LAFAYETTE COLLEGE

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

Senior Design Project
Class of 2023

Remotely Accessible Portable Solar Charging Evaluation System (RAPSCES)

Fall 2022

Final Proposal Version 2
November 14th, 2022

SENIOR DESIGN
2023
LAFAYETTE COLLEGE ECE

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Revision History

I. 22. Informational Website
    A. Reworked website layout to add easier user interface
    B. Added a video overview of the 3D model onto website
II. Fixed Section 3.3 (Data collection)
III. Rewrote the description of the motor control mechanism. Added the relay H-bridge schematic.
IV. 15. Mechanical Design
    A. Edited 3D Model
        1. Increased mask to allow for more stability based off of Professor Helms suggestions
V. Added temperature and fuse requirements for battery safety precautions
VI. Added a portability section in database management to describe the structure of the software
VII. Added a service usage section in the remote dashboard which describes the function of each service in more detail.
VIII. Added updated wiring harness
IX. Included Solar angle cost benefit analysis
X. Modified GUI figures and included test mode button
XI. Included percentage gain compared to 1-axis tracking

1. Abstract

Lafayette College's Department of Electrical and Computer Engineering requested the 2023 senior class to design a remotely accessible portable solar charging system for performance and environmental conditions evaluation. The main objective of the proposed system is to collect environmental, directional, and performance data and transmit them wirelessly to a remote computer. The system is composed of solar panels, a 12V battery that serves as a solar charge storage, an inverter to convert 12V DC to 110V AC output voltage, a solar tracking mechanism, wireless data transmission, and environmental and performance sensors. The proposed system is required to be portable and terrain-proof.

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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 or better output with the help of solar panels to power recreational applications and provides a more environmentally friendly alternative.

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3. Design Objectives

3.1. Power

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 system should use an inverter to power convert from 12V DC to 110V AC output.

3.2. Structure

The system must be configured to be portable and accommodate various but reasonable terrain. Should be configured for research into optimizing the charging system under different environmental conditions for recreational applications.

3.3. Data collection

The system should acquire environmental and electrical performance data from the charging system and positioning system by wireless transmission of this data to a remote computer. Measure and display charge controller's input AC and DC voltage, input and output AC and DC current, and battery temperature.

Environmental factors play a major role in this design so aspects such as temperature, pressure, and humidity. Battery temperature should be tracked for safety purposes. Photovoltaic sensors should be used to assist in identification of solar intensity for a solar tracking feature of the system. Also, a compass and accelerometer will be used to detect the solar panel's orientation for a correct solar tracking path.

3.4. Solar Tracking

The system should include 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 should have full control of panel orientation, being 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.

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4. Design Metrics

Each unit in the system cannot be heavier than 100lbs. Preliminary research of solar kits found that each solar panel approximately weighs 14. 1lbs, battery weighs 49.6 lbs,, and inverter is about 55lbs. Additionally, the system is required to be portable, which means its size must be minimized. Renogy 200 Watt 12 Volt Solar Premium Kit, its has dimensions of 41.8 in x 20.9 in x 1.4 in, charged controller is about 8.3 x 5.9 x 2.3 in, and inverter is 17.8 x 8.6 x 4 in. Budget for this senior design project should be kept under $5,000.

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5. Design Constraints

The system is required to be charged by a 12V battery. It must provide a standard AC

110V 60Hz output voltage with the load compatibility equivalent or exceeding the nominal 20A. We will be using a 2000 W inverter as 1000 W will not sufficiently provide power specifications. Each unit in the system should not exceed 100 lbs total. It is also important that the enclosures of the batteries and inverter are non-conducting. All internal electronics should be powered by the same 12V battery.

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6. Relevant Codes and Standards

We plan to use standards set by an International Electrotechnical Commision (IEC Homepage) for installing, testing, and maintaining solar panels. Battery Council International (LINK) has established technical standards for maintaining batteries that we plan to use as a guide. Solar panel and battery warranties are also good standards documents.

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7. Concepts applied from other classes

In our work so far on our senior design project, we have applied many of the concepts we have learned over our time here and we will continue to see these concepts applied as we get into the process of physically building our solar device.

Our Mechanical team has had to stretch back to skills they learned in our Engineering Graphics during our Introduction to Engineering class. They have modeled our design using different software, eventually settling on Inventor, the option they were collectively most comfortable with. They continue to model our design using this software in increasing detail. They have also worked with professors from other departments on this design, pulling communication and collaboration skills from a variety of classes throughout their education.

The Arduino team has used knowledge from the Embedded Systems class and some of our Computer Science classes on campus. They have worked together to design a Graphical User Interface (GUI) for the device and for the website the device will connect to. They have also used Arduinos to communicate information from different parts of the final project, collecting sensor data, designing systems to move the device to track the sun, and sending data to an outside device through Wi-Fi.

The Power team has used knowledge gained from our Solid State courses as well as the elective Power Electronics to design a working power board that will ensure every part of the final product can be supplied with the correct power for its needs without damage occurring internally.

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8 . Concepts we need to learn and have learned so far

Everyone in the class has learned new things through this process already and we will continue to learn more throughout the year. While we are all learning from each other, some groups have learned a more in depth knowledge in different areas.

Our Power team has spent a good amount of time learning about solar tracking and what angles our solar panel will need to reach for best capacity. They have also shared this information with the rest of the class, specifically to support the mechanical design process.

The Mechanical team has improved their knowledge of the mechanical drafting process and has worked with the Mechanical Engineering Department to finalize a design for our solar device. They have learned about linear actuators, stepper motors, and worm gears, and they have worked to fit every component of each team's work into a detailed final 3D model of what we intend to build.

The Arduino team has greatly expanded on their prior knowledge of arduinos, GUI design, and details of how to connect sensors to arduinos in order to collect and transmit data. They have also worked with various types of display systems in order to determine which will be best for our user experience.

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9. User's Manual

The Operation Manual will include a quick start guide, a more detailed set up guide, some quick solutions to common problems, and resources in case someone needs to reach parts manufacturers, along with the technical specifications that a user could be interested in.

The quick start guide will start off the Operation Manual, coming right after the table of contents and any title pages. It will consist of mostly easy to understand graphics that will demonstrate the minimum amount of work necessary to start using the solar panel battery assembly. It will not include information on collecting data, rather it will focus on assembly and end with where to plug things in with some brief safety notes. This section will also include information regarding how to find a quick start video on our senior design website.

After the quick start guide, there will be a much more detailed explanation of each step for set up as well as a guide to how to use the data collection feature. It will also give more information on what each step of the set up actually accomplishes. This will include pictures that we will take once there a product to take pictures of but the information included will be very similar to the quick start guide. From this point, there will be references to the quick fix guide for any problems that might arise from set up. That way if you are stuck on a specific step in the set up process, you can quickly and easily find more information on what may be causing the problem.

The start guide will naturally lead into a more detailed description of how to use the GUI and further enhance the experience of the user. This part of the Operation Manual will outline how to use the GUI as well as how to use the Dashboard online and how to collect data if that is something the user is interested in.

Following the description of the GUI and the Dashboard, there will be a section on quick fixes to common problems. This section will include details on how to stay safe while troubleshooting and how to fix anything we find to be common problems during our design and building process. This will allow users to solve problems on their own rather than having to pay someone else to do it down the road.

If they have a problem that cannot be fixed on their own, the Operation Manual will lead into a section with information on how to get support for the solar kit we choose to use, as well as the solar panel itself. This section will be similar to an owner's manual in a car referring to the dealership for larger issues. This allows users a source for further information since we will not be around as a company to be that support.

This will be followed by technical specifications for both the finished product and various components of the device. That way if a user needs to replace a part for any reason and they want to use the original components, they can do so, but if they want to choose a different version, they will know what specifications to look for to ensure they are safe in their choice for a replacement part.

Throughout the guide there will be information on how to stay safe during operation and appropriate uses of the device. Safety will be important with use just as it is in the building process and we would not want any customer to get hurt while using our product. By emphasizing safety to the user throughout, we will hopefully be able to encourage any user to remain safe while operating our product.

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10. Graphical User Interface

10.1. 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.

10.2. 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 lead 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.

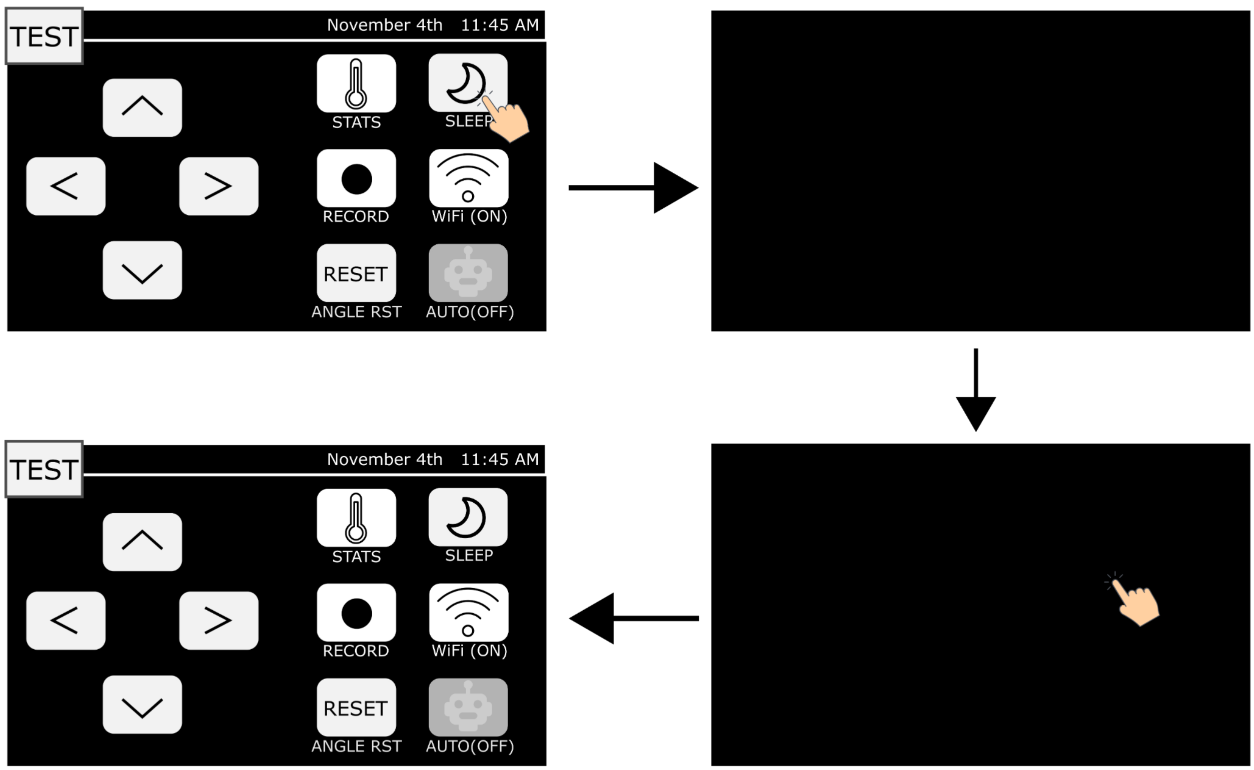

Figure 1. Turning on/off the sleping mode

The RECORD button leads to the Record schedule page. The WiFi button turns on/off the WiFi connection.

