyramid structure placed on top that adds about another 3" in height and has the same dimensions as the cart for its width and length. The front of the cart consists of the charging prongs that will plug into the dock's charging port as well as an IR camera that will be reading off of the array of LEDs on the Dock that will help guide the cart back to charge. The top of the cart has an antenna that will be sticking out of its center that will be communicating with radar. The back end of the Cart is fitted with a vent at

the bottom of the base so that it doesn't overheat and damage any components that are inside. The inside of the cart will have two layers which are split between the first foot of the cart and the second along with space within the pyramid. Starting from the bottom and working our way up, the Cart will be fitted with 4 motors, motor drivers, and a battery. The second layer will consist of LORA, IR sensor, Pico boards, step down, and current sensor. The entire structure will be supported with L-Channels that will help with distributing weight evenly throughout the Cart and will allow us to take off any one of the sides to work on the interior design.

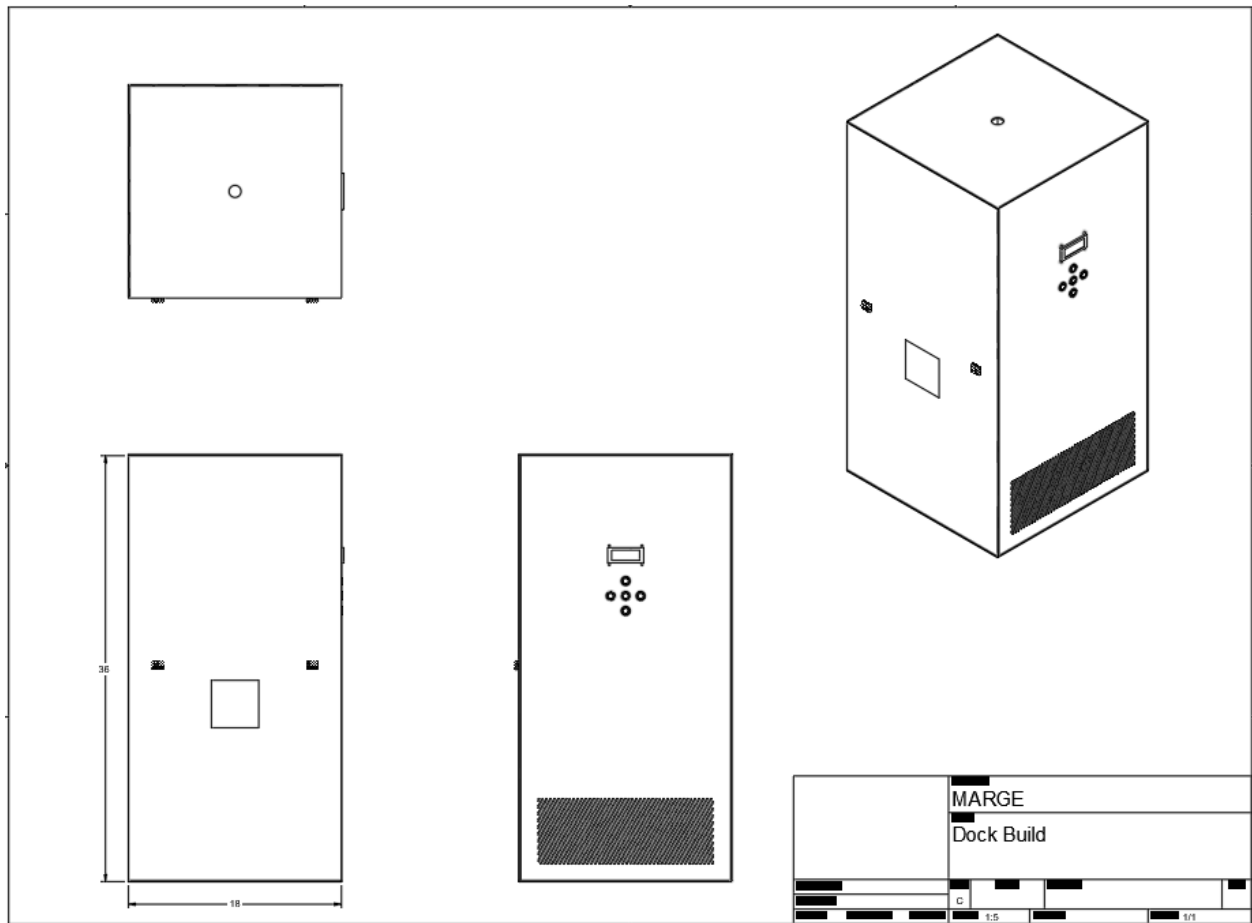


Figure 4g2: Dock Design

Our dock design is an 18" x 18" x 3' rectangular prism with an internal structure to provide all of the storage and structural support. The 18-inch sizing was chosen so that the dock would be slightly wider than the cart. The front of the dock will consist of a charging port for the cart to plug in to, and an array of LEDs to allow the cart to guide itself back to the dock. The right side of the dock will have the user interface, buttons to maneuver the menus, and a large vent to allow airflow to the bottom layer, which will be housing the elements that may have higher temperatures. The internal structure will be composed of three layers. The bottom layer will have heavier items such as the battery and the DC to DC charger. To combat the potential of the weight being too much for the base to support, four parallel U-channels will be placed evenly under the battery and DC to DC charger. The U-channels will run from an L-channel on one side of the

dock to a different L-channel on the other side to allow the weight to be evenly distributed on the internal structure, rather than the base of the dock. The second and third layers of the dock will hold all of the boards that control the LED array, the user interface and buttons, the antenna on the roof, and all of the other miscellaneous components that will be implemented in the dock.

