Remotely Accessible Portable Solar Charging Evaluation System

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1. Abstract

Our team is tasked with building a remotely accessible portable solar charging evaluation system, also known as RAPSCES, for performance and environmental conditions monitoring. The main objective of the proposed system is to collect environmental, directional, and performance data and transmit them wirelessly to a remote computer. Overall, the system functions as a user-friendly, portable, and solar tracking battery charging system. The system consists of solar panels, custom housing for all internal electronics, a steerable panel mount, a 12V battery that serves as a solar charge storage, an inverter, a solar tracking mechanism, wireless data transmission, and environmental and performance sensors.

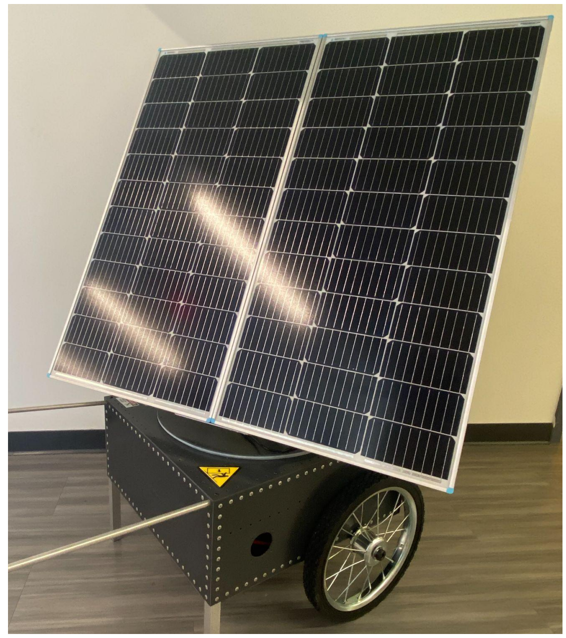


Figure 1: Full Assembly

2. Motivation

Whether you are tailgating at a football game or dealing with a power outage, a generator is a useful tool to grant you electricity when not connected to a power grid. One such generator is the Honda EU2200i portable generator, which has a fuel capacity of 0.95 gallons of unleaded gasoline and a run time of approximately 3.2 hours. Producing 2.2 KW worth of power, it has the capacity to operate a wide range of appliances making it the perfect tool at home, camping, or at the job site.

Despite its benefits in supplying power and portability, the Honda EU2200i portable generator's major drawback comes in with its use of fossil fuel which negatively impacts the environment. The proposed system attempts an electrically equivalent output with the help of solar panels to power recreational applications and provides a more environmentally friendly alternative.

Our system aims to provide a standard AC 110V 60Hz nominal output voltage compatible with a standard residential wall outlet with load capability meeting or exceeding the nominal 20 amps. The system uses an inverter to power convert from 12V DC to 110V AC nominal output. These specifications were put in place to meet the Honda EU2200i's output.

3. Design Objectives

3.1. Mechanical Structure

The system is configured to be portable and accommodate various but reasonable terrain. It is detachable into two subsections: the turret and the base.

3.2. Data Collection

The system acquires environmental, electrical performance, and safety data from the charging system and positioning system by wireless transmission of this data to a remote computer. It measures and displays the charge controller's input DC voltage, input and output DC current, and battery temperature.

The main function of the system is evaluation of environmental statistics, so sensors are used to test temperature, pressure, humidity, battery temperature, and solar intensity. Photoresistors are used to assist in identification of solar intensity. Also, a compass and accelerometer are used to detect the solar panel's orientation for a correct solar tracking path.

3.3. Solar Tracking

The system includes a panel solar tracking feature that can be set at a fixed angle, or run in a user defined path mode, or a solar feedback tracking mode. The user has full control of panel orientation and is able to view its relevant rotation and pitch angle during its operation. When the system is in operation relevant solar measurements such as light intensity should be reduced.

3.4. Design Specifications

Design specifications for our system are as follows:

- The system should provide a standard AC 110V 60Hz output voltage compatible with a standard residential wall outlet with load capability meeting or exceeding the nominal 20 amps.
- The solar charge storage is to be a "12V" battery system, and utilize an inverter to power convert from 12V DC to the required 110V AC output.
- It is anticipated these units should not exceed 100lbs.
- The charging system, if on, must be fully functional without communication to a remote device.
- All electronics related to the sensing units and wireless transmission must be locally powered by the solar charge storage 12V battery system.
- DC power management circuits must be designed to provide appropriate power levels for all sensing circuits, MCUs and MPUs.

4. Solar Kit Study

One of the first steps of this project was to purchase the main parts of the solar system, the panels. Inverter, and battery. First off we selected two Renogy 100 watt panels, this was the one area where we had some flexibility in terms of the parts we picked. We found these 2 100W panels provided a nice middle ground between weight and charging capability(Calculations Shown Below). While we could obviously continue to add panels to increase the charging capacity of our system, we felt 2 x 100 Watt panels provided a good middle ground between weight, physical size and performance that meets portability goals. Solar Kit Study Link

Panel Rating	Appliances Attached	Load	Runtime*
2 x 100W	Blender(1400W) for 10 minutes Phone(11Wh battery) 0=100% charge	244W	54 Hours

Figure 2: Panel Specifications

The other two components were selected to meet the required spec. We selected a 200 aH battery in order to provide 200A for the inverter. We picked a LiFePO4 battery due to the significant weight difference between other comparable batteries. As for the inverter, we selected a 2000W Renogy pure sine wave inverter. When looking at Inverters we had to take into account if the one we selected was safe for electronics. While a modified sine wave inverter may have been cheaper and less heavy, we felt as if the increased performance and safety for sensitive electronics was worth the extra cost.

