Senior Design 1 Documentation

Motor-Assisted Solar-Charging Cooler

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1. Project Description

Before a product can be properly designed, the purpose of the design needs to be fully defined. In the first sections of this design document, our group aims to do just that. Here we will set the scene in which our project will develop, we will describe the motivation behind the idea, explain the goals and objectives, and finally we will talk about the functionalities that are to be implemented within the design.

1.1 Executive Summary

Florida is known for many things, Disney, beaches, and of course the elderly. It has become commonplace in movies and television shows when Florida is brought up, they are almost always talking about retirement. With that being said, these people enjoying their twilight years should be able to enjoy the beautiful beaches that this state has to offer without having to rely on anyone else to not impede on their independence. For this reason, our Senior Design team wanted to focus on the older generation and their ability to enjoy the great outdoors like everyone else.

For this reason, MAC (Motor assisted cooler) came into being. The MAC comprises three main parts, our motor design, refrigeration unit, and it's solar charging capabilities. The mobility of this project will solely rely on the two motors that will be attached to a flatbed cart with a handle to help the user move the load with relative ease, whether they are pushing or pulling the cart. The cart itself will have all terrain wheels to help the elder traverse any terrain to reach their destination. We added a way to cool the inside of the cooler to not add any unnecessary weight for the user to haul around. We have gone with thermoelectric refrigeration for this purpose for its lightweight and power consumption. The refrigeration unit will be installed inside a cooler to keep whatever is inside nice and cold. These two systems are dependent on a power source which will increase its longevity is where our solar charging comes into play. We will be including retractable solar panels in our design to keep the fun in the sun going even longer. All these systems will be powered by microcontrollers which will be hidden from the user for a sleek and functional design.

This report will document the details of the MAC research and subsequent development. It starts with our motivation and goals that we wanted to achieve throughout the whole process. Then it will go into the specific specifications and requirements such as the power needed to enable all parts to function properly. The research section will go into various types of parts and methods that were considered as well as the choices that were made, such as which materials to use for our solar panels to the types of motors that will be utilized. Then the paper goes into the many types of constraints and standards that have affected our decision processes. We move on to our design details such as software and hardware used. This portion includes the block diagrams, flowcharts and schematics. Then on to the housing units to help protect our cooler from the elements and how we tested our design. The last section goes into our budget and scheduling to help us develop our final product.

1.2 Motivation

To guarantee that our design is innovative, research was conducted on competitive products in the market of battery powered and "smart" cooler systems. There are, in fact, many products currently that have made improvements to the original design. For example, CostWay is selling a portable cooler/refrigerator which does not need ice, the refrigeration can be powered by 120v AC as well as it's 12v DC battery. Homedepot is selling the LiON Cooler which also boasts solar charging capabilities and a mobile app for refrigeration control as well as USB ports for personal device charging. Aside from the cooler itself, there are products designed to make it easier to transport the cooler from place to place. Through teamsportsgift.com, it is possible to buy a RC controlled cooler. There is even a cooler scooter on the market from saferwholesale.com.

The problem with the current products on the market is that none of them combine these features into a single machine. The biggest oversight in these smart coolers are the weight added by the refrigeration systems and battery. The average weight of the products mentioned, not including the motor-powered coolers, is 34 lbs. empty. The current products that are motor-powered do not include any of the other,

very desirable features. Aside from the lack of other features, the controls provided are not intuitive or even very useful. For example, the RC cooler requires the user to operate a controller which needs two hands. A fun toy but does not add much value. The second motor-powered example given is a scooter which is ridden by the user. This makes the cooler less useful as the user's weight is now added to the cooler and there is no hope of getting through beach sand or any outdoor trail, another fun toy that doesn't add value.

We want to combine the most important features of the previously mentioned smart coolers and add an intuitive motor-assist system that will not only counter the extra weight of the device but will make the entire system feel weightless to the user. This will allow people of all types to bring this cooler to any location they desire.