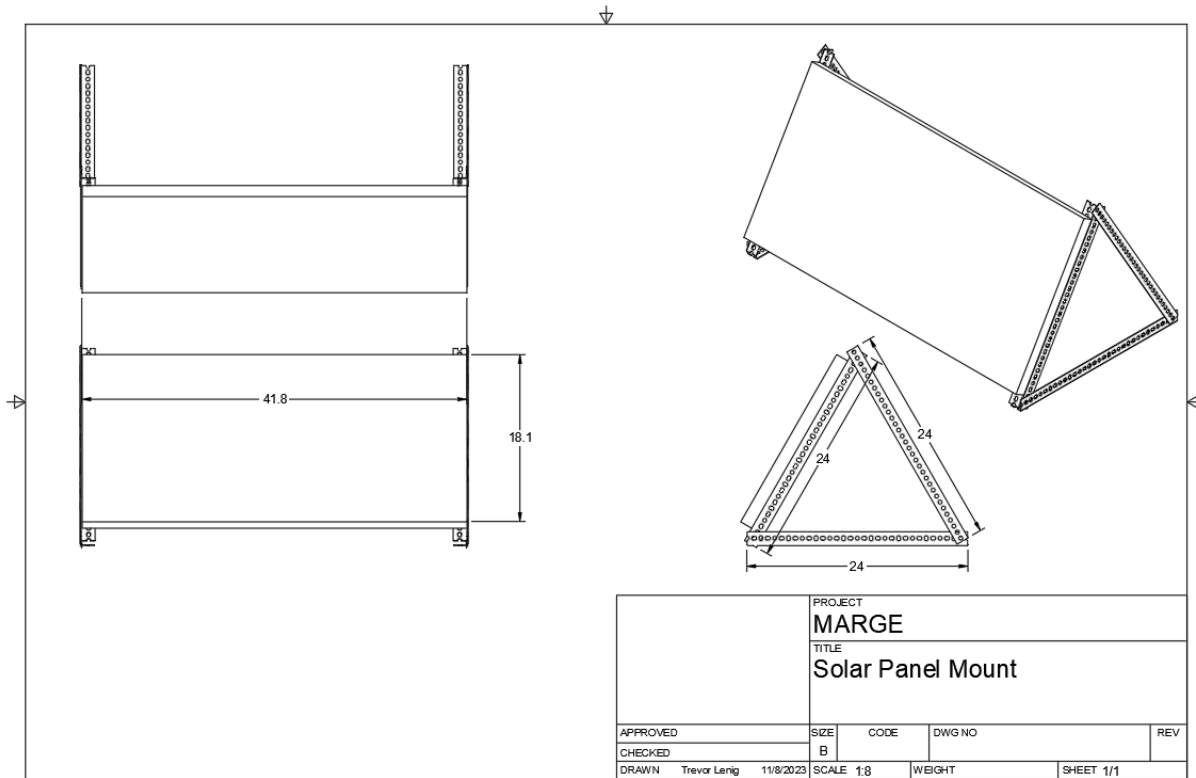


Figure 4g3: Solar Panel Mount Design

The solar panel mount consists of four 2' slotted angle brackets, and two 2' punched flat bars. Each triangle part of the mount has two of the slotted angle brackets and one of the punched flat bars. One of the slotted angle brackets is mounted to the solar panel, the other just lay flat on the ground. A bolt is placed through these two brackets, allowing the panel to rotate with a range of 180°. The punched flat bar is then bolted to the angle bracket laying on the ground and then bolted to the angle bracket mounted on the solar panel. To adjust the angle of tilt on the solar panel, one can remove the bolt that connects the angle bracket to the punched flat bar, and then slide the angle bracket down the punched flat bar and re-bolt the two together.

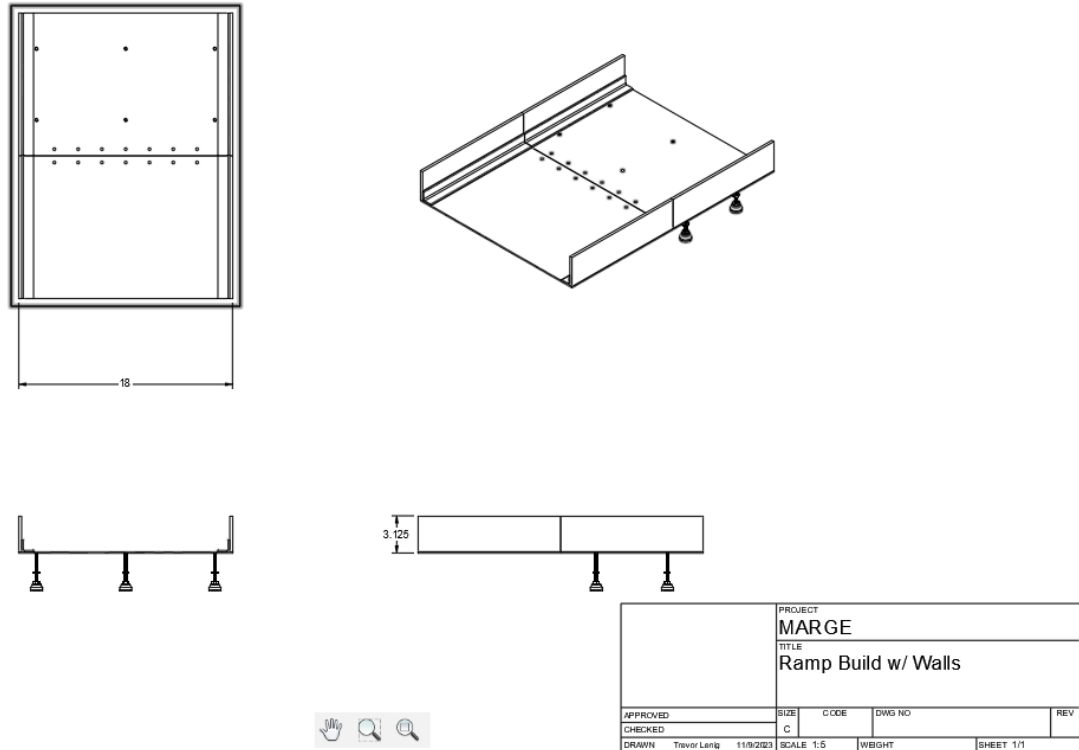


Figure 4g4: Ramp Design

The ramp design consists of two 18” x 12” PVC sheets held together by a piano hinge. The upper level of the ramp will be held in place by six leveling mounts so that the ramp can be adjusted to match the height of the curb or driveway. The piano hinge will allow the lower level to self-adjust its angle to match the height of the upper level. The ramp’s walls will act as a guide to allow the cart to drive straight into the charging port on the dock. The walls of the ramp are made of a more forgiving PVC sheet so that the cart can bump into them with no risk of breaking. These walls will be held in place by L-channels, and are tall enough to not allow the cart’s wheels to traverse over them.