5. Solar Panel Tracking Control

The solar panel is made unique by its dual axis solar tracking mechanisms, which includes tracking using preset values according to the location of the panel and using light sensors to determine the direction of the sun.

In order for the solar panel to always be perpendicular to the sun beams and generate maximum power, it would need to be able to make a total range of 240 degrees horizontally and 74 degrees vertically.

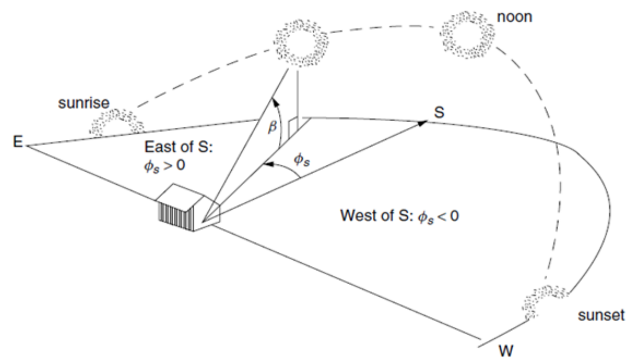


Figure 3. Illustration of the solar angles (Solar Time, Angles, and Irradiance Calculator - User Manual | New Mexico State University - BE BOLD. Shape the Future., n.d.)

This means that on the horizontal plane, and on an average day in the summer it will need to move from 60 degrees to 300 degrees, with the north being 0 degrees. On the vertical plane, the panel needs to be able to move from a position where it is perpendicular to the ground, at which the azimuth angle will be zero, until it goes to 74 degrees. Due to design constraints the minimum tilt angle was changed from 28 degrees to 33 degrees which gave us a theoretical energy loss of 1%. Figure 4 below represents an estimate of the exact angles the linear actuator will grant us.

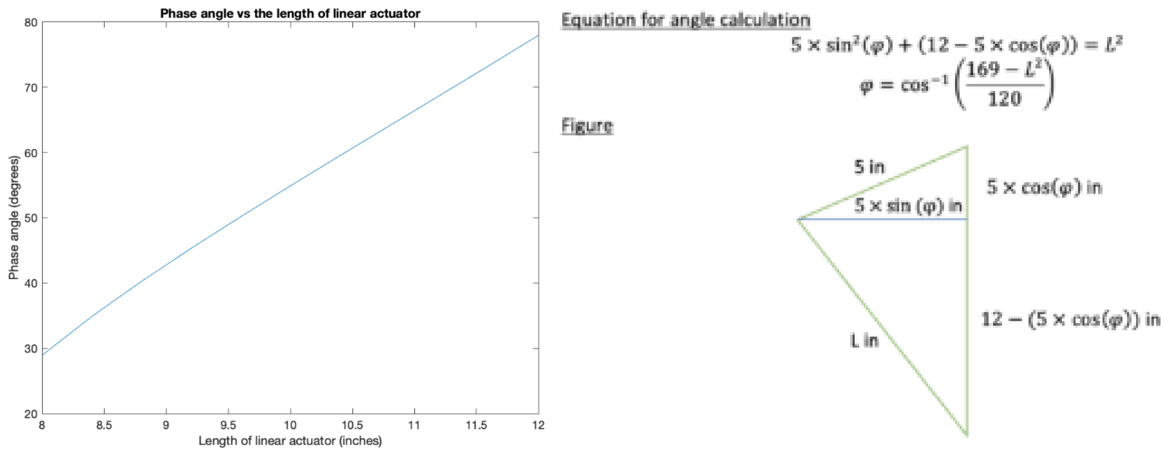


Figure 4. Panel Angle calculation

5.1. Open Loop Sensor Design

Values of the different starting azimuth and altitude angles for each morning and every hourly change afterwards until dawn will be stored as an array, so the solar system can track or verify the sun's position using pre-calculated values.

5.2. Closed Loop Sensor Design

The photoresistors will be placed in the four slots, so the accuracy will be adjustable as we either move them closer or further away from the center. Each photoresistor will aid in determining the direction in which to move the panel in order to track the sun. For that, a wheatstone bridge and an amplifier is used (see Figure 5). If the sun beam is not parallel to the wedges, they will cast a shadow on some of the photoresistors, therefore giving us a high resistance, so we will adjust the solar panel such that we have relatively similar values of resistance from each photoresistor. [Solar Tracking Link]

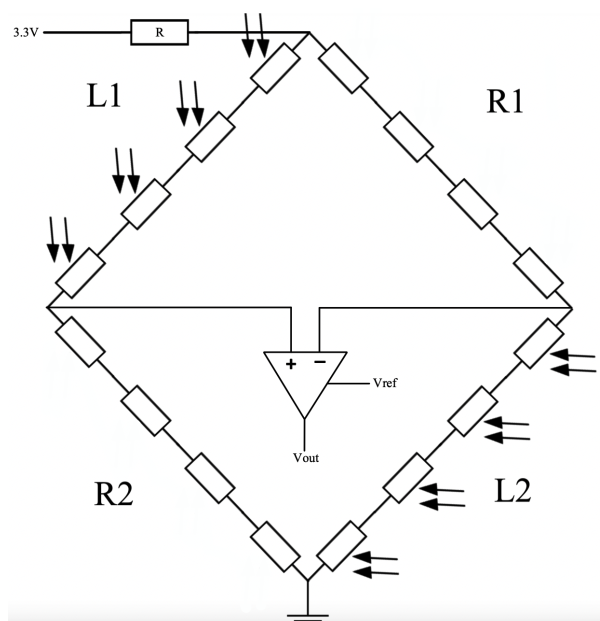


Figure 5. Wheatstone bridge for closed loop solar tracking.