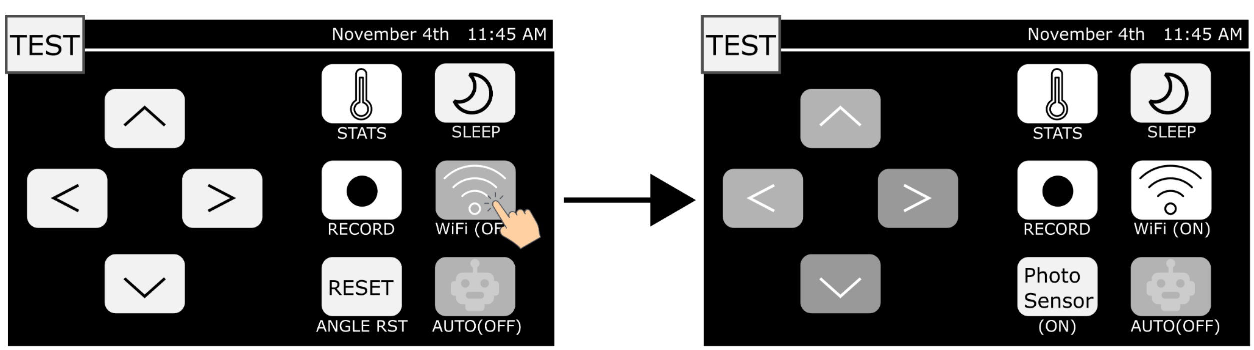

Figure 2. Turning on Wi-Fi connection

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 time on a lookup table in the microcontroller according to the time and date. The user could press the Photo Sensor button to enbale precise solar tracking. When 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.

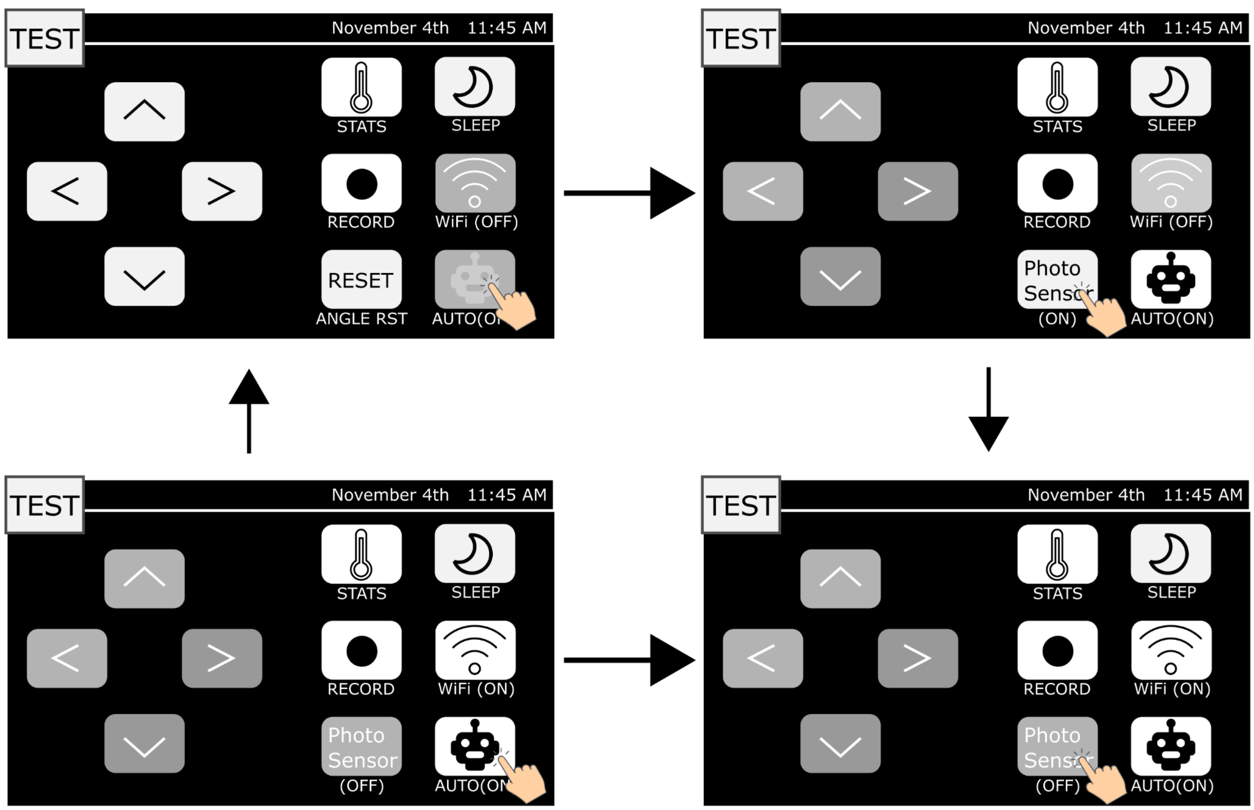

Figure 3. Turn on sunlight tracking mode

When 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.

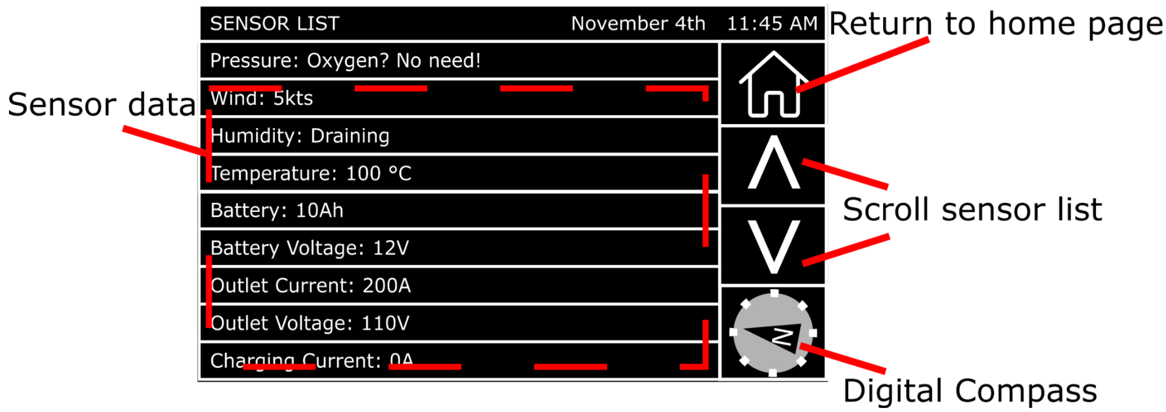

Figure 4. Sensor data display

On the Record Schedule page, the user could set the time to start and stop recording sensor data by clicking on the arrow buttons. The home button leads back to the main page.

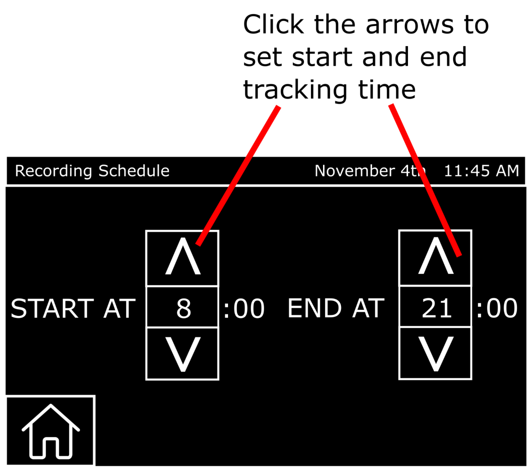

Figure 5. Setting start and end tracking time

10.3. Sensor Schedule

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.

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11. Solar Panel Tracking Controller

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

Solar tracking system objectives:

- The PV panel must be perpendicular to the direction of the solar radiation beams in order to charge at its maximum capacity.
- The solar tracking mechanism should position the solar panel to achieve the optimum angle of incidence.
- The solar panel sun tracking mechanism will have both an open loop and a closed loop tracking system. The open loop system will use an array with predetermined sun positions to track the sun's position whereas the closed loop system will use four light sensors to determine the exact position of the sun at any given moment.
- The system will use the closed loop tracking system and the array with predetermined sun positions will act as a watchdog for the closed loop system.
- The closed loop system will give much more accurate results, however it will use more power as compared to the open loop system. This technology of sun tracking is reasonably accurate except on very cloudy days, hence the need for the watchdog system.
- Open loop tracking system - it is cheaper and simpler to implement in comparison with the closed loop tracking system but it involves no rectification process and thus the algorithm alone has to ensure that it achieves the desired goal. (Chabuk, 395)
- In both systems, the solar panels will be moved at specific times throughout the day in order to follow the sun's position.

11.1. Open Loop Sensor Design

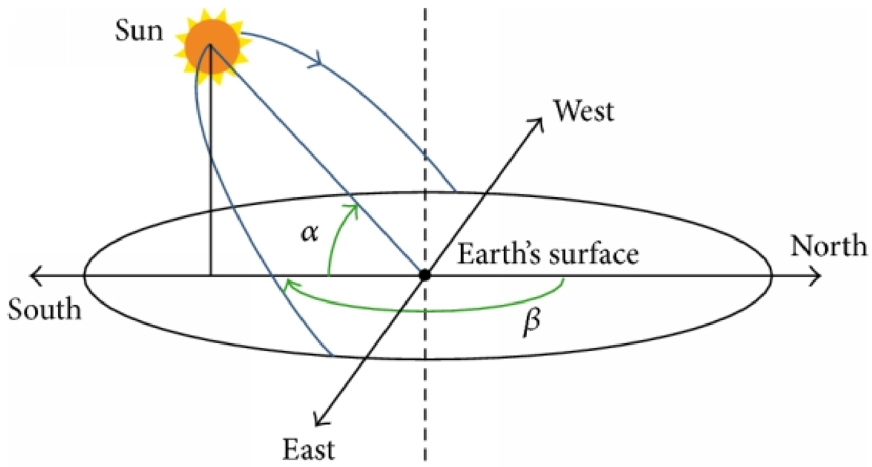
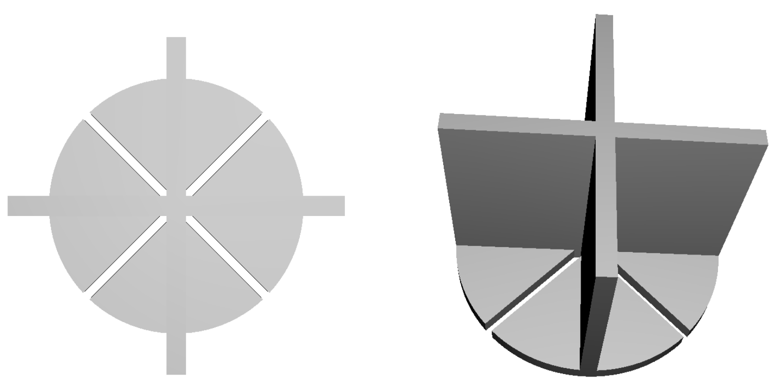


Figure 6. Illustration of the solar angles

For the solar angles, we have (a) altitude angle alpha and (b) azimuthal angle Beta. Solar noon is the time of day when the sun is approximately south and is halfway between sunrise and sunset. The azimuth angle starts from zero degrees when we will be pointing directly to the north. The azimuth angle will be the angle between the solar panels flat surface and the vertical line, therefore at noon in the summer it will be at about 75 degrees.

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.

11.2. Closed Loop Sensor Design



Figures 7 & 8. Sun tracker's sensor placement

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. 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. This device will be placed alongside the solar panel such that it is perpendicular to the plane of the panel, so during the tracking the sun beams will be parallel to it.