5. Design Constraints

The MARGE cart shall be able to move from the dock to the center of the driveway to block a moving vehicle. The cart needs to not be too heavy, allowing it to move both fast and efficiently. In this move, the cart needs to be able to scale a curb of approximately 2 inches. The motors need to have high enough torque to move over the curb at ease. The cart should not exceed 25 lbs. The cart will run off a 12V 10Ah battery. All electronics and movements need to be powered by this battery.

The MARGE dock will be stationary, sitting beside the owner's driveway. The dock will have to withstand the weight and dimensions of the solar panel, approximately 15 lbs and 4 ft x 2 ft. The dock will also have to be water-proof, making sure the batteries and electronics inside are not affected by weather conditions. The dock shall not exceed 100 lbs. The electronics in the dock will run off a 12V 50Ah battery. All electronics in the dock, including the cart's battery, need to be powered by this battery.

6. Relevant Codes and Standards

In our design safety of the building team and clients is of utmost importance. For those reasons, we intend to follow several standards including FCC regulations for title 47, regulations outlined in the IEC 60335-1 standard for household appliances, and all safety information provided by manufacturers of parts of the design. Our standards will also abide by any applicable laws. Other standards we will comply with are ones outlined by IEEE. The relevant IEEE standards to our project include IEEE 1874-2013, IEEE/IEC 82079-1-2019, IEEE 1872.2-2021, IEEE 1375-1998, IEEE 1657-2009, IEEE 1562-2021, and IEEE 2836-2021.

7. Operation Manual

7a. Set Up

When the MARGE system is first deployed, it will be in normally-open mode. To set up MARGE, the user will be able to select the setup option on the UI screen. The setup screen allows the user to set the distance MARGE moves into the driveway, as described by the calibration section, and the scheduled time the user wants MARGE to charge while it is in normally-closed. To set the distance the MARGE moves into the driveway, MARGE will move from the dock into the driveway and the user will stop MARGE at their desired distance. The user will also be able to select the two times, one-hour periods each, the user wants MARGE to charge.

7b. General

Within general operation, the screen will display the current mode, three options that can be chosen by the buttons below the screen, and if the cart battery is being charged by the dock battery. The three options will allow the user to change the operation mode, set up distance/charging hours, and power off the MARGE device. The charging of the cart battery will be indicated by an asterisk in the top right corner of the screen. The function of the user interface can be seen below, in the State Machine of User Interface on the Dock.