The analysis shown below in *Figure 6* and *Figure 7* are based on Solar Time, Angles, and Irradiance Calculator. (*Solar Time, Angles, and Irradiance Calculator - User Manual | New Mexico State University - BE BOLD. Shape the Future.*, n.d.). They demonstrate the ideal tracking capabilities for the solar tracker based on different yearly times.

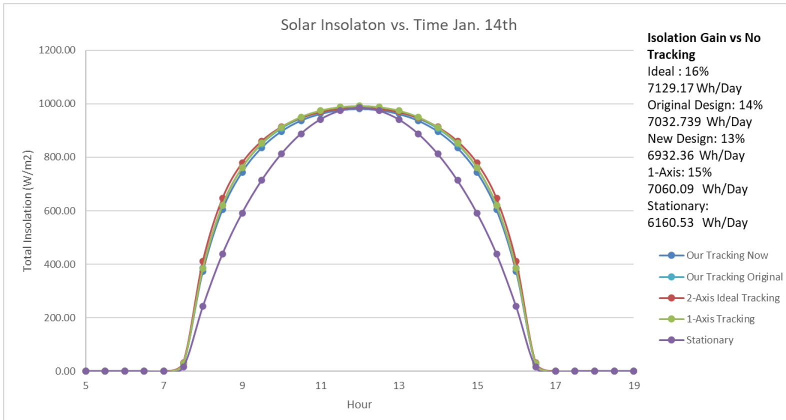


Figure 6. Hourly Power Generation vs. Time Jan 14th (Max Angle of 28.56)

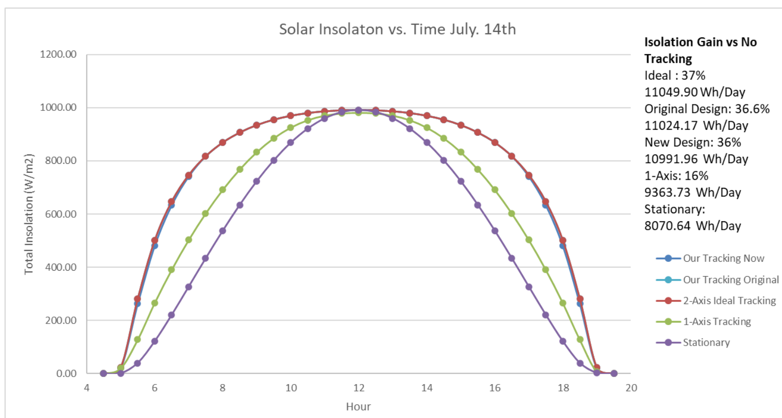


Figure 7. Hourly Power Generation vs. Time July 14th (Max Angle 71.67)

6. Mechanical Design

Mechanically, the driving constraints for this system are the size/weight restrictions and the necessary movement of the solar panel to track the sun. There are two principal degrees of freedom: azimuth (Z-axis rotation) and elevation (y-axis rotation). Thus, we have elected to design a base and a turret, with the solar panel and its elevation mechanism mounted on the turret, which rotates on the base. There is also a requirement for unpowered movement; thus, we have elected to mount the base on a wheel system, similar to a dock cart/wheelbarrow.

6.1. Base

The base is principally a mounting system for the electronics and azimuth control. Azimuth is controlled by a window motor connected via belt to the shaft which the turret is mounted on. The turret is further supported by a low-friction plastic ring to reduce the transverse moment on the main turret shaft.

The electronics mounted within the base include the charge controller, LCD for system interaction, motor drivers, microcontrollers, and power distribution boards. The base itself is constructed from 1x1 aluminum L channel and PVC panels.