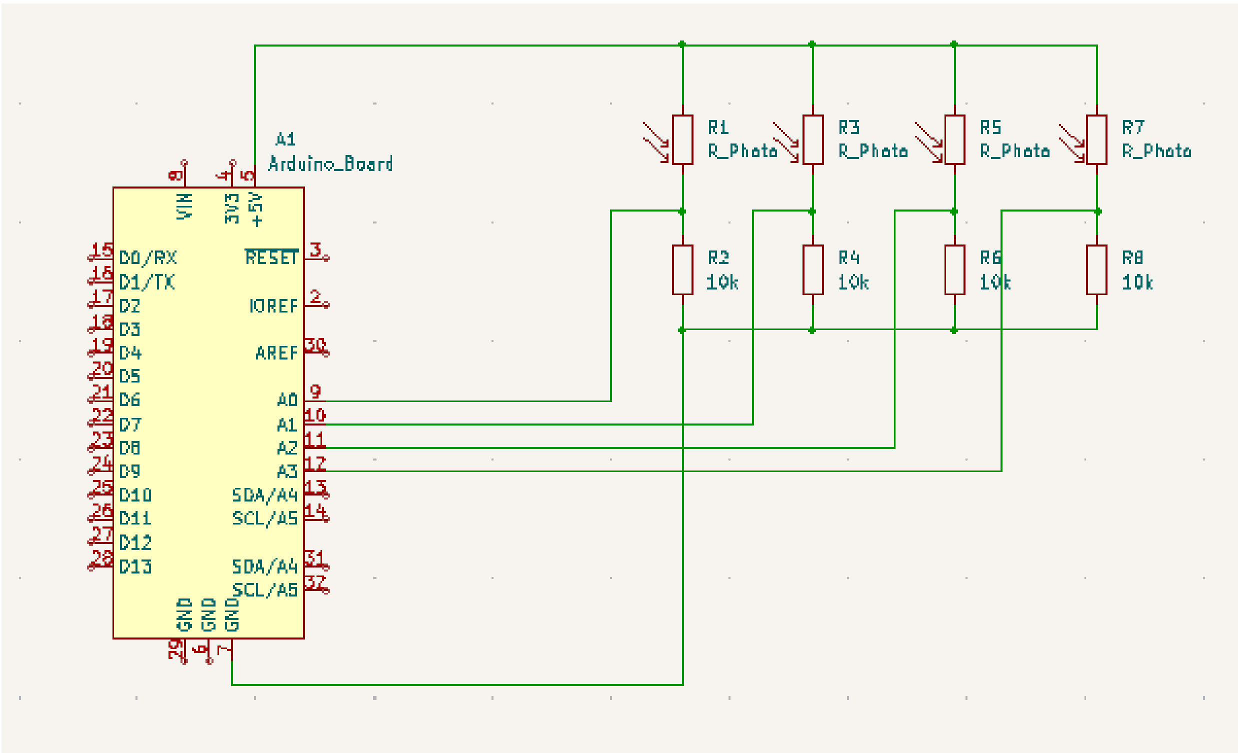


Figure 9. Schematic of how the photoresistors will be connected to the analog inputs of the Arduino board.

11.3 Solar Panel motion

Angle ranges and resolution

During the middle of the summer, that is when we will have the longest days and the most sunlight, therefore the solar panel will have a higher range of movement both vertically and horizontally. 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.

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.

However due to motor limitations and a cost benefit analysis of the power generated at different times of the day, we will only focus on the times when there is the greatest solar radiance.

The resolution from the motors and linear actuator movement is as small as 1 degree for a 10ms pulse, so it will be possible to easily move the solar panel structure with precision.

When we are not connected to the wifi we will be using the stored arrays on the Arduino's flash memory as well as the external clock to manage tracking.

11.4 Solar Panel Angle Range Cost Benefit Analysis

Due to mechanical design constraints, we will start from 30 degrees for vertical solar angle tracking. Because the maximum solar altitlude angle is about 25 degrees, 30 degrees is chosen as the minimum tracking angle to reduce energy loss. The expected power loss from choosing a non-zero minimum tilt angle for different seasons is shown below. The energy loss is negligible. The 1-Axis tracking angle is set to the optimal angle according to the Solar Declination optimal angle. The calculation are performed by the Excel sheet from (*Solar Time, Angles, and Irradiance Calculator - User Manual | New Mexico State University - BE BOLD. Shape the Future.*, n.d.).

Table 1. Energy Loss in different season with 30-degree minimum tilting angle

Time	Energy Loss to Full 2-Axis Tracking(%)	Energy Gain to Full 1-Axis Tracking(%)
Winter, Jan 14th	1.72	1.4
Spring, Mar 14th	0.76	4.74
Spring, May 14th	0.43	12.65
Summer, July 14th	0.37	13.85
Autumn, Sep 14th	0.52	5.74
Winter, Nov 14th	1.36	1.63

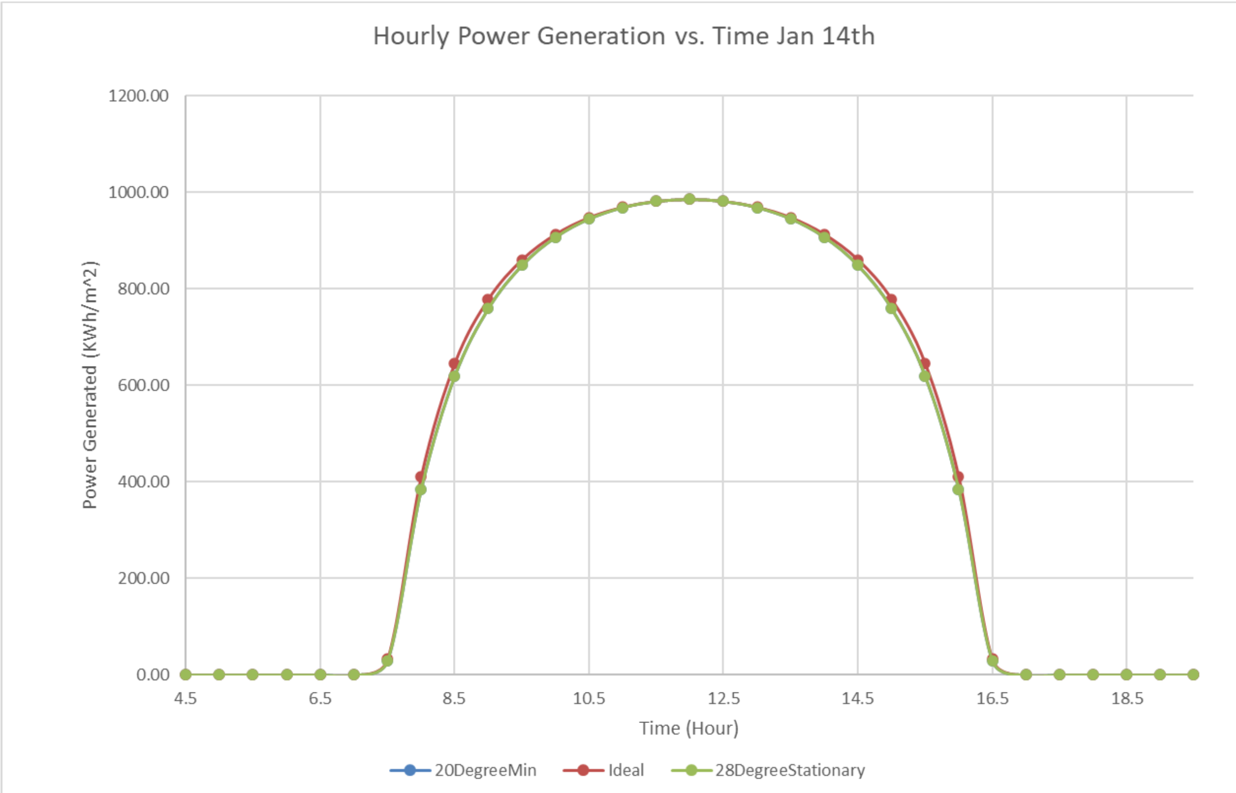


Figure 10. Hourly Power Generation vs. Time Jan 14th

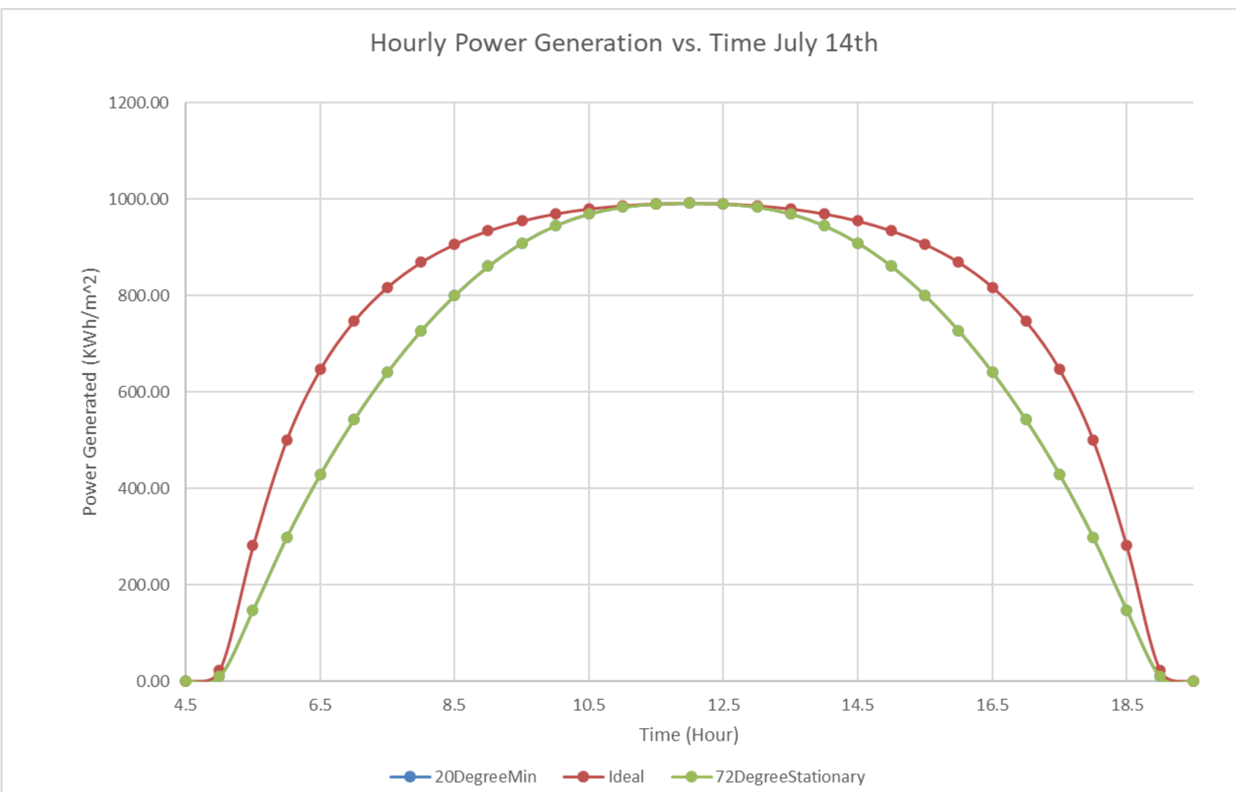


Figure 11. Hourly Power Generation vs. Time July 14th

12. Safety Analysis

12.1 Battery Precautions

Batteries are “always on”, in that their terminals are always energized. Thus, steps should always be taken to prevent accidental shorts. When in storage, keep terminals covered. We should use a very low gauge wire to connect the battery leads directly to a breaker which is also capable of handling the high current pulled from the battery. The breaker should remain off unless in use. Completely cover the leads in a non-conductive jacket from the battery itself to the breaker, including the lug nuts. Additionally, make efforts to prevent the breaker from accidentally being shut.

Furthermore, batteries are made from strong acid and alkaline materials. A spill can prove dangerous, thus it may be worthwhile to purchase or make a battery spill kit and become familiar with using it. If damaged, report it immediately. Finally, ensure that the battery itself is properly grounded.