7c. User Interface

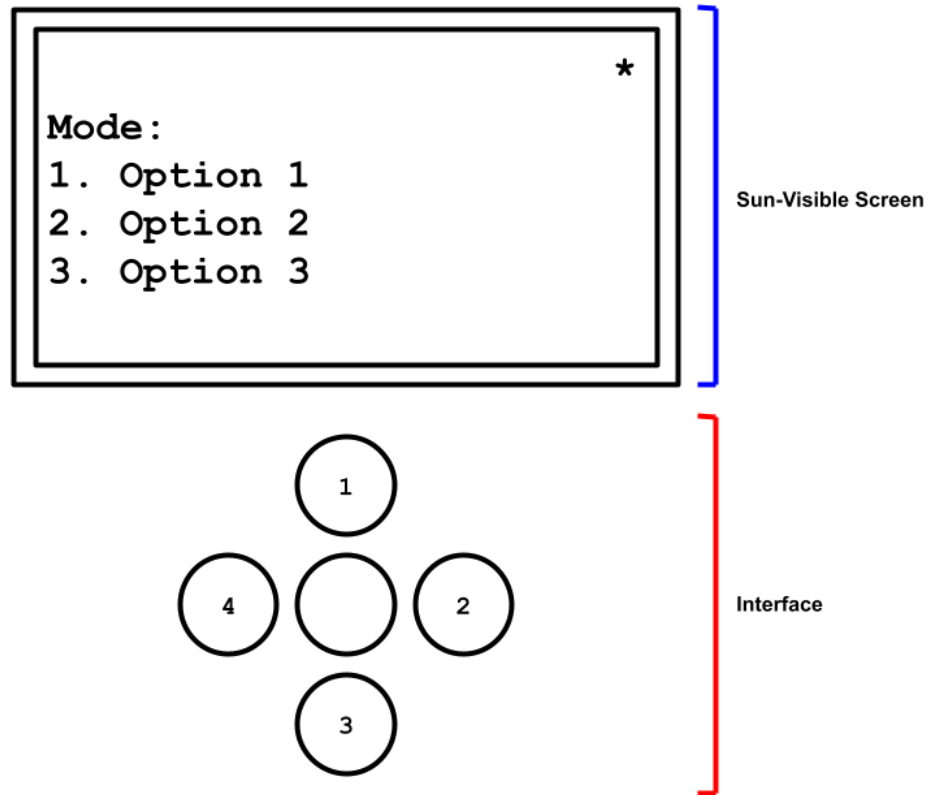


Figure 7c 1: User Interface on the Dock

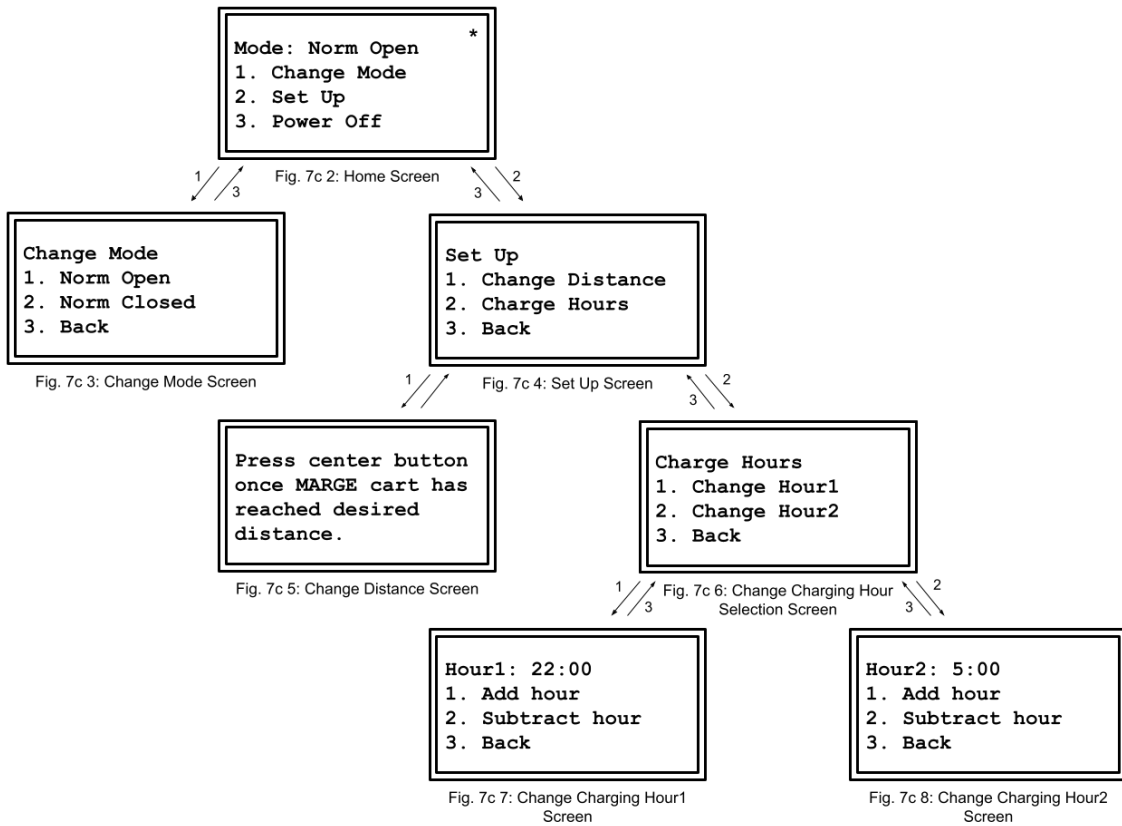


Figure 7c 9: State Machine of User Interface on the Dock

7d. Remote Control

- The remote control will have a more limited selection of four buttons:
 - Btn1: pressed - Open the gate
 - Btn2: pressed - Close the gate
 - Btn3: pressed - switch to normally open mode
 - Btn4: pressed - switch to normally closed mode