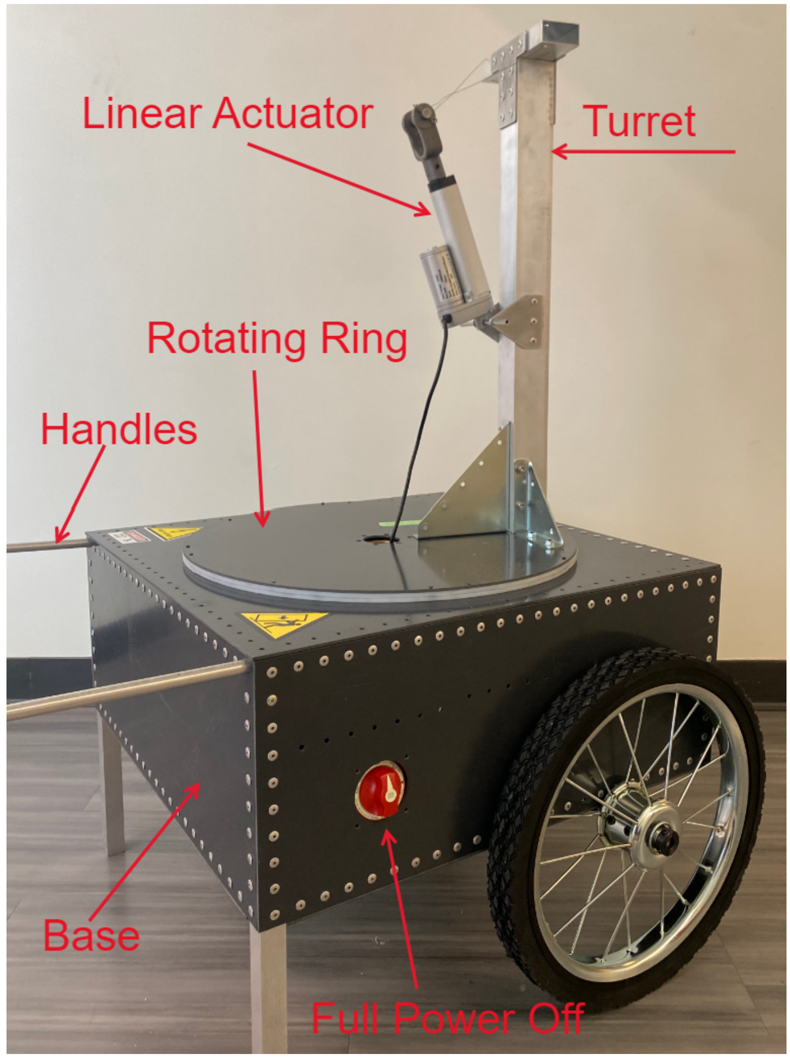


Figure 8. Full Assembly without Solar Panels

6.2. Turret

The turret serves as a mount for the solar panel and its elevation control. Elevation control is achieved via a linear actuator, which is mounted to a main mast and the solar panel. When it extends, the solar panel becomes more "flat". The turret base is a piece of PVC plastic which mounts a second set of low-friction plastic to react against the track on the base. It mounts a main mast, which extends vertically on one side of the base and mounts the solar panel on top.

6.3. Assembly

The full assembly is merely a combination of the base and the turret. The turret is layed on the base and the turret shaft connects the turret to the base. It rotates along its plastic race and all cabling is fed through the turret shaft from the turret to the base. [Mechanical Design Link]

7. Electrical Design

7.1. Wire Harnessing

A wire harness will be a key component of our design. Given the number of sensors used in our design, proper cable management will be necessary to keep wires organized. Another major component of the wire harness is making sure wires stay secure. Our system will be mobile and that means wires will be shaking around. Secure connections are of the utmost importance. Connections will also be important when connecting sensors on the frame to the Arduino in the case. Making sure we have secure connections between these wires, as well as using a connector that the user will be able to easily attach and detach is important. The key components of the harness are detailed below.

One of the most important aspects of harnessing was picking correct wire gauges. For all of the sensor wiring we used 22 AWG wire. Given the low current demands, we picked a gauge that was small as well as supported by a wide range of connectors. For connecting the battery to the power board and Inverter we used 2x4 AWG wire, to deal with the high current demands. For motor connections we used 16 AWG wire, providing a nice middle ground between current demands and sizing.

For connectors we used a couple different options. For our sensor connectors we used a 2.5 mm pitch Molex(Pictured below). These connectors allowed for easy use with our boards and were very plug and play in nature. One of the important specialty connectors were the Squaba Sealed Connectors. These connectors were used as disconnects between the turret and base They provided relatively high current capacity (14A) as well as a waterproof connection. Wire Harness Link

Figure 9: Squaba Wire-Wire Connections

Figure 10: Molex Board Headers

7.2. High Level Power Board Design

The power system design consists of three hierarchical levels: a battery, a foundation board, and functional boards that include a voltage-conversion board and H-bridge motor-control boards. The system architecture is illustrated in Figure 11 below. The battery is directly connected to the foundation board, which then distributes 12.8V to the two H-bridges and the voltage-conversion circuit. The two H-bridges are responsible for controlling the DC motor and linear actuator, while the step-down circuit provides 5V to the touch screen and Arduino boards.

The overall system design incorporates a foundation board with connectors that allow the H-bridge and step-down circuits to be easily plugged in. This design was chosen for several reasons, including the possibility of IP reuse in other projects. The foundation board also serves as an intermediate layer in the modularization and fungibility of the functional boards. Furthermore, the foundation board includes three fuses to protect each of the circuits, thus reducing the required space for individual circuits.