To protect the electronics, a wiring diagram is shown below. It consists of the battery-main breaker-inverter system discussed above. The breaker will be tripped when the current exceeds the maximum current the Inverter can handle. For our 2000W inverter, that would be 167A. Given this spec, we’re going to want to pick a fuse slightly above this rating, so 175A. It feeds to a quick disconnect to allow easy removal of the electronics. A power distribution board will then give all components power as necessary. A diagram is included below.

We’ve also decided to add a cutoff switch to the battery itself, as mentioned above the terminals are always energized. We need an easy way for the user to disconnect the battery from the overall system and that’s what the cutoff switch will provide. This will allow for maintenance to be performed safely on the rest of the circuit, as well as providing a quick way to turn the system off if something goes wrong. The switch we will be using is a waterproof, rotary switch. This will provide the user a clear indication of whether the battery is connected or not, as well as being able to withstand environmental conditions.

Another consideration is the heat generated by the battery and inverter. Both of these components can run hot, so proper ventilation will be important. We have added vents to our cases design in order to provide for proper airflow and to keep temperatures low. We’ve also decided to make use of temperature sensors within the case to make sure nothing is running too hot. We will have a thermistor mounted to the terminal of the battery and it will be constantly monitored by the Arduino effectively functioning as a watchdog. The temperature we will be looking for is 55 degrees Celsius. On Power Queen's website they list the maximum discharging temperature as 60 degrees Celsius. We would like to avoid hitting the maximum temperature for safety reasons. When 45 degrees is hit, a warning will alert the user, and the user can then turn of the device with the cutoff switch . Given the safety critical nature of this sensor, we will monitor the temperature once every 15 seconds.

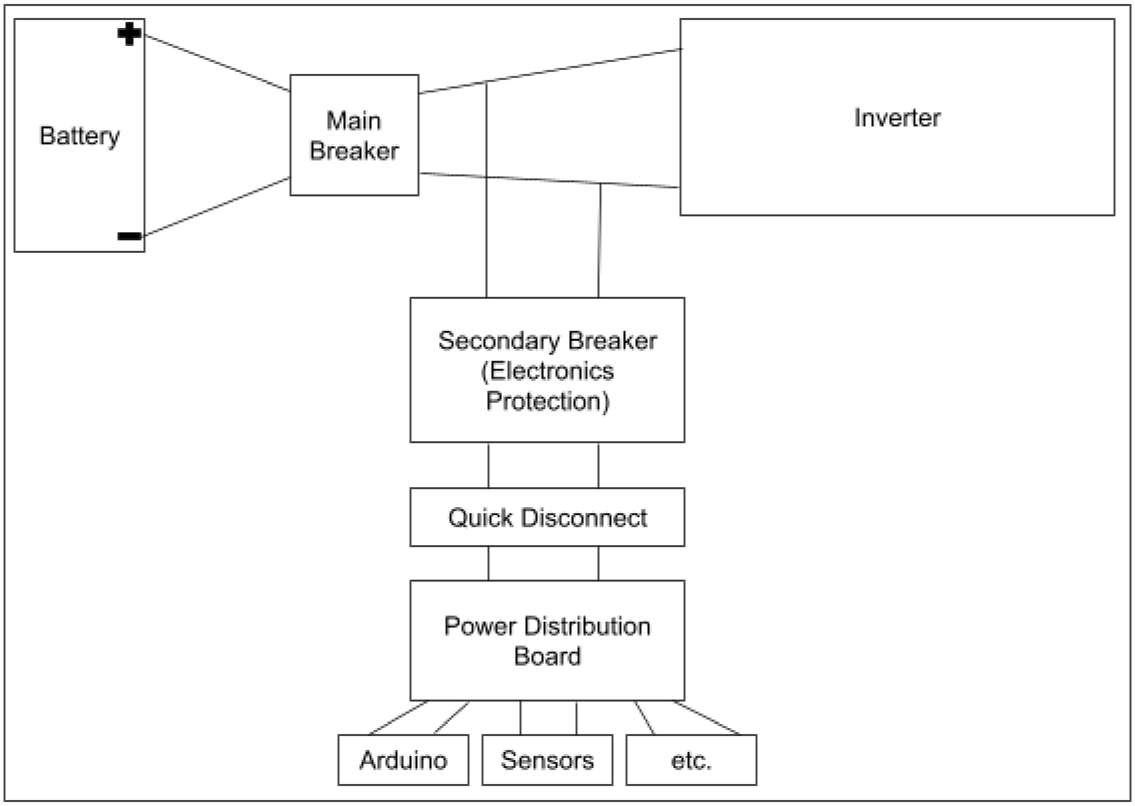


Figure 12. Diagram of of power path

12.2. Weight Concerns

This system will likely weigh in excess of 100lbs. Steps must be taken to ensure both that each individual assembly will weigh no more than 100lbs, and that these assemblies will be ergonomic. One way we will deal with this problem is with the addition of wheels to the system. Wheels will allow for easier movement by the user. They will also be complimented by a wheelbarrow-eque design. Only using two wheels will allow the user to lift it up and roll it, as well as providing more stability. We will also be splitting up our system into two separate pieces in order to allow for easier transportation by the user.

12.3. General Safety Concerns

Common sense safety practices should be followed while working on this project such as wearing closed toed shoes, safety glasses when necessary, and tying back long hair. Other things to consider are following proper safety procedures when using a soldering iron. We will also want to make sure we are careful whenever connecting or using wires with high current (i.e from battery to inverter). We will also want to make sure that the room containing the battery and inverter is properly labeled and secured, so other people won't enter or disturb what is in the room.

13. Safety Plan

Safety will be very important during this project. The electrical team will have to be the most careful when it comes to safety. The high voltage of the batteries poses a risk if they are not properly handled. It is very important for the people working with the batteries so they do not cause harm to themselves or ruin the batteries.

13.1. General rules

General rules for the lab will apply no matter what you are doing. No eating or drinking in the labs or when using any equipment. Proper clothing should be worn so that it does not get in the way. Being aware of your surroundings and not staring at your phone when using potentially dangerous equipment is mandatory. Anyone who has not slept in 24 hours should not be working with potentially dangerous devices.

13.2. High Current Power Supplies

For handling the high current Power Supplies we will need wires to carry these currents. We will need to make sure that the connections of the wires are secure and also make sure that the places where the wires are connected are covered and insulated to prevent accidents or connected to ground to make sure that we avoid electrocution. Although it seems simple we need to make sure we do not touch high current areas by accident and to help we need to make sure all connections are properly insulated. Turning off the power is also very important and we also need to make sure if people are working with high currents they make it clear to people around them by using warnings.

13.3. Soldering

Using proper soldering iron safety is needed to make sure people do not get hurt. Always wear safety glasses when soldering and make sure that the soldering fans are on to make sure you are not breathing in harmful fumes. No open toe shoes when using a soldering iron in case of accidental drops. Turning off soldering irons are important and putting them back in the proper place when you are done.

13.4. If Accidents Happen

If accidents do occur people will need to know what to do to make sure they are handled safely. Minor injuries like burns from soldering irons or small cuts will need to be treated with proper first aid so they do not get infected. If something more serious happens the emergency number for public safety is 610-330-4444. Any form of injury should not be taken lightly because the safety of every member of this project is of the utmost importance.

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14. Estimated Cost

BOM can be found under the “Project Documentation” subsection of the Senior Design Website- https://sites.lafayette.edu/ece2023/administrative/

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15. Mechanical Design

15.1. Overall 3D Model

Final Proposal 3D Model

Updated drawings of the Mechanical design can be found located under the “Design” subsection of the Senior Design Website. Please then press “Mechanical Design” to see complete views.

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16 . Electrical Design

16.1. I^2C

In our proposed design we are planning to use several Arduino boards notably Pro Mini and Nano RP2040 Connect. In order to communicate between these devices we will be using I2C to allow for connections to multiple slave Arduino’s. We have tested communication between Arduinos using I2C and found that it is highly reliable, as well as when it is using I2C and analog sensors. One of the limitations of I2C is the distance that it can cover reliably is typically a few meters which is not an issue in this case as the Arduino’s will be significantly closer then that. The current plan for using I2C is to relay sensor data from the master to the Wifi enabled Arduino so that it can be uploaded to the dashboard. In order to do this we will send a singular number from the Master to the Wifi enabled Arduino containing all of the sensor data with each sensor being assigned a specific number of digits.

16.2. 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 wire 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 Arduinos 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.

For the wires connecting the sensors, we should use 22 AWG. The wires connecting the two sensors won't be carrying a lot of current so they will be fine using 22 AWG. Standard wire should be fine since we will be protecting most of the length of the wire with braided sleeving. If we decide to use wire ties or another form of cable management that leaves the wires more exposed, we might want to grab wires that come with more substantial insulation. We should be able to make use of the spools of wire that we have in the Senior Design lab, though purchasing more 22 AWG wire would not be difficult at all.

Braided sleeving

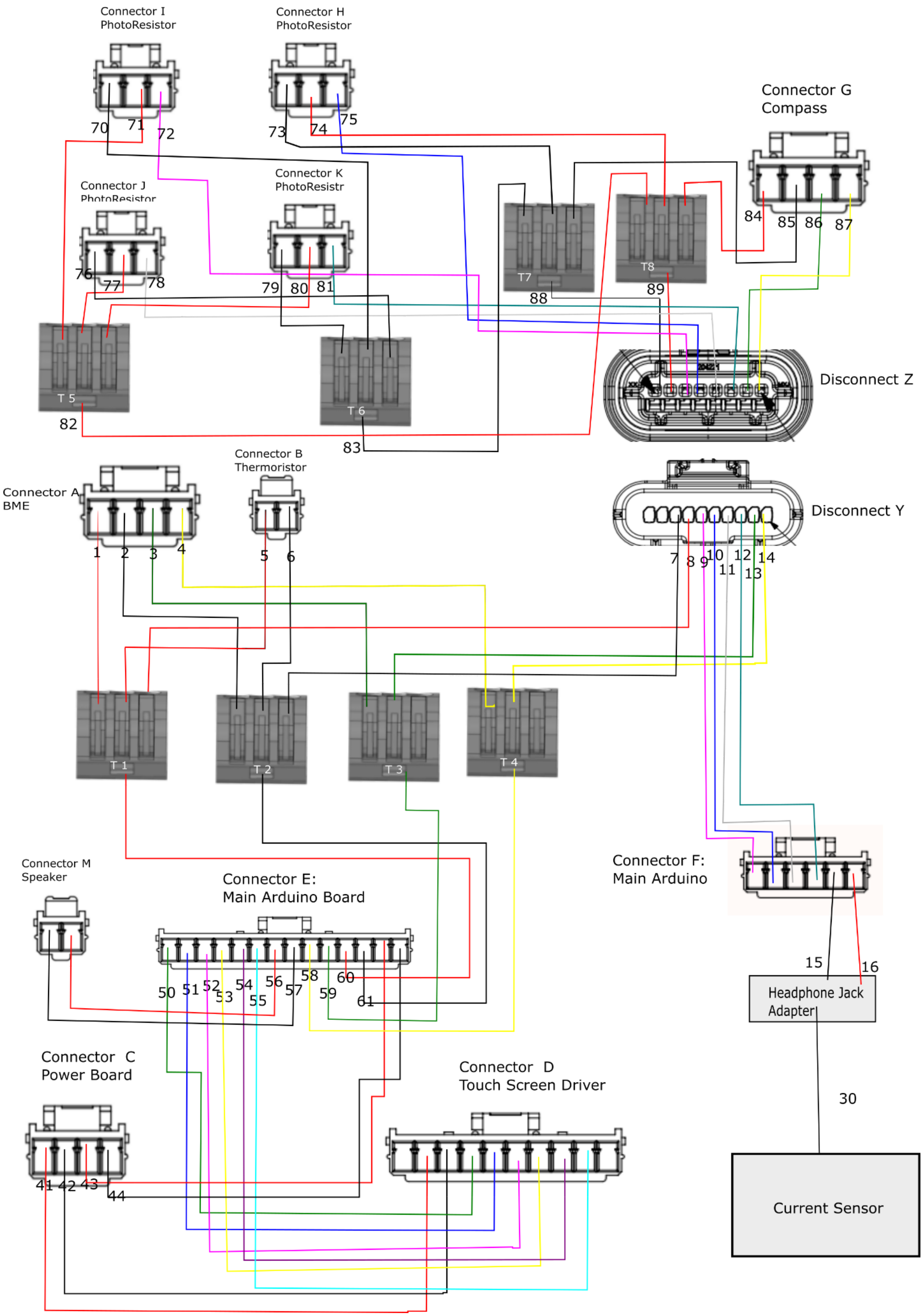
Sleeving we can use for cable management. Since we will have multiple wires going to almost every component it would be good if we could easily keep them together. Beyond that, sleeving should protect from heat and wear and tear, given the battery and especially inverter, could operate hot. We also will need sleeving, for the exterior wiring. While interior sleeving is more so for cable management, exterior sleeving will also need to protect from the elements. Insulated sleeving will be more infected from rain or other liquids that could potentially come in contact with the wire

Molex Connector Board **Molex Connector Wire**

For wire to board connectors, we have decided to go with Molex connectors. These connectors have 2.5 mm pitch, so they will be compatible with the spacing of arduino pins, as well as the pins on our power board. The Molex connectors come in sizes from 2 circuits to 15 circuits, allowing for some flexibility in terms of sizing and the amount of wires we will be sending through each sleeve.