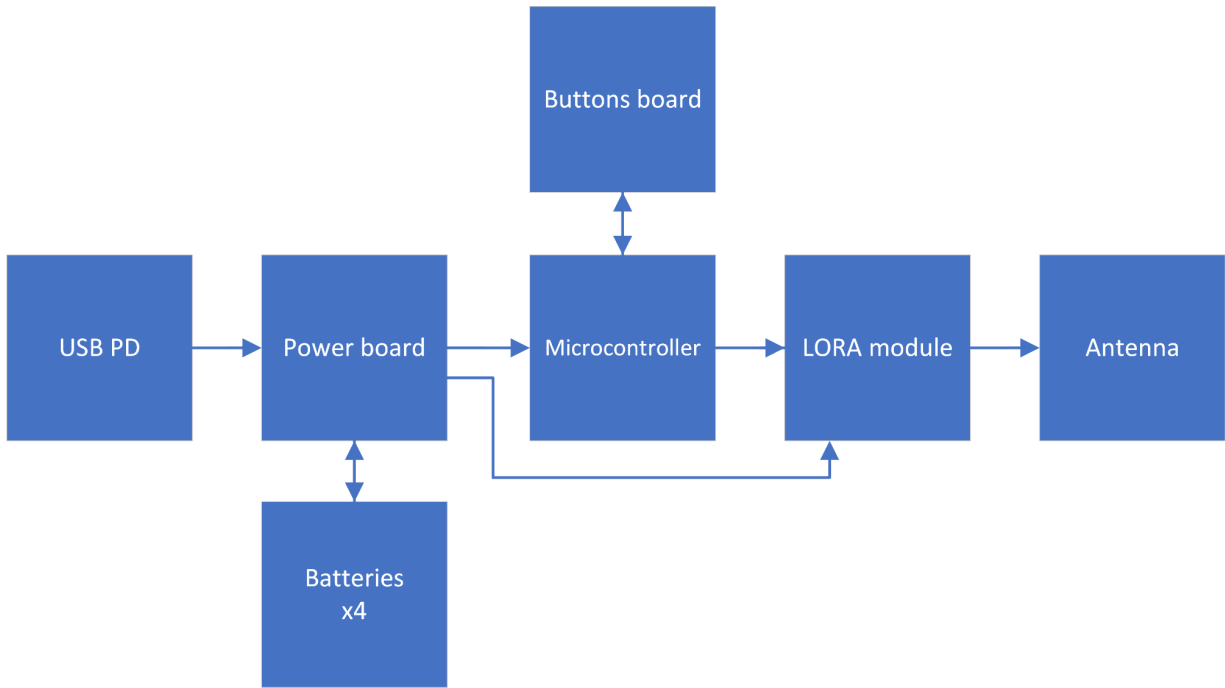


Figure 7d1. Block diagram of remote and clicker

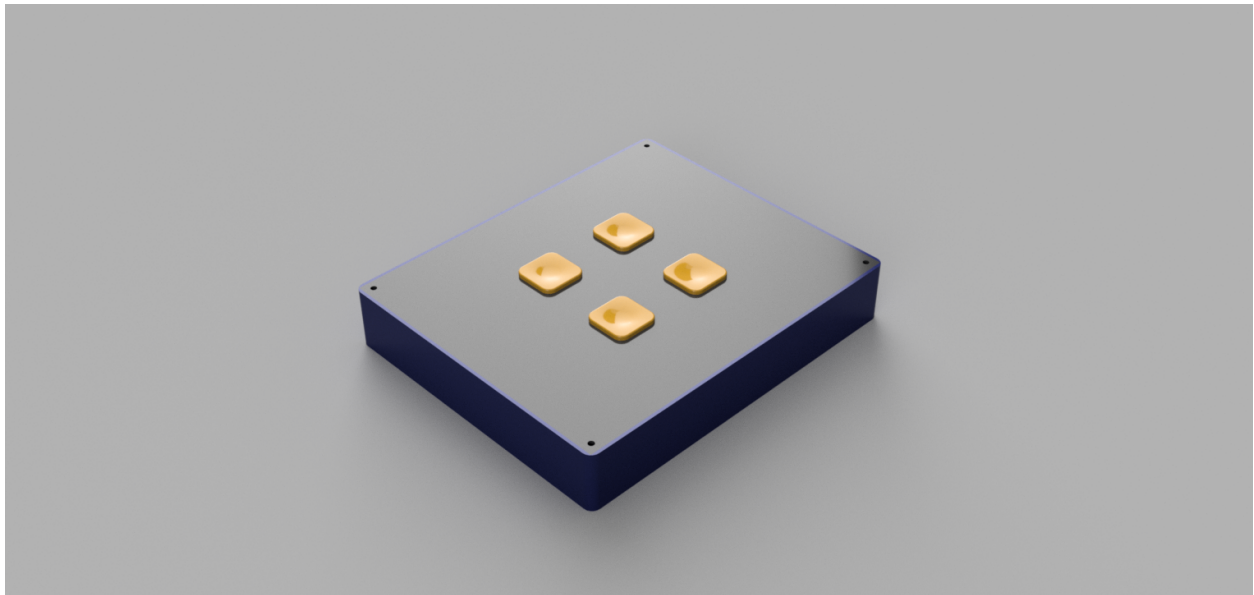


Figure 7d2. Render of a remote control

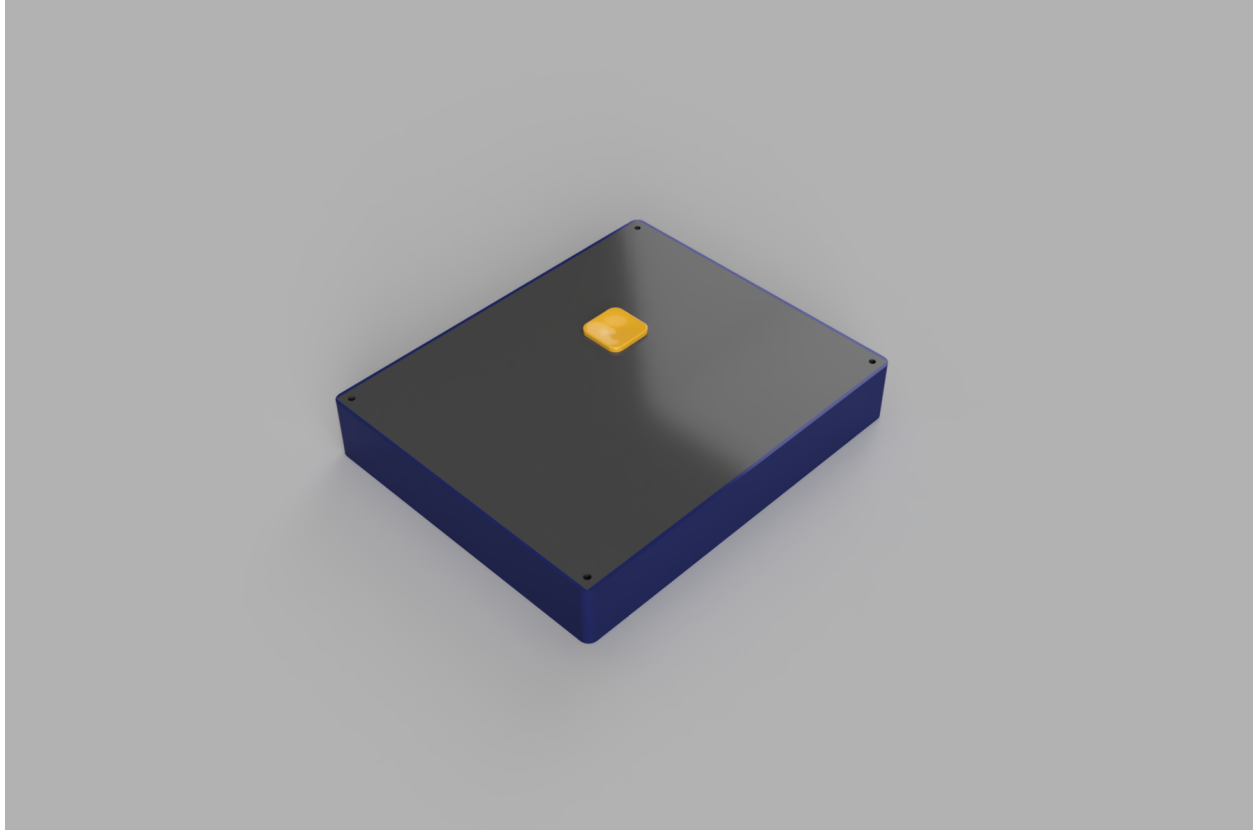


Figure 7d3. Render of clicker

The remote and clicker are essential parts of the senior design project. They allow the owner to operate and set up the system remotely from their car or house. Their designs are provided in Figures 7d1, 7d2, and 7d3.