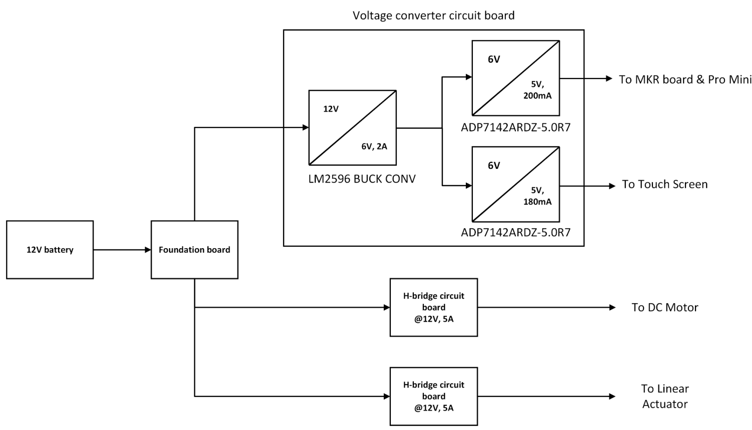


Figure 11: The block diagram of power system

7.3. Power Board Electrical Specifications

7.3.1. H-Bridge

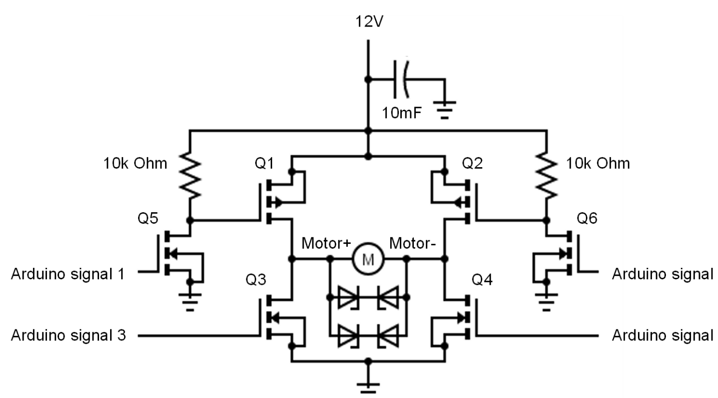


Figure 12: The schematic of H-bridge

The motor-control H-bridge circuit is implemented by two power P-channel MOSFETs, two power N-channel MOSFETs, and two regular N-channel MOSFETs. The two regular N-channel MOSFETs, Q5 and Q6, are each connected to a 10K Ohm resistor which in turn is connected to the 12V input. Such a connection builds a pull up switch that draws current in 12V directly from the battery to satisfy the switching current *circuit*\requirement of power P-channel MOSFETs which cannot be met by Arduino's signal output. Furthermore, a 10mF capacitor is connected in parallel with battery power inputs to decouple the voltage transmission along the wire. Figure 12 shows the complete circuit schematic of H-bridge. The datasheet and KiCAD drawings can be accessed on page 3 of the power board datasheet.

Input (Arduino Signals)				Output		
1	2	3	4	Motor+	Motor–	Mod
L	L	L	L	0V	0V	Motor off
H	L	L	H	12V	0V	Motor On forward biased
L	H	H	L	0V	12V	Motor On reverse biased

Figure 13: Motor & Linear actuator control guide table

The control of H-bridge is accomplished by four signal inputs as each of them controls one MOSFET. As the table and the H-bridge schematic shows, Arduino signal 1 & 4 that control Q1 and Q4 forms a pair to drive the motor forward biased; Arduino signal 2 & 3 that control Q2 and Q3 forms a pair to drive the motor reverse biased.

The control mode of the DC motor and linear actuator is pulse-wise stepping; with each pulse of the control signal, the motor/linear actuator is turned by one step. A pulse with 10ms width would drive the DC motor to rotate 1 degree of a step and drive the linear actuator to extend/contract 2mm of a step. The pulse signals are simultaneously sent to the designated pair of MOSFETs to drive the motor; for example, Arduino signal 1 & 4 would send a pulse starting at exactly the same time to MOSFETs Q1 & Q4 to step the motor forward biasedly.

However, the inductive nature of motors opposes any instantaneous change in the current flow in itself. Therefore, after current is terminated by MOSFETs, the energy/current remaining inside the motor is needed to be re-circulated and decayed in order to protect the MOSFETs. To achieve that, when a half-bridge(one N-MOSFET and one P-MOSFET) is turned on and then off to complete a step, the N-MOSFET remains on for an extra time after P-MOSFET is turned off.

For instance, Arduino signal 1 which controls the P-MOSFET turns low after 10ms while the Arduino signal 4 which controls the N-MOSFET should remain ON for an extra time of 10ms. Such procedure makes N-channel MOSFETs on to decay the current remaining in the motor after it is energized and expected to be off/de-energized. The example signal timeline plot is shown on Figure 14 and the actual effect on the H-bridge circuit is shown in Figure 15.

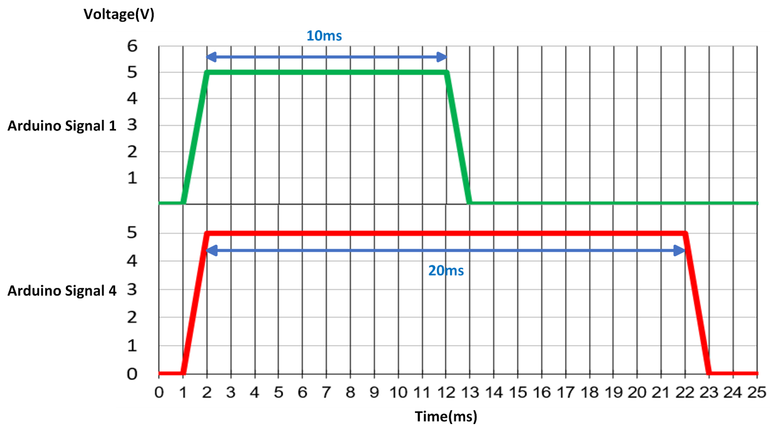


Figure 14. The signals controlling P-MOSFET(green) and N-MOSFET(red)