Wire Connectors

For wire to wire connectors, we will be making use of two different types. One will be a weatherproof, buckle connector. These will be used for external sensor connections, as they will be exposed to the elements, and need to be attached and detached by the user while assembling and disassembling.


Connector I
PhotoResistor
Connector H
PhotoResistor
Connector G
Compass
70
71
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Connector J
PhotoResistor
Connector K
PhotoResistr
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T7
T8
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89
T 5
T 6
82
83
Disconnect Z
Connector A
BME
Connector B
Thermoristor
1
2
3
4
5
6
Disconnect Y
7
8
9
10
11
12
13
14
T 1
T 2
T 3
T 4
Connector M
Speaker
Connector E:
Main Arduino Board
Connector F:
Main Arduino
50
51
52
53
54
55
56
57
58
59
60
61
15
16
Headphone Jack
Adapter
30
Connector C
Power Board
Connector D
Touch Screen Driver
41
42
43
44
Current Sensor

Figure 13. Wiring Harness Diagram

The diagram above shows any wiring connections that will have to be made, that will not be contained to a PCB or other board. All wires will be 22 AWG except for wire 30(this is an 3.5mm audio cable that comes attached to the sensor. See below tables for more detail and part numbers for individual parts and wires in the above diagram

Wire No.	Color	Connecting	Purpose
1	Red	Connector A(VCC) - T1	Power
2	Black	Connector A(GND) - T2	Ground
3	Green	Connector A(SCL) - T3	I2C
4	Yellow	Connector A(SDA) - T4	I2C
5	Red	Connector B(VCC) - T1	Power
6	Black	Connector B(GND)- T2	Ground
7	Black	Disconnect Y(GND) - T2	Ground going to Panel Frame sensors
8	Red	Disconnect Y(VCC)-T1	Power going to Panel Frame sensors
9	Pink	Disconnect Y - Connector F(A1)	Analog signal from photoresistor to Arduino
10	Blue	Disconnect Y - Connector F(A2)	Analog signal from photoresistor to Arduino
11	Gray	Disconnect Y - Connector F(A3)	Analog signal from photoresistor to Arduino
12	Teal	Disconnect Y- Connector F(A6)	Analog signal from photoresistor to Arduino
13	Green	Disconnect Y - T3	I2C Communication
14	Yellow	Disconnect Y - T4	I2C Communication
15	Red	Audio Jack(+) - Connect F(A7)	Current Reading
16	Black	Audio Jack(-) - Connect F(A8)	Current Reading
41	Red	PowerBoard(VCC) - Touchscreen(VCC)	Power
42	Black	PowerBoard(GND)- Touchscreen(GND	Ground
43	Red	PowerBoard(VCC) - Arduino Board(VCC)	Power

44	Black	PowerBoard(GND - Arduino Board(GND)	Ground
50	Green	Arduino Board(SCK)-TouchScreen(SCK)	TouchScreen
51	Blue	Arduino Board(MISO)-TouchScreen(MISO)	TouchScreen
52	Pink	Arduino Board(MOSI)-TouchScreen(MOSI)	TouchScreen
53	Yellow	Arduino Board(D10)-TouchScreen(CS)	TouchScreen
54	Purple	Arduino Board(D9)-TouchScreen(RST)	TouchScreen
55	Teal	Arduino Board(D8)-TouchScreen(INT)	TouchScreen
56	Red	Arduino Board(R)-Speaker(+)	Speaker Audio
57	Black	Arduino Board(L)-Speaker(-)	Speaker Audio
58	Yellow	Arduino Board(A4)-T4	I2C
59	Green	Arduino Board(A5)-T3	I2C
60	Red	Arduino Board(VCC)-T1	Power
61	Black	Arduino Board(GND)-T2	GND
70	Black	Connector I(GND) - T6	GND
71	Red	Connector I(VCC) - T5	Power
72	Pink	Connector I(Output) - Disconnect Z	Analog Output
73	Black	ConnectorH (GND) - T7	GND
74	Red	Connector I(VCC) - T8	Power
75	Blue	Connector H(Output) - Disconnect Z	Analog Output
76	Black	Connector J(GND) - T6	GND
77	Red	Connector J(VCC) - T5	Power

78	Gray	Connector J(Output) - Disconnect Z	Analog Output
79	Black	Connector K(GND) - T6	GND
80	Red	Connector K(VCC) - T5	Power
81	Teal	Connector K(Output) - Disconnect Z	Analog Output
82	Red	T5 - T8	Power
83	Black	T6 - T7	Ground
84	Red	T8 - Compass(VCC)	Power
85	Black	T7 - Compass(GND)	Ground
86	Green	Compass(SCL)-Disconnect Z	I2C
87	Yellow	Compass(SDA)-Disconnect Z	I2C
88	Black	T8 - Disconnect Z	VCC
89	Red	T9 - Disconnect Z	GND

Connector Letter	**Part No.**
A	511630400
B	511630200
C	511630400
D	511630800
E	511631400
F	511630600
M	511630200
I	511630300
H	511630300
J	511630300
K	511630300

G	511630400

Disconnect Letter	Part No.
Y	204223-0008
Z	204220-0008

16.3. Sensors and actuator and motor wiring

<u>Sensors wiring</u>

We have two I2C sensors: the compass sensor and BME 280 environmental sensors which will be connected to the Pro Mini. The rest of the sensors are analog with only the AC current sensor requiring an adaptor circuit to read it:

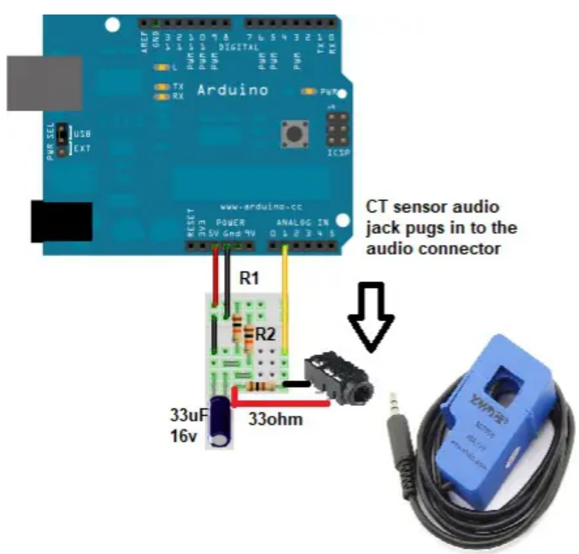


Figure 14. Sensor wiring with Arduino board

<u>Actuator & motor wiring</u>

To control both Linear actuator and DC motor, we shall use two H-bridge ICs(BD63150AFM-E2) as first option and four relay as a backup option with an Arduino Pro

Mini board which sends 10ms-width pulses as switching signals to H-bridge ICs or relays. For the DC motor, it will be driven as a stepper motor energized with current pulses every half second to rotate a 1 degree step like a ticking clock in order to achieve a steady speed as well as a low power consumption. In case of using H-bridge ICs, six D/A pins are used to send signals as each four control either the actuator or the motor to do the designated movement while only four are required for using relays. Linear actuator and DC motor is fed with 12V directly from the battery. As security, two fuses are inserted between H-bridge and voltage sources which will break once current exceeds 20A preventing short circuit.