From the PCB hardware standpoint, both of these devices have the same design, but they have different applications, and to address this, we will be using different software and populating boards differently.

As shown in Figures 7d2 and 7d3, the remote and clicker contain several buttons, that handle different tasks. The Remote's buttons enable users to open and close the roadway and switch the MARGE system between normally closed mode and normally open mode. The clicker, on the other hand, aims to allow the MARGE system to identify a recognized vehicle. The clicker will be used in the car, and the only available function of it will be to open the gate.

USB PD block allows devices to communicate with a USB charger and get necessary power and voltage through a USB connection safely. USB PD contains USB C port GT-USB-7010ASV and CH224K power delivery sink controller.

The power board contains a battery controller that handles the charge and discharge of batteries and provides protection from overvoltage and overheating. The power board is based on the DS2715Z+ charge controller and contains all components necessary for work with batteries, indicator LED, and allows connection of a 10KOhm thermocouple. The power board provides DC-DC voltage conversion and provides 3.3V at the output to power the microcontroller and LoRa module. The battery module contains 4 NiMh batteries and a thermocouple. NiMh batteries

were selected due to their size, appropriate for wearable devices, and safety compared to LiIon batteries, which are usually utilized in portable electronics.

8. Safety Analysis

8a. Battery Precautions

The batteries we will be using are Lithium-Iron Phosphate (LiFePO₄). LiFePO₄ batteries are the safest option, as they are not prone to overheating or exploding due to their strong covalent bonds in the cathode of the battery. Our batteries will be stored in a closed environment, shielded from weather conditions and other hazards that could affect the battery or the MARGE user.

8b. Weight Concerns

The cart will be around 25 lbs and the dock will be around 50lbs. The cart is light enough to move quickly but heavy enough to not be blown away by a storm. The dock is heavy enough to stay in place beside the owner's driveway, and will not have to be moved for weather conditions.

8c. General Safety Concerns

The MARGE cart will be moving into the center of the driveway in front of a moving vehicle. The cart will be large enough to be seen, with bright colors to be seen at night. If the cart is hit, it will be damaged, but it will not damage the car enough to hurt any of the passengers in it. The goal of MARGE is to stop incoming vehicles into a driveway, but it is safe to come in contact with.

While building MARGE, the team will wear closed-toed shoes, safety glasses, and no loose accessories. The team will also adhere to all laboratory safety rules set forth by Lafayette College and the safety rules set forth by the team in the Safety Document.

9. Calibration

While setting up the MARGE dock, the distance option will set the cart in motion perpendicular to the driveway. The owner will be able to push a button to stop the cart when it has reached the center of the driveway's width. From there the midway point of the driveway will be stored value for each time the cart enters the driveway. Each subsequent time the cart enters the driveway, the distance from the dock will be calculated and the cart will stop in the center of the driveway as selected by the user.

10. Estimated Cost

| Preliminary Bill of Materials | | | | | | | | |
|-------------------------------|--|--------------------|----------------|---------------|------------|---|---|------------|
| Quantity | Item | Manufacturer | Part Number | Cost Per Item | Total Cost | Website | Datasheet | Total Cost |
| 1 | Lithium Iron Phosphate Battery 12 Volt 50 Ah | Ecoworthy | N/A | \$149.99 | \$149.99 | https://www.eco-worthy.com/prod | | \$1,983.55 |
| 1 | DAKOTA LITHIUM 12V 10AH BATTERY | Dakota Lithium | N/A | \$99.00 | \$99.00 | https://dakotalith | https://dakotalith | |
| 1 | 100 Watt 12 Volt Solar Premium Kit | Renogy | RNG-KIT-PREM | \$279.99 | \$279.99 | https://www.renogy | https://www.renogy | |
| 5 | Button | adafruit | 481 | \$4.95 | \$24.75 | https://www.adafruit | N/A | |
| 4 | Motor | DigiKey | FIT0186 | \$30.00 | \$120.00 | https://wiki.dfrobot | https://mm.digikey | |
| 4 | Wheels | GRAINGER | 53CM80 | \$12.36 | \$49.44 | https://www.grainger | N/A | |
| 1 | Framing/Casing | McMaster-Carr | Various | \$680.92 | \$680.92 | https://www.mcmaster | Various | |
| 1 | Panel Angle Adjuster | Home Depot | 802067 | \$17.93 | \$17.93 | https://www.homedepot | N/A | |
| 8 | Raspberry Pico H | Raspberry | N/A | \$6.00 | \$48.00 | https://www.raspberrypi | https://www.raspberrypi | |
| 4 | SX1276 LORA | Semtech | SX1276IMLTRT | \$10.08 | \$40.32 | https://www.digikey | https://semtech.com | |
| 4 | TPS79330DBVR | Texas Instruments | 296-12159-2-ND | \$0.50 | \$2.00 | https://www.digikey | https://mm.digikey | |
| 4 | CS11336-32M | NDK America, Inc. | | \$0.58 | \$2.32 | https://www.digikey | https://mm.digikey | |
| 4 | NJG1816K75-TE1 | Nisshinbo Micro De | 2129-NJG1816K | \$0.77 | \$3.08 | https://www.digikey | https://www.nisshinbo | |
| 1 | IR Tracking Camera | DFRobot | SEN0158 | \$28.55 | \$28.55 | https://www.arduino | https://cdn.dfrobot | |
| 24 | IR Leds | adafruit | 387 | \$0.68 | \$16.32 | https://www.adafruit | https://cdn-shop | |
| 10 | Step Down LM2596 | TI | LM2596 | \$5.83 | \$58.30 | https://www.digikey.com/en/produc | | |
| 1 | Short Range Radar | InnoSenT | 80.00000062 | \$15.13 | \$15.13 | https://www.digikey | https://mm.digikey | |
| 1 | Long Range Doppler Radar | OmiPreSense | OPS243-A | \$209.00 | \$209.00 | https://omnipresense | https://cdn.livechat | |
| 1 | White on Blue 20x4 Character LCD | Crystalfontz | CFAH2004D-TM | \$26.05 | \$26.05 | https://www.crystalfontz | https://www.crystalfontz | |
| 2 | PC Termination D-Sub Connector, DB37 Female | L-Com | SD37S-PC | \$11.99 | \$23.98 | https://www.l-com | https://www.l-com | |
| 2 | Solder Cup D-Sub Connector, DB37 Male | L-Com | SD37P | \$8.89 | \$17.78 | https://www.l-com | N/A | |
| 14 | Solder Cup D-Sub Connector, DB9 Male | L-Com | SD9P | \$1.65 | \$23.10 | https://www.l-com | N/A | |
| 14 | PC Termination D-Sub Connector, DB9 Female | L-Com | SD9S-PC | \$3.40 | \$47.60 | https://www.l-com | N/A | |