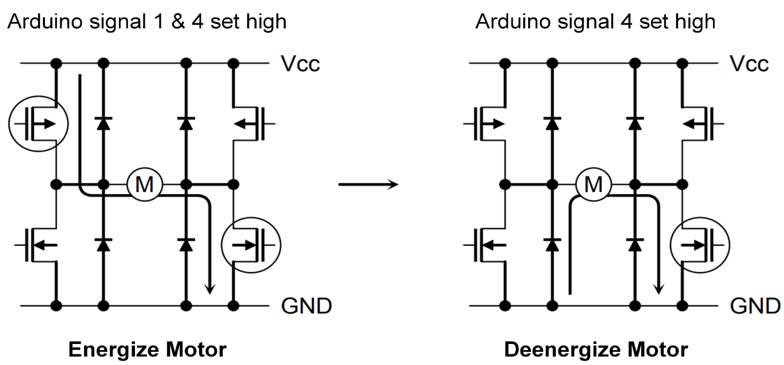


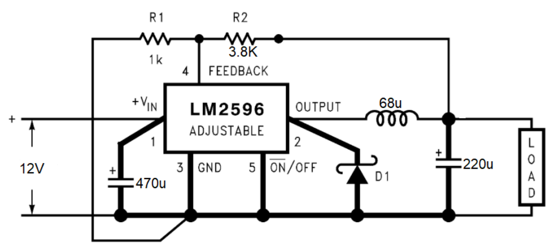
Figure 15. Current flow during energization and deenergization during first 10 ms and remaining 10 ms respectively.

7.3.2. Step Down Circuit

A step-down circuit was selected to power small electronic components within the system due to its high efficiency, which conserves power from the primary battery source. The circuit operates in two stages, a voltage step-down stage from 12.8V to 6V using an LM2596 buck converter, followed by a regulation stage to 5V using two Low Dropout Regulators. A Low Dropout Regulator (LDO) is a voltage regulator that can maintain a stable output voltage with a very small input-output voltage differential and low noise, thereby reducing power dissipation and heat generation. The board provides three 5V outputs, each capable of delivering up to 200mA, with a maximum output power capacity of 3W.

The two-step voltage regulation system was chosen for its advantages over a standard linear regulator solution. It takes advantage of the 95% power efficiency of the buck converter and the low power dissipation overhead of an LDO operating at a 6V input. Compared to a linear regulator solution operating from a 12.8V input, the overall power dissipation overhead of the two-step regulator system is about 25% of the electronics power load, which is significantly lower than the 150% overhead of the linear regulator. The use of a buck converter in the two-step regulator system helps prevent overheating by minimizing power dissipation.

In summary, the two-step voltage regulation system provides higher efficiency, reduced power dissipation, and lower voltage drops, making it a superior solution for powering small electronic components in this system. Figure 16 and 17 below illustrate the implementation of these two stages. The KiCAD drawing of this circuit can be accessed on page 4 of the power board datasheet.



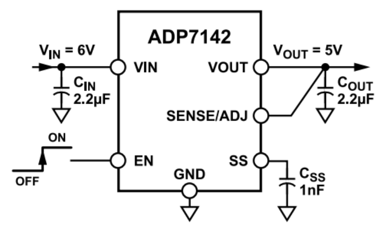


Fig 16. Step Down Circuit: 12V to 6V

(Source: LM2596 Datasheet, pg 27)

Fig 17. 6V to 5V LDO

(Source: ADP7142 Datasheet, pg 1)

7.4. I/O Configuration

The figure below shows the final circuit after being built:

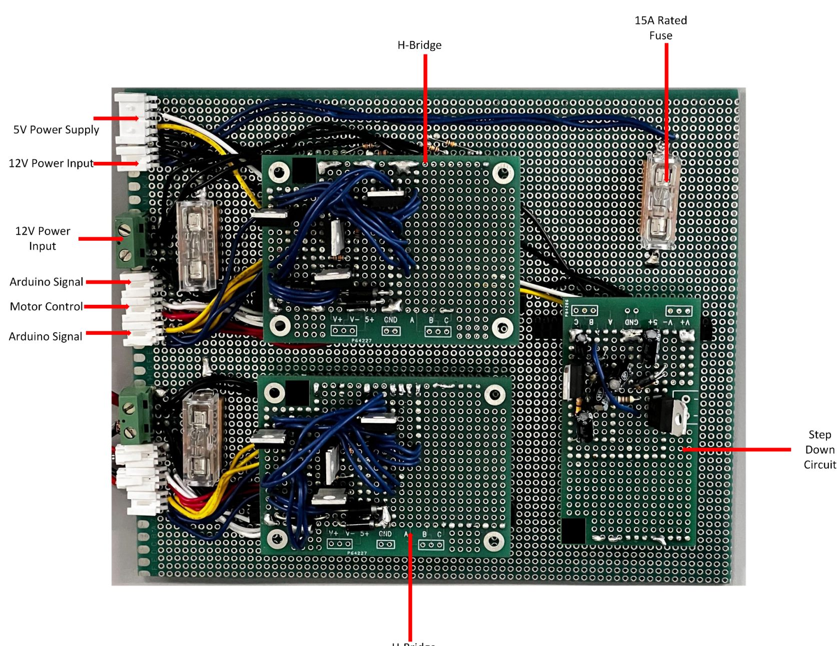


Fig 18. IO Configuration Photograph

[Power Board Datasheet]