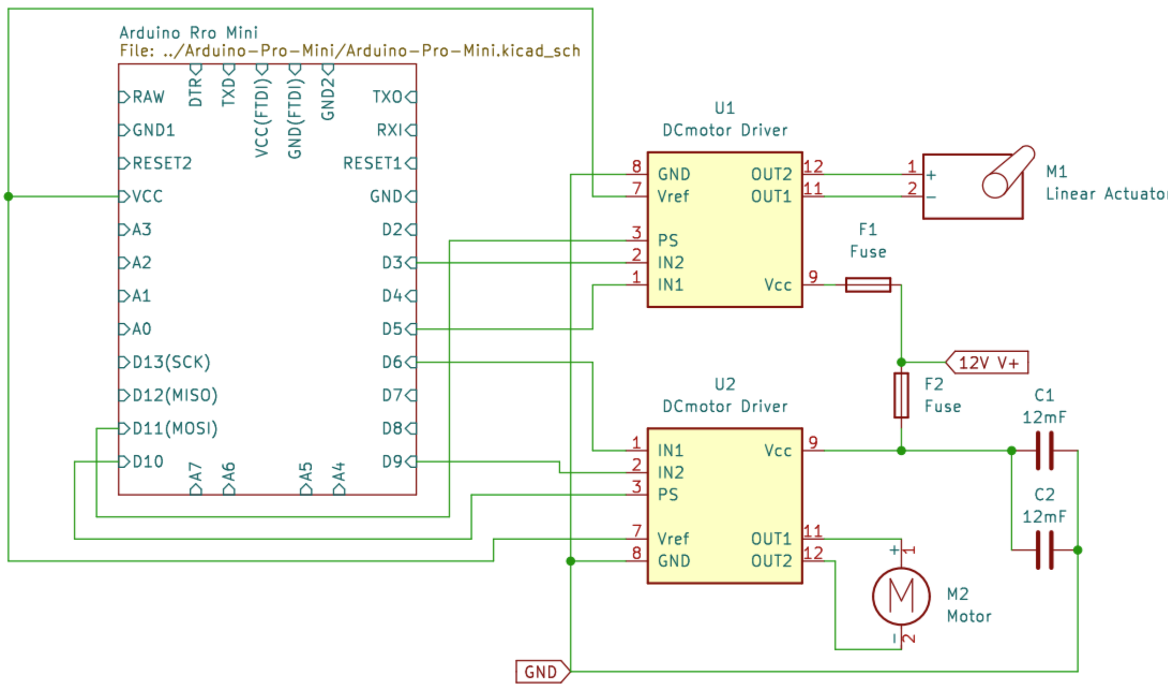
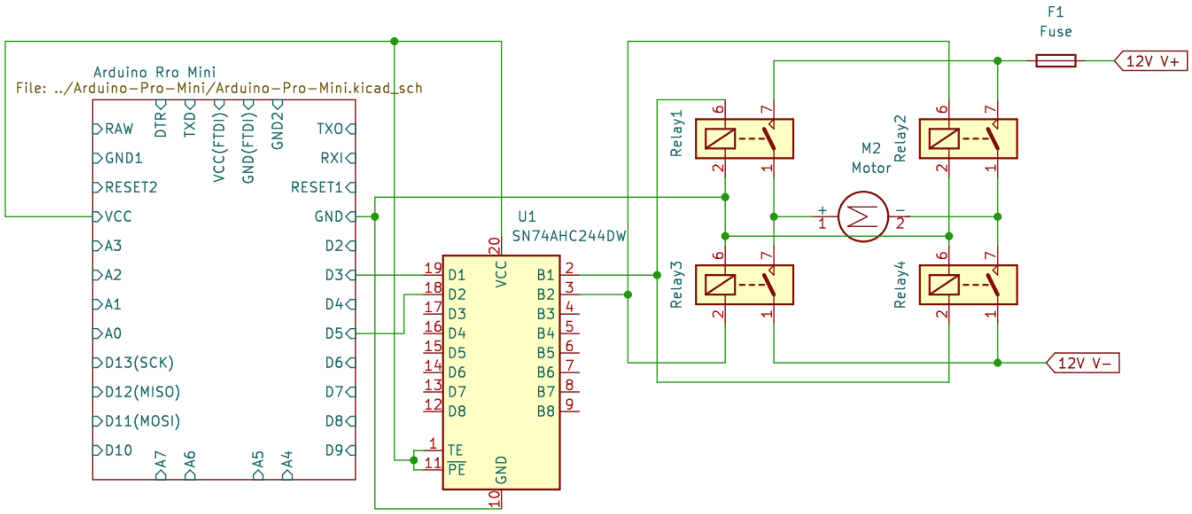
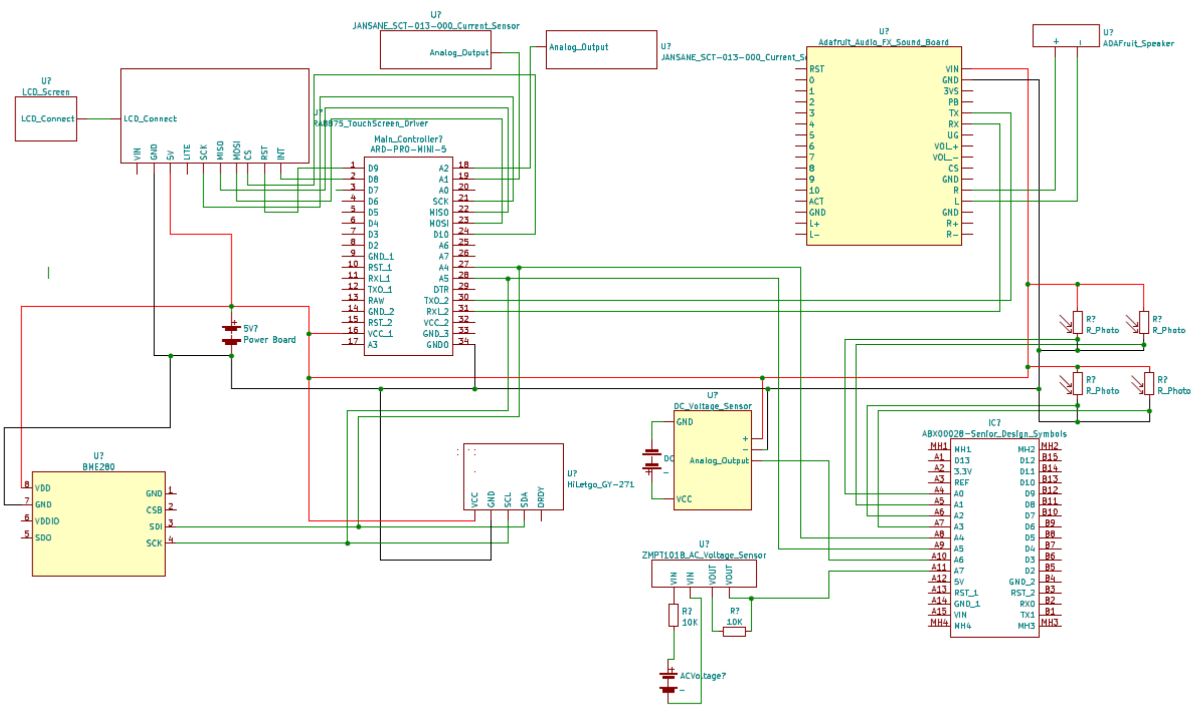


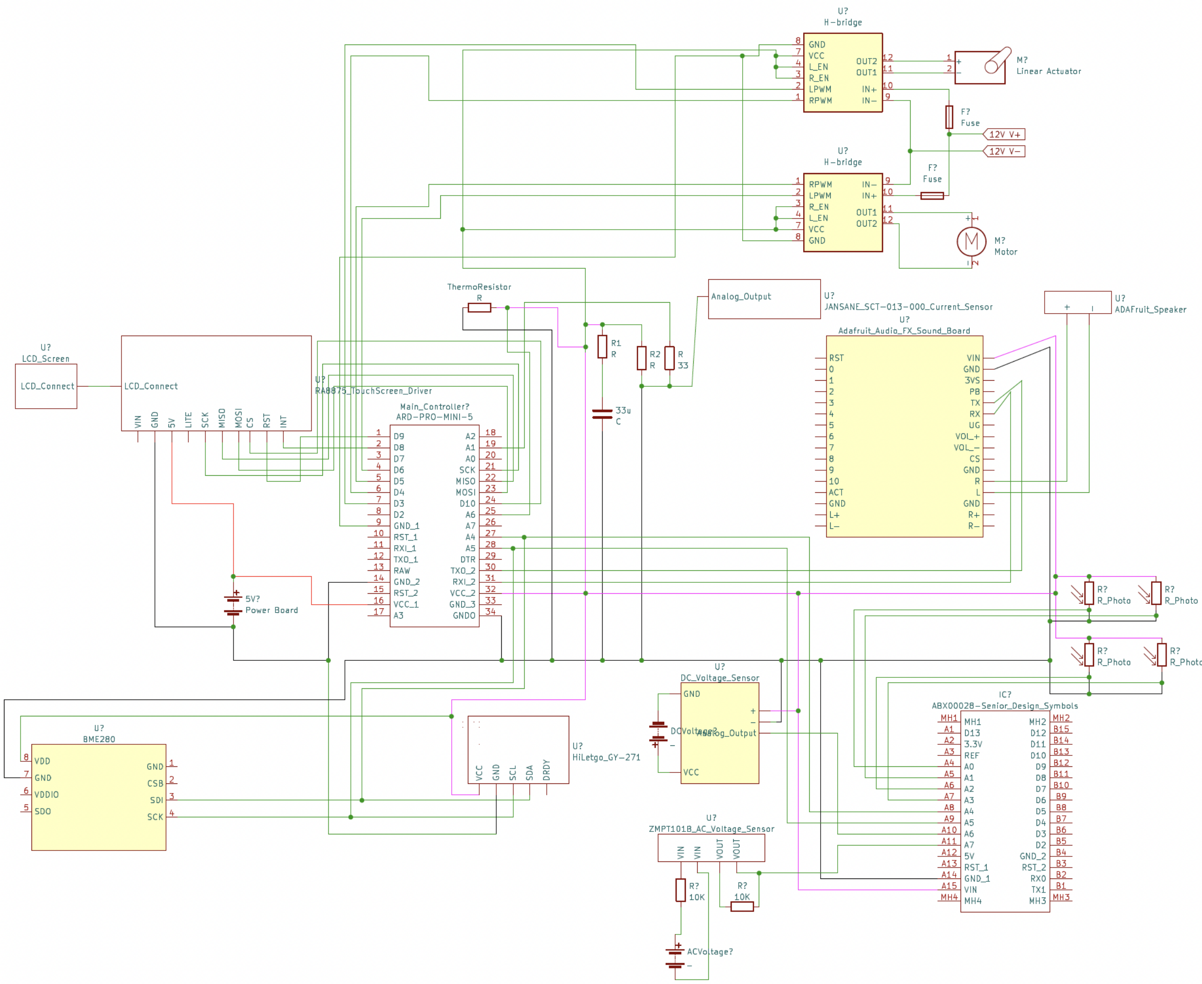
Figure 15. Wiring diagram of actuator & motor control system



Alternative wiring diagram of DC motor control system



Wiring Diagram of Sensors



Combined schematic diagram of the main controller, sensors, and motor/actuator subsystems

16.4 Solar Panel Kit Wiring

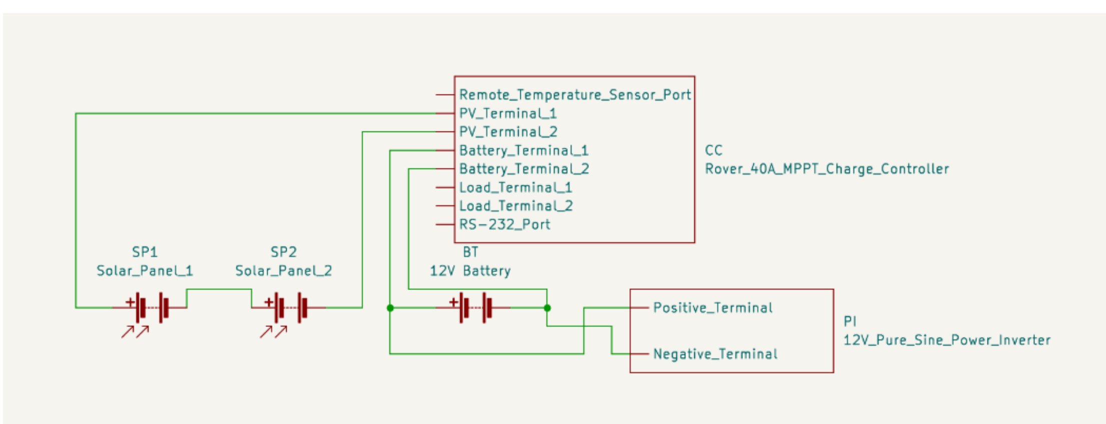


Figure 19. Solar Panel Kit Wiring

16.5 Power Board

The power management board is supposed to power up the Arduino sensors, the touchscreen and the H-bridge. The design was implemented through a hierarchical design with three major sub-blocks as shown below:

16.5.1 High Level Design

The sub-blocks of the design include a 12V-6V main converter, followed by LDO's which power Arduinos and touchscreen. The third block is a fused H-Bridge as shown in the figure below:

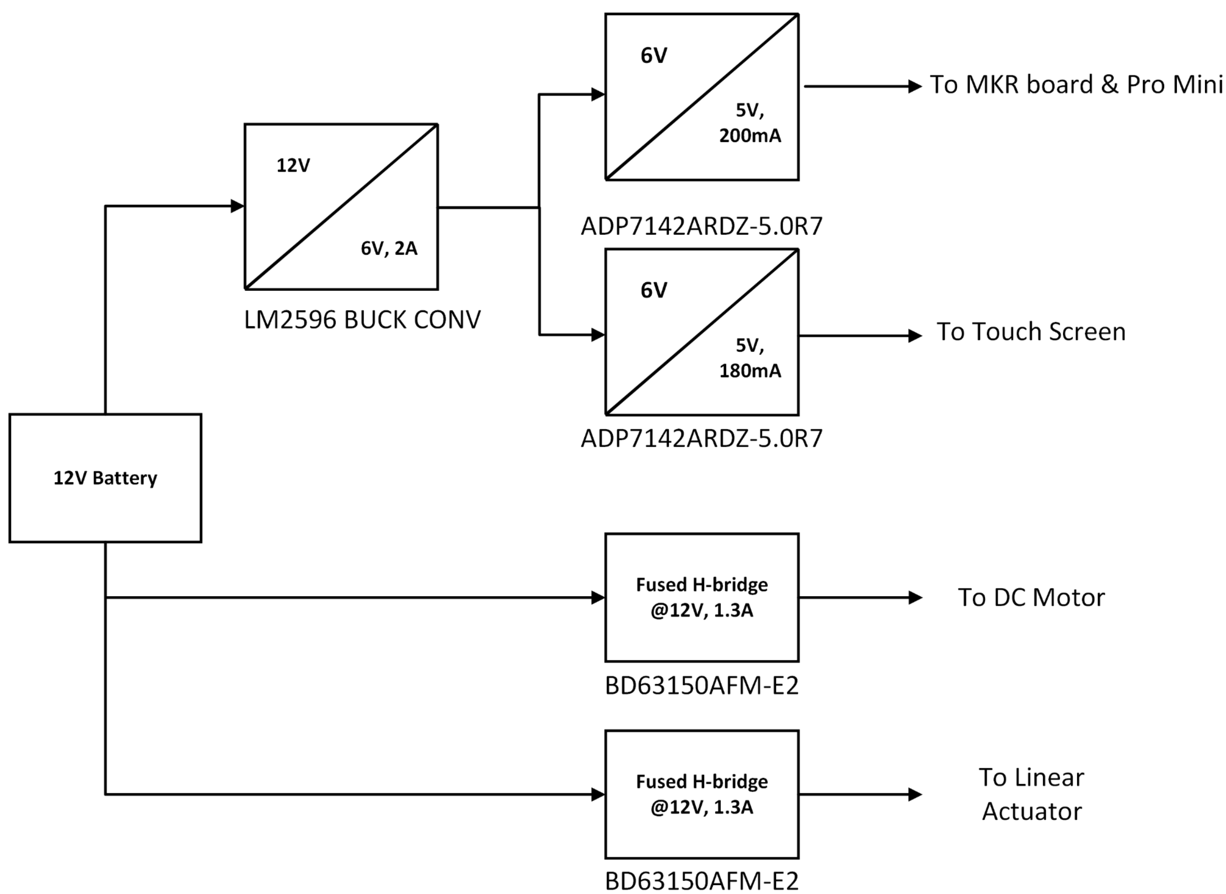


Figure 20. High Level Design of Power Management board

16.5.2. Electrical Specifications

- The main 12V- 6V on the board is an adjustable buck converter with a pre-build circuit around an LM2596 chip.
- To power up the Arduino boards, two ADP7142 chips shall be used. These are LDOs with low voltage drop out, and whose circuit can easily be built and incorporated into the

main board. Each of these LDOs will convert 6V to 5V as required by the Arduinos and touchscreen

- The H-bridge is a connection to the motor. The selected part for this purpose shall be the BTS7960. To protect against potential short circuiting of the system, it is fused with a 0805L150SLYR fuse rated at 1.5A.

16.5.3. Power Consumption and Efficiency

- Power consumption of DC-motor's H-bridge IC is 1.12W and of linear actuator's is 1.2W consumed by MOSFET inside when activated.
- Power consumption of the DC-motor is 120W for 2ms per 0.5s & 60W for 20ms per 0.5s, average of 2.64W, and the linear actuator is 24W when activated.
- The Arduino boards each consume power of 0.16W, 0.6W while the touchscreen consumes 0.9W.
- The total power delivered by the board is therefore 9.46W.
- The LM2596 boasts an efficiency of 92% while supplying 2A. With an output of 12W, the total power consumed by this board is 13.04W.
- Thus, power being used by the system is currently at 72.55%.

16.5.4. I/O Specifications

The buck converter has inputs where a 16 gauge wire can be fastened onto. The figure below illustrates this clearly:

Figure 21. Input of power board

Figure 22. Output connectors of power board

At the output, regular PCB mount headers shall be used. These shall be soldered onto the board and 22 gauge jumper wires shall be connected to the respective component.

The inter connections of the components on the board shall be made using PCB traces and soldering techniques.

16.5.5. CAD Drawing of the power management board

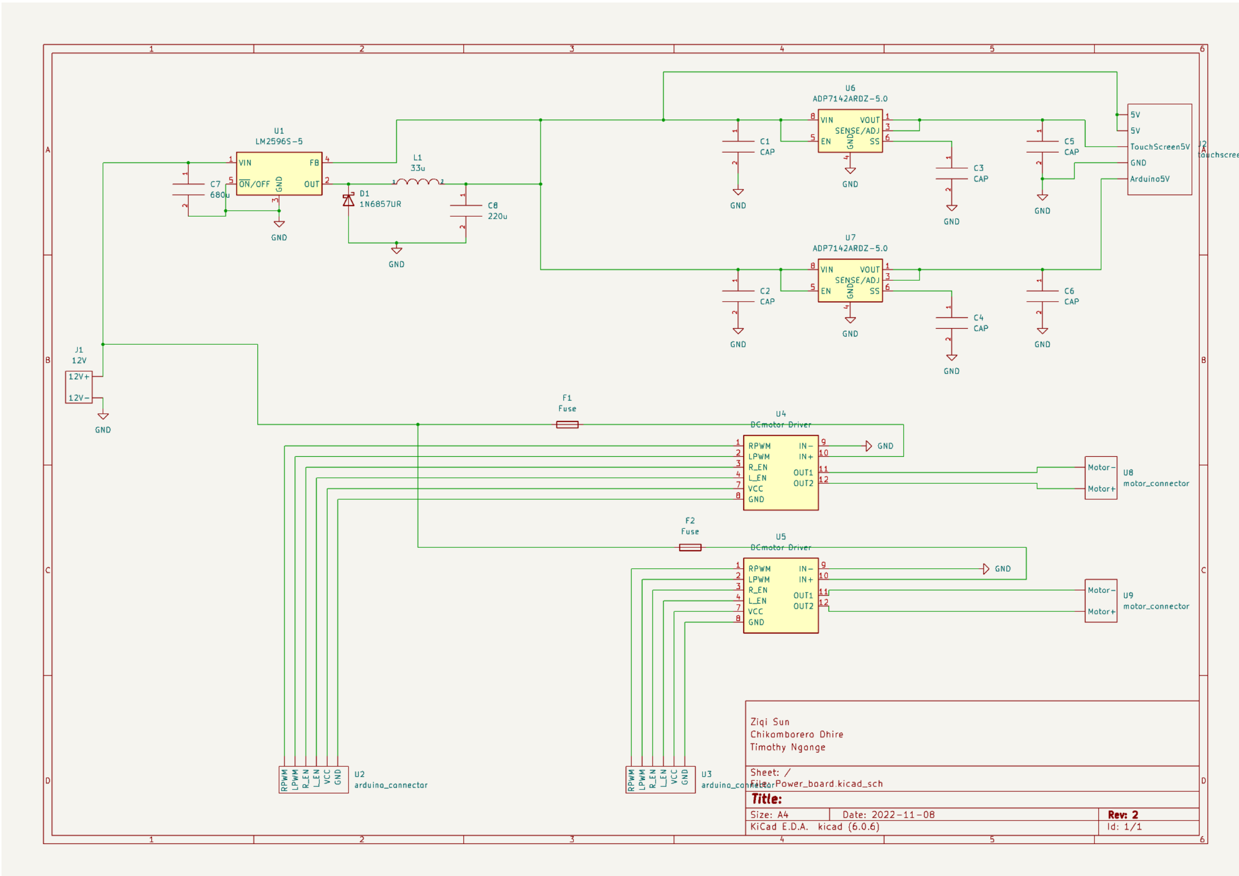


Figure 23. Power management board schematic

16.5.6. Board Measurements

- The 12V- 6V buck converter measures 4.5" L x 3" W x 1.1" H.
- The two LDO circuit boards are estimated to each measure 1.75" L x 1.30" W.
- The H-bridge IC chip each will only occupy 0.73" L x 0.39" W x 0.1” H.
- This part will be protected by an SMT fuse measuring 6" L x 4" W x 2" H.
- The whole board can thus be estimated to measure 12.46" L x 10.38" W

16.5.7. BOM

- LM2596 Buck converter: $10.49
- ADP7142 ARDZ-5.0-R7 LDO, $3.88 x 2 = $7.76
- BD63150AFM-E2 H-Bridge x 2: $8.2
- C1206J225J4RACAUTO 2.2uF Capacitor $0.85 x 4 = $3.4
- C0805C102J3GACAUTO 1 nF Capacitor $0.33 x 2 = $0.66
- Input connector: $0.99

- Fuse Holder $3.82
- Glass Fuse $5.99
- Total : $44.29

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17 . Testing Procedures

17.1 Performance Testing

Compass Sensor: To test the compass sensor we will test both the accelerometer and the magnetometer functions of it. To test the magnetometer we will use a compass on a phone to see if the directions of north match up with the sensor. To test the accelerometer we will measure the angles of rotation using a protractor and compare them with the measurements of the sensor.

AC Voltage Sensor Testing: Input a known AC voltage into the sensor and read the output from the Arduino UNO the sensor test will be considered a success if the reading is within 1% of the input.

DC Voltage Sensor Testing: Input a known DC voltage into the sensor and read the output from the Arduino UNO the sensor test will be considered a success if the reading is within 1% of the input.

AC Current Sensor Testing: Input a known AC Current into the sensor and read the output from the Arduino UNO the sensor test will be considered a success if the reading is within 1% of the input.

Environmental Sensor Testing: Read the sensor to the Arduino UNO the sensor test will be considered a success if the reading is within 5 degrees of the exterior temperature as determined by a thermostat, the altitude is similarly known and the humidity can also be measured with an external humidity sensor.

Battery Temperature Sensor Testing: Measure the temperature of the battery at the terminal with a previously known accurate temperature reading then compare the sensor readings from the Arduino Uno this test will succeed if it is within 5 degrees of the known temperature. Howeve given that we need to calibrate the thermister this may be subjective.

Power Board Testing: Measure the output voltage of each connector to match the specified requirements. Run motors and observe the behavior of the board. This is key to ensure that the board can accommodate current spikes when the motor starts.

PV Sensor Testing: Measure the expected output of a PV sensor from the solar panels that we have and calibrate the PV sensors so that they are within 1% of the reading from the solar panel

I2C Testing 1: Send known messages from one Arduino to the other. This test will be successful if the message is received at the same value that it was sent.

I2C Testing 2: Send known messages from one Arduino to the other from an analog sensor. This test will be successful if the value read from the serial monitor of the master is the same as that of the slave..

I2C Testing 3: Send known messages from one Arduino to the other from a digital sensor. This test will be successful if the value read from the serial monitor of the master is the same as that of the slave..

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18. Solar Kit Study

18.1. Rationale

For the solar panel, we looked for something that would compliment our mechanical design. A single panel would necessitate a more rectangular frame, while two panels allow us to use a frame that is more square shaped and more stable .To start off, we decided that we wanted a panel or panels that would be able to provide, ideally, 200W of charging per hour. As shown in the battery calculations below, a 100 Watt panel would take multiple days of ideal conditions to charge the battery. With this constraint in mind we had two options, go with a single 200 Watt panel, or two 100 Watt Panels.

We ended up choosing 2 100 Watt Panels, as we decided these would be easier to deal with mechanically, then a single 200 Watt Panel. As for the specific Panels, we decided on the 100 Watt panels from Renogy. Renogy is a well established company that has a good reputation when it comes to solar panels and related systems. Another reason for choosing Renogy was that they sell Solar Kits. The kit we are purchasing includes the panels, charge controller(described below) and necessary wiring and connectors.