11. Test Procedure

11a. Acceptance Test

Car Recognition (Normally Open)

A car drives towards the dock over 200ft away from the dock while in normally open mode.

Pass: Dock senses the vehicle and the cart moves to the center of the driveway.

Fail: Dock does not sense the vehicle or the cart does not go to the center of the driveway.

Car Recognition (Normally Closed)

A car drives towards the dock over 200ft away from the dock while in normally closed mode.

Pass: The cart does not move from the center of the driveway.

Fail: The cart moves from the center of the driveway.

Car has passed the MARGE System detection

A car passes the MARGE system while leaving the driveway.

Pass: Once the roadway-facing radar detects the leaving vehicle the Cart moves back into the roadway if in NC mode.

Fail: The cart fails to return to the roadway while in NC mode after the roadway-facing radar detects the vehicle.

A car passes the MARGE system while entering the driveway.

Pass: Once the home-facing radar detects the entering vehicle the Cart moves back into the roadway if in NC mode.

Fail: The cart fails to return to the roadway while in NC mode after the home-facing radar detects the vehicle.

Clicker

User drives a car to the driveway while the cart is in the center of it and then the clicker is pressed from 100ft away.

Pass: Cart moves out of the way of the car and returns to the dock

Fail: Cart does not move out of the way of the car or does not return to the cart

User Interface

User selects the normally open mode on the dock UI while the cart is in normally closed mode.

Pass: Cart moves to dock and runs in normally open mode.

Fail: Cart does not move to the dock or does not run in normally open mode.

User selects the normally closed mode on the dock UI while the cart is in normally open mode.

Pass: Cart moves to the center of the driveway and runs in normally closed mode.

Fail: Cart does not move to the center of the driveway or does not run in normally closed mode.

User

Remote

User presses the open button while the cart is in NC mode from 300ft away.

Pass: The cart moves to the dock and remains in the dock.

Fail: The cart does not move to the dock and stays there.

User presses the open button while the cart is in NO mode from 300ft away.

Pass: The cart remains in the dock.

Fail: The cart moves from the dock.

User presses the close button while the cart is in NO mode from 300ft away.

Pass: The cart moves to the driveway and remains in the driveway.

Fail: The cart does not move to the driveway and stays there.

User presses the close button while the cart is in NC mode from 300ft away.

Pass: The cart remains in the driveway.

Fail: The cart moves from the driveway.

User presses the NO button while the cart is in NO mode from 300ft away.

Pass: The system remains in NO mode.

Fail: The system does not stay in NO mode.

User presses the NO button while the cart is in NC mode from 300ft away.

Pass: The cart moves to the dock and goes to NO mode.

Fail: The cart does not move to the dock.

User presses the NC button while the cart is in NC mode from 300ft away.

Pass: The system remains in NC mode.

Fail: The system does not stay in NC mode.

User presses the NC button while the cart is in NO mode from 300ft away.

Pass: The cart moves to the driveway and goes to NC mode.

Fail: The cart does not move to the driveway.

Leaving Cars

In NO mode a car drives past the system.

Pass: The cart stays in the dock and the car is allowed to leave.

Fail: The cart moves to the driveway not allowing the car to leave.
In NC mode a car drives up to the cart from behind.
Pass: The cart moves to the dock and allows the car to leave
Fail: The cart does not move to the dock and the car is not able to leave.

Setup

In setup mode, the user enters the width of their driveway in the UI.
Pass: The cart moves towards the center of the driveway when closed.
Fail: The cart does not move to the center of the driveway.

Charging

When the solar panel is connected to the dock battery during daylight
Pass: The solar panel charge controller displays the dock battery is being charged
Fail: The solar panel charge controller displays the dock battery is not being charged
When the cart socket is connected to the dock charger
Pass: The UI displays the cart battery is being charged by the dock battery
Fail: The UI displays the cart battery is not being charged by the dock battery

Navigation

The cart moves from the dock to the driveway
Pass: The cart disconnects from the dock and moves to the desired destination
Fail: The cart does not move or does not move to desired destination
The cart moves from the driveway to the dock
Pass: The cart moves from the driveway and connects to the charger in the dock
Fail: The cart does not move or does not make it to or connects to the dock charger

12. Informational Website

To store the information on our Senior Design Project we have created a website. On the website, you can find the members of the senior design team, the goal of the project, and the progress we make. Our progress on MARGE will be shown on the website by displaying our preliminary and final proposals and designs. As we dive further into the project the website will continue to be updated. The website will be accessible to the public, being a catchall of information regarding MARGE.