8. Digital Design

8.1. High Level Overview

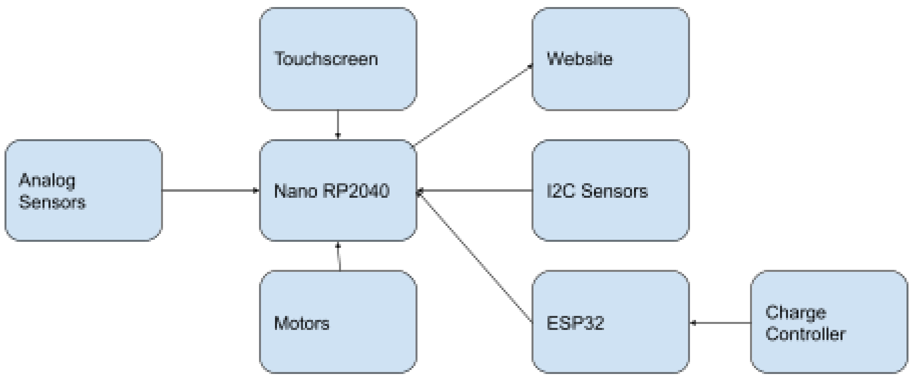


Figure 19. High Level Overview of Digital Design

As specified in Figure 19 above sensors will be wired across two MCU's. The first MCU is the Arduino Nano RP2040 which will control the functionality of the system as well as Wifi connectivity. The second MCU will be to interface with the charge controller and transmit the relevant data to the other Arduino. In regards to the sensor wiring we have three I2C sensors that will share the same bus, as well as four pins dedicated to the motors and four pins dedicated to the solar tracking. Figure 19 additionally shows the data flow as specified within this paragraph.

8.2. Remote Dashboard

The remote dashboard is a web application which communicates with the system to transmit environmental data over WiFi. Furthermore, the user of the application can also choose what tracking algorithm they would like the system to use remotely. This functionality is useful as a user can set up the system anywhere where there is a WiFi connection and proceed to operate the machine from a different location.

Website Details

The technical specifications of the web application are as follows:

Back-end: PHP, MySQL

Front-end: HTML, CSS, TailwindCSS

The website consists of three pages: dashboard, profile, and control center. The dashboard displays the sensor data that is transmitted from the system, as well as the time of the latest transmission. The profile page shows the team members involved in the project and their respective positions. The control center page has a menu where users can select the control algorithm they want the system to operate in and submit it to the system.

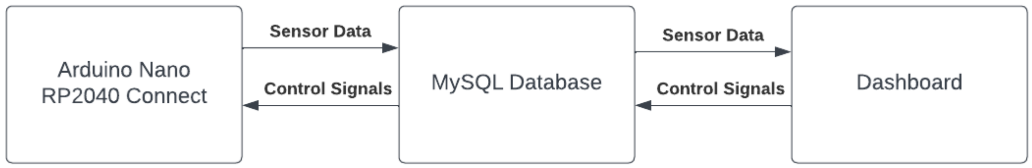


Figure 20. Sensor data flow from the Arduino to the dashboard

The advantage of using a database as an intermediate connection between the dashboard and arduino is portability. It allows for the flexibility of switching services at ease or repairing any issues which may arise in the future. Based on the above figures, the database could be terminated and reconstructed on another hosting provider due to the modularization of the design

8.3. Sensors

The sensors that are used in the system are as follows:

1. AC current sensors (SYUAB 2Pcs SCT013000-Link): Used to confirm that we are getting the correct output from our pure sine wave inverter and that we are not going over our capacity
2. AC voltage sensor (ZMPT101B-Link): Used to confirm that we are getting the correct output from our pure sine wave inverter
3. DC voltage sensor (Hi LetGo 0-25V DC sensor-Link): Used to monitor the car battery voltage to monitor battery levels
4. Battery Temp Sensor (NTC Ring Cable Temperature Sensor-Link): Used for safety purposes so that the system can shut off if the battery is overheating
5. Temp/Humidity/Pressure (BME 280-Link): Used to monitor environmental data
6. Photovoltaic sensor (HiLetgo 100pcs 5528 Light Dependent Resistor LDR 5MM Photoresistor Photoconductive Resistance-Link): Used to assist solar tracking
7. Compass and Accelerometer (Adafruit LSM303AGR Accelerometer Magnetometer-Link): Used to know the orientation of the solar panels so that we can create an accurate solar path for the solar tracking
8. Real Time Clock (Adafruit 3296 DS1307 Real Time Clock Breakout Board-Link): Used to keep track of time for the closed loop solar tracking path
9. Interface with Renogy MPPT Charge Controller used to pull relevant information from the charge controller using an FTDI converter and manually stripping relevant data points

9. GUI

9.1 Main Features

The GUI will be displayed on a 800*480 resolution 7 inch LCD touchscreen display. User control will be done through the touch screen. The GUI could be turned off manually for power saving and turned back on by re-clicking the screen. The GUI could display sensor data, control panel rotation, activate automatic sun tracking, set sensor data recording schedule, connect/disconnect the generator to WiFi and self test of panel control.