For the battery, we were also looking for something relatively small. Initially we looked at batteries that were rated 100Ah. The appeal of this came down to weight. We were able to find 100Ah batteries that weighed about 26 pounds. With weight being a major constraint, looking for a light weight battery, our heaviest single component, would have been ideal. However, using a 100aH battery would have crippled our design, as our Inverter needs 2000 Watts to function, and the vast majority of 100Ah batteries can only supply 1200 Watts of Power. While we did find some 100Ah batteries that could supply 200A of instant power, these weighed over 60 pounds, so we decided to go with a 200Ah battery.

The battery we ended up choosing is the Power Queen 12V 200Ah battery. As mentioned above, weight is one of our major concerns, and this increase in Amp hours also led to an increase in weight, to 49,6 pounds. While doubling the weight is not ideal, this will allow our inverter to function, which is well worth the tradeoff in weight. Our Inverter needs 2000W to function, and with a 200A discharge current at 12V, this battery will be able to provide 2400W, enough for our inverter to function. Power Queen itself is also a reputable brand, with numerous well reviewed products on the market.

The Sine Wave Inverter was probably the easiest major component to decide on, as the Spec that we needed 2000 Watts of power was well defined. We ended up deciding on a Renogy Inverter, capable of providing 115V AC and 2000W of power. We ended up picking this inverter initially because we were planning to use all Renogy components, in order to make compatibility less of a concern. However, even though we ended up changing batteries we decided to stick to this Renogy inverter. We didn't see a reason to reselect an inverter that already fit spec, from a company that we were already comfortable with. This inverter, like most 2000 Watt inverters, is relatively low weight at 11 pounds, as compared to higher power inverters, which is why we didn't try to go beyond the 2000 Watt minimum.

The last major component we had to pick was the charger controller, we ended up going with MPPT charge controller from Renogy, that is included in the Kit that our solar panels came with. When choosing between kits, we had the option to go with one with a PWM controller vs. a MPPT controller. We ended up going with an MPPT controller due to its superior performance and potential to be much more efficient than the PMW charge controller. There is no weight or size drawback when picking MPPT over PWM. The only drawback is price, but considering we have a 5000 dollar budget to work with, the extra 100 dollars spent on a superior charge controller should be well worth it.

18.2. Parts and Specifications

Table 2. Solar Panel Kit parts and their specifications

Part	Vendor	Datasheet	Where to Buy	Specs
200 Watt 12 Volt Monocrystalline Solar Panel Starer Kit	Renogy	Link	Link	● 2 x 100 Watt Panels ● Panel Weight: 14.1 lbs ● Panel Dimensions: 41.8 x 20.9 x 1.38 ● See below for charge Controller
Power Queen 12V 200Ah Battery	Power Queen		Link	● Rated Capacity 200Ah ● Nominal Voltage: 12V ● Max Charging Current: 200A ● Max Discharge Current: 200A ● Dimensions: 20.5 x 9.37 x 8.54 inches ● Weight: 49.6 lbs
Renogy Power inverter	Renogy	Link	Link	● Rated 2000W: ● Input voltage: 12V ● Efficiency: > 90% ● Output voltage: 115V AC ● Dimension : 17.8 x 8.6 x 4 ines ● Weight 11.7 lbs
MMPT Solar Charge Controller	Renogy	Link	Link (Comes with Panel Kit)	● System Voltage: 12/24V Auto Recognition (for non-lithium batteries) ● Mac Battery Voltage: 32V ● PV Input Voltage Range: 15V - 100V VOC ● Max Power Input: 12V @ 520W; 24V @ 1040W ● Self Consumption: ≤ 1.5 W ● Temperature Compensation: -3mV/°C/2V. Excludes LI ● Controller Terminals: 20-6 AWG ● Operating Temperature: -4°F ~ 113 °F

18.3. Battery Calculations and Runtime Comparison

Our battery is rated 200Ah. A ninja BN701 Pro Series operates at a max Power of 1400W. In order for a 12V battery to meet this demand, 116 amps will be required. That means if this blender was run continuously it would last for about 102 minutes assuming a full charge. This calculation also assumes 100% efficiency from the inverter, which is not realistic. At the worst possible efficiency 90%, the blender would operate for about 92 minutes.

$$200Ah*12V = 2400W$$
$$(2400/1400)*60 = 1 \text{ Hour and } 42 \text{ minutes}$$

Another more nuanced example, would be to have the blender on for only short periods of time, with constant charging of a mobile device, as well having the sun full out. We will run the blender for 10 minutes every hour, A 3000mAh Iphone charging constantly, and the solar panels constantly recharging the 12V battery

For the blender mentioned above, running it for 10 minutes would use 233 watts of power an hour. An iPhone can fast charge to 50% in about 30 minutes, while the fast charging does turn off around 80%, to make the calculations cleaner we will assume it fast charges to 100%. That means an 3000mAh iPhone will be charged to full every hour. These batteries operate at 3.8V meaning they require about 11 Watts for a full charge. That means betweens the blender and Iphone we will be using 244 Watts power per hour. Our solar panels on the other hand will be recharging the battery 200 Watts every hour. Theoretically the system could supply power at this rate for a little over 54 hours, though this is obviously unrealistic. It does however demonstrate the feasibility for its use for activities that require constant low power draw, like charging phones, with occasional high power draw, like using an appliance

We also wanted to compare our system to the Honda EU2200i gas powered generator. On a single tankful of gas the Honda generator can run at 1800W continuously for up to 3.2 hours. If our solar generator ran at this capacity, it would last for approximately 1.33 hours. While we are well aware that our solar generator will not be able to match the efficiency or acapcity of the gas generator,, we are fine as long as it can provide similar performance,aleibit over a shorter time frame. Our Solar generator is capable of this, as we can match the 1800W rated load, as well as the 2200W, max output, as our inverter can handle peak surge up to 4000W, though our battery can only provide up to 2400W.

$$2400W / 1800W = 1.33 \text{ hours}$$

While designing our system we had to make a decision between using 100 watt vs. 200

watt solar panels. On one hand, 100 watt panels are small and lighter, and since we highly value portability, this was appealing. However when taking into account charging time, we had to reconsider. Assuming that the conditions are optimal for the solar panel. It would take 24 hours to charge a 200Ah 12 volt battery. We came to this conclusion this was not acceptable charge time, as this would require almost half a day to charge, again assuming optimal conditions. A 200 Watt panel would cut this time in half. While we are now making our system larger and more cumbersome, we are also making it more practical to use. A 6 hour ideal changing time is much more acceptable then 12 hours.

Another aspect to take into account is the efficiency gain we will obtain from implementing solar tracking. In the calculations above, the rating of the Solar panel was used to determine how much power would be produced by the panel. This rating however is one determined in a label, and not necessarily indicative of real life performance. Solar tracking should help mitigate this difference in real life vs. laboratory performance. This will help to ensure that our calculated performance and real performance agree more closely with each other.

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19. Wireless Data Communication

19.1. Connection Details

The arduino connects to the internet using a wireless chip that is located in the Arduino Nano RP2040 Connect board. In order to connect easily, we are using the WiFiNina library included in the arduino library manager. This library uses the SSID and password fields to connect to a specified network.

19.2. Database Management

We are using a mySQL database which is hosted on the RDS Amazon web service. Using this method, the database already has security and other protocols setup so we do not have to worry about that aspect. Furthermore, we use mySQL workbench to actually access the tables and data in the database as this information is inaccessible on Amazon Web Services. The following is the specific information for our database connection:

Hostname: senior-design.cwk33wgniqe5.us-east-1.rds.amazonaws.com

Port: 3306

Database name: sys.test

In this database we will store the sensor values which we wish to see at all times. Among the most important sensors for this are the current and heat sensors for the battery as this is one of the largest concerns for the system. Using this strategy, we can update these database values live while the system is connected to the internet and we also have the freedom to only send data at a certain interval.

19.3. Portability

One concern that might arise when using multiple services is that there is not a way to change individual services. In our case, it would be very easy to move our database, for example, to another platform instead of AWS. We chose Amazon Web Services because it is very cheap, reliable, and already takes care of all security protocols. If we needed to switch to another hosting service later on, it would be as easy as copying the database table and pasting it onto another host. The same logic applies for our website hosting as well. Overall, we choose these specific tools to make the website as dynamic as possible so that we could change things later on if needed.

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20. Remote Dashboard

20.1. Dashboard Description

Originally we planned to use the Arduino Dashboard to display our data however after 2 weeks of attempting to implement it we found that it would be easier to set up our dashboard. Currently our Arduino will not be hosting a website but rather only transmitting data to a database from which we will pull the data onto a regular website. This way the Arduino is doing the minimal amount of computing and we can do all the data processing and website design remotely. This will help keep the power down on the Arduino as we do not have to constantly have Wifi on, and it will help us with memory as we will not have to keep data locally.

20.2. Website Details

The website described above will have two main purposes: viewing important sensor data while away from the system and allowing a user to have some control over the system remotely. We will be using a service called DigitalOcean for web hosting once the website is complete and ready to be deployed. The backend for the website is programmed using simple PHP code for retrieving data from the mySQL database. The main reasoning for using PHP instead of just HTML, CSS, and Javascript is because later on we want to be able to create users as admins to prevent every user from controlling the system. Because of this, we need the website to be dynamic. We are using TailwindCSS, a popular modern CSS framework, on the website for style components such as button presets.

The full tech stack is as listed below:

Front-end: HTML, CSS, TailwindCSS

Back-end: PHP, mySQL

Other Services: DigitalOcean, mySQL Workbench, XAMPP Apache Server (for testing), AWS

20.3. Service Usage

HTML, CSS, and TailwindCSS:

These two services will be used to display what the user will be seeing on the website. TailwindCSS is simply a library for the CSS styling language which makes it easier for us to design the website as there are many presets for buttons and other UI elements.

PHP:

PHP is a server side scripting language that we will be using to pull data from the database. We do this on the server side to protect the data being transferred from anyone being able to see it. Using this, we will send queries from website to the mySQL database to retrieve the sensor data to be displayed.

mySQL:

mySQL is the database query language that we have used to store and retrieve the sensor data from the system. This database will serve as a middle man as the system will post data to the database and the website will retrieve the data for display. The flow of data is as shown below:

Sensor Data -> Written to mySQL database when connected to WiFi -> displayed on website using PHP to pull from database.

User clicks control button on website -> PHP sends an http "POST" request to the arduino -> arduino receives value and changes function

21. Sensors

21.1. List and Description of Use

Table 3. List of the sensors and their descriptions

Sensor Type	Function	Part	Datasheet/Link
AC current sensors (non invasive AC current sensor transformer)	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	SYUAB 2Pcs SCT013000	Link
AC voltage sensor	Used to confirm that we are getting the correct output from our pure sine wave inverter	ZMPT101B	Link
DC voltage sensor	Used to monitor the car battery voltage to monitor battery levels	Hi LetGo 0-25V DC sensor	Link
Battery Temp Sensor	Used for safety purposes so that the system can shut off if the battery is overheating	(NTC Ring Cable Temperature Sensor)	Link
Temp/Humidity/Pressure	Used to monitor environmental data	(BME 280)	Link
Photovoltaic sensor	Used to assist solar tracking	HiLetgo 100pcs 5528 Light Dependent Resistor LDR 5MM Photoresistor	Link

		Photoconductive Resistance for Arduino	
Compass and Accelerometer	Used to know the orientation of the solar panels so that we can create an accurate solar path for the solar tracking.		Link

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23. Information Website

This website will be the main source of documentation for our Senior Design Project. It contains all necessary components of the project easily laid out for accessibility. The main headers include About, Meet The Team, Project Basics, Design, Project Documentation, Solar Panel Definition, and Research Documentation.

Website is constantly evolving as the project progresses and develops further. Current changes being made include updating project specifications and updating standardized diagram labeling.

The website can be found here: Senior Design 2023 Website

24. Bibliography

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/