The link to our website can be found here: [Senior Design 2023 - MARGE](https://sites.lafayette.edu/ece491-fa23-02/)
(<https://sites.lafayette.edu/ece491-fa23-02/>)

Appendix

1. Cart Battery Verifications

A 12V 10Ah battery will be used as our energy storage unit on the cart. When the cart is in normally closed mode, the cart will be in idle mode, using minimal energy. The reasoning behind the selection of this battery is provided by the math supplied below:

Variables

40 trips per day

Each trip is 10 sec (a high estimate but we want to design for worst case)

| Product | Active Current (Amp) | Passive Current (Amp) |
|----------------------------|----------------------|-----------------------|
| Motor | 0.7 | 0 |
| Raspberry Pi Pico | 0.05 | 0.01 |
| Lora Communication Circuit | 0.12 | 0.002 |
| Infrared Circuit | 0.05 | 0 |
| Current Sensor | 0.05 | 0.05 |

Notes:

The Lora Communication Circuit, the Raspberry Pi Pico, and the Current Sensor will only draw the active current 75% of the time.

There are four motors.

The motors and the Infrared Circuit are only in use when the cart is moving.

When traveling:

$$0.7A * 4 \text{ motors} = 2.8A$$

$$2.8A + (3 * 0.05A) + 0.12A + 0.7A = 3.77A$$

$$3.77A * 10 \text{ sec} = 37.7 \text{ Asec}$$

$$37.7 \text{ Asec} * 40 \text{ trips} = 1508 \text{ Asec}$$

$$1508 \text{ Asec} = 0.419 \text{ Ah}$$

When idle:

$$0.75 * 24 \text{ h} * 0.12A = 2.16 \text{ Ah}$$

$$0.75 * 24 \text{ h} * 0.05A = 0.9 \text{ Ah}$$

$$0.75 * 24 \text{ h} * 0.05A = 0.9 \text{ Ah}$$

$$2.16 + (2 * 0.9) = 3.96 \text{ Ah}$$

$$0.25 * 24 \text{ h} * 0.002A = 0.012 \text{ Ah}$$

$$0.25 * 24 \text{ h} * 0.01A = 0.06 \text{ Ah}$$

$$0.25 * 24 \text{ h} * 0.05A = 0.3 \text{ Ah}$$

$$0.012 \text{ Ah} + 0.06 \text{ Ah} + 0.3 \text{ Ah} = 0.372 \text{ Ah}$$

$$0.372 \text{ Ah} + 3.96 \text{ Ah} = 4.332 \text{ Ah}$$

Total Daily Usage:

$$4.332 \text{ Ah} + 0.419 \text{ Ah} = 4.751 \text{ Ah per day}$$

Thus the battery we have selected can handle the necessary amount of current required by the system in the day with the required charging. This calculation is also an over-calculation.

2. Dock Battery Verifications

A 12V 50Ah battery will be used as our energy storage unit on the cart. When the cart is in normally closed mode, the cart will be in idle mode, using minimal energy. The reasoning behind the selection of this battery is provided by the math supplied below:

| Product | Active Current (Amp) | Passive Current (Amp) |
|----------------------------|----------------------|-----------------------|
| Raspberry Pi Pico | 0.05 | 0.01 |
| Lora Communication Circuit | 0.12 | 0.002 |
| Long Range Radar | 0.14 | 0.06 |
| Short Range Radar | 0.03 | 0.03 |
| Infrared Beacon | 0.5 | 0 |
| User Interface | 0.035 | 0 |

Notes:

The Lora Communication Circuit, the Raspberry Pi Pico, and both radars will only draw the active current 75% of the time.

The Infrared Beacons are going to only be powered on when the cart is traveling.

Daily Usage:

$$0.75 * 24 \text{ h} * 0.12\text{A} = 2.16 \text{ Ah}$$

$$0.75 * 24 \text{ h} * 0.05\text{A} = 0.9 \text{ Ah}$$

$$0.75 * 24 \text{ h} * 0.14\text{A} = 2.52 \text{ Ah}$$

$$0.75 * 24 \text{ h} * 0.03\text{A} = 0.54 \text{ Ah}$$

$$2.16 + 0.9 + 2.52 + 0.54 = 6.12 \text{ Ah}$$

$$0.25 * 24 \text{ h} * 0.002\text{A} = 0.012 \text{ Ah}$$

$$0.25 * 24 \text{ h} * 0.01\text{A} = 0.06 \text{ Ah}$$

$$0.25 * 24 \text{ h} * 0.06\text{A} = 0.36 \text{ Ah}$$

$$0.25 * 24 \text{ h} * 0.03\text{A} = 0.18 \text{ Ah}$$

$$0.012 \text{ Ah} + 0.06 \text{ Ah} + 0.36 \text{ Ah} + 0.18 \text{ Ah} = 0.612 \text{ Ah}$$

$$0.035 * 1 \text{ h} = 0.035 \text{ Ah}$$

$$2 \text{ Beacons} * 0.5 * 40 \text{ trips} * 10 \text{ sec} = 400 \text{ Asec}$$

$$400 \text{ Asec} = 0.111 \text{ Ah}$$

Total Daily Usage:

$$6.12 \text{ Ah} + 0.612 \text{ Ah} + 0.035 \text{ Ah} + 0.111 \text{ Ah} = 6.898 \text{ Ah per day}$$

Thus the battery we have selected can handle the necessary amount of current required by the system in the day with the required charging. This calculation is also an over-calculation.

3. Charging Duration

The 12V 10 Ah battery in the cart will take 1.25 hours minimum to charge from no battery percentage left. The 12V 50 Ah battery in the dock will continuously charge. However, with a steady output current of 20A from the solar panel, it will take approximately 2.5 hours minimum to charge fully from no battery percentage left. The calculations for the charging time is provided by the math below:

Equation:

$$\text{Charge Time (hours)} = \text{Capacity of Battery (Ah)} / \text{Charger Output (A)}$$

12V 10Ah Cart Battery

$$10 \text{ Ah} / 8 \text{ A} = 1.25 \text{ hour minimum}$$

12V 50Ah Dock Battery

$$50 \text{ Ah} / 20 \text{ A} = 2.5 \text{ hours minimum}$$