9.2. Theory of Operation

The touchscreen user interface consists of 8 buttons on the main page. The two horizontal arrow buttons control the left and right rotation of the solar panel and the two vertical arrow buttons control the up and down rotation of the solar panel. The STATS button leads to a sensor list page. The SLEEP button turns off the display, the display could be re-activated through a touch on the screen. If the screen stays inactive for 5 minutes, it will also go to sleep mode.

There are 3 modes for panel control:

- Manual control
- Defined path auto tracking
- Defined path auto tracking + photosensor adjustment

Users could press the arrow buttons on the main page to perform manual control. The ANGLE RST button resets the solar panel back to the original position.

The AUTO button turns on/off the sun tracking of the solar panel. When solar tracking is on, the manual control will be disabled. The Defined Path auto mode will move the solar panel to a certain angle at certain times on a lookup table in the microcontroller according to the time and date. The user could press the Photo Sensor button to enable precise solar tracking. When the photo sensor is on, the panel will first move to the location of the defined path and then adjust the angle to gain maximum solar energy.

When the test button is pressed, the microcontroller will move the panel for 10 degrees in each direction and compare the change in angle with the reading from the digital compass to check if the system is functioning correctly

On the sensor list page, the home button leads back to the main page, the up and down arrow buttons scrolls the list upward and downward, the compass displays north from the digital compass. The sensor data is refreshed every 3 seconds.

The sensor schedule will consist of a user interface as pictured above at the end of the theory of operation section. In this interface, the user will be able to select a specified amount of time throughout the day to record data. After selecting this time period, the user will then be prompted for how often they would like to record data. For example, if the user wants to store data from 7 AM to 7 PM at an interval of 15 minutes, this interface will accommodate the request.

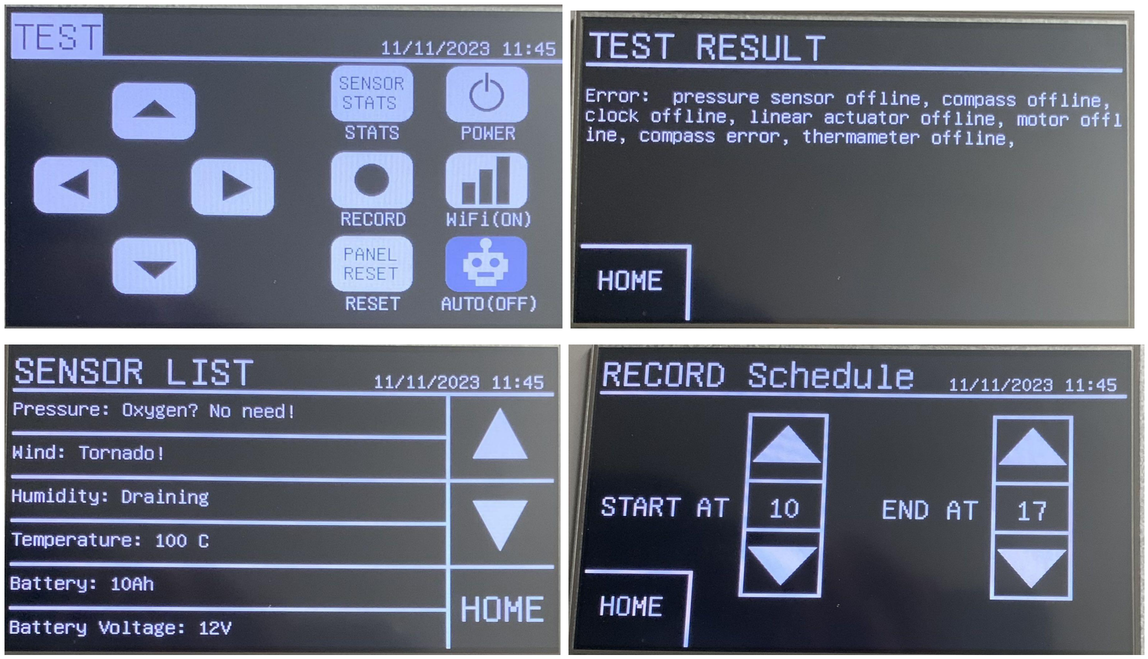


Figure 21. Photographs of GUI output

10. Results & Conclusion

The mechanical structure succeeded in our original design. We planned for it to be configured as portable and accommodate various but reasonable terrain. We succeeded in this and it is detachable into two subsections: the turret and the base. The mechanical structures portability allows for easier transportation and the detachability allows for the user to replace any parts if needed without a hassle.

Overall the digital design was successful in meeting our objectives. We planned to design a touch screen interface as well as a system of the MCU’s that could communicate with each other, read sensors, and subsequently drive motors. The digital design was designed to be low power which was implemented in our design through the use of low power Arduinos and eliminating functionality in software that was not used.

The power system design has achieved its intended objectives as per the original design specifications. The design aimed to incorporate a voltage conversion circuit to step down the battery voltage of 12.8V to a lower voltage level of 5V, which could subsequently power the MCU and the touch screen. The board has functioned effectively as a power source and a motor-control circuit, facilitating the control of the DC motor and linear actuator based on commands relayed from the MCU. The design of the power system has been carefully crafted to ensure safe, error-free, and modular implementation of power conversion and motor control.

Reference

Solar Time, Angles, and Irradiance Calculator—User Manual | New Mexico State University—BE BOLD. Shape the Future. (n.d.). Retrieved November 16, 2022, from https://pubs.nmsu.edu/_circulars/CR674/