1.3 Goals and Objectives

This project aims to have a completed prototype of a motor-assisted, solar charging, portable smart cooler by the end of the next semester. There are inherent challenges in designing and completing this project and our goal is to prove that these challenges can be met. The prototype needs to be extremely efficient in order to provide both refrigeration and motor power. An intuitive user control system must be designed that requires no training and feels effortless to the operator. Of course, above all else, the cooler must keep contents below a threshold temperature.

1.4 Project Functionality

As part of our project description, we have listed some of the core functionalities we plan to implement in our final design. We have chosen these functionalities for two main reasons. The first being the obvious fact that they will give our design the ability to serve the purposes stated in the executive summary and motivation sections of this document. The second, not so obvious reason, is because these functionalities are important to our team in terms of skills which we are interested in developing.

This senior design project has given our team not only the chance to design a working product that can be helpful for many people around the world, but also a chance to test our engineering skills by building something which we have never attempted to build before. As a team, we are interested in control systems, alternative energy, and thermo-electric engineering. This project is an almost perfect opportunity to gain experience in these engineering disciplines.

There are four main functionalities of this project: motor-assistance, solar charging, powered outlets for personal device charging, and powered refrigeration. The motor-assistance will give our team a chance to gain experience in control systems. The solar charging aspect of the project will give us a great chance to work with alternative energy solutions. The powered outlets will be easy to implement and will add much value to the users. Powered refrigeration is a perfect example of a thermo electric device. With these functionalities the user will be provided with the essentials needed for any outdoor recreational activity and we, as a team, will gain our much-desired experience in these disciplines.

The following sections will explain in detail the four functionalities that were just mentioned, focusing more from the user point of view and the impact that these functionalities will have on creating a design that meets the product goals.

1.4.1 Motor-Assistance

The motor-controlled movement of this project is very important because it will provide the greatest advantages to its users. This feature adds value in the following ways: the cooler will be able to be used by almost anybody in the world, users will have the ability to carry much heavier loads, and the cooler will be able to traverse rougher terrain with this added weight.

1.4.2 Solar Charging

The solar-charging feature is necessary for the entire project to function. This feature will add value to the project in the following ways: The battery life will be extended drastically when used in sunny locations and it will allow for the possibility of providing power externally without draining the battery.

1.4.3 Powered Outlets

Powered USB outlets, while not necessary, will add a level of comfort and safety to our users. The powered outlets will add value by allowing the users to charge cell phones and other personal devices when not around other power sources.

1.4.4 Powered Refrigeration

Powered refrigeration may not be the sole source of refrigeration but can be used to greatly extend the life of the ice within the cooler. This will allow our users to spend more time enjoying the outdoors and less time refilling their cooler with ice.

2. Requirements and Specifications

Now that the project design idea has been fully explained, the specifications and requirements can be defined. A design specification is defined as a detailed document providing a list of points regarding a product or process. This means that every aspect of our design must meet these specifications in order to be a complete design. These specifications actually aid in the design process because they give the engineers a goal to reach when creating their design.

Aside from specifications, requirements are also necessary. These requirements should be the first thing that is defined when creating the design. Design requirements are defined as the functional attributes that will enable the design team to convert their ideas into a complete design. The requirements are derived from the problem statement set before the engineers. These can include many different types. Power consumption requirements, for example, will be determined by certain aspects of the problem. If the proposed solution needs to be portable, work in remote environments or work for an extended period of time, the power consumption of the total design is very important. This requirement will also dictate the components used for the design, the amount of functionality that can be achieved in the design, along with many more decisions that will have to be made. This is just one example of requirements of a design. There are also requirements due to the environment in which the design will function. It may need to work in very high temperatures for example, which calls for added cooling equipment and protection for the components within the design. Both of the mentioned requirements in this paragraph will be used to aid in the design of our project. Because of the high temperatures experienced in a beach setting, the circuitry will have to be insulated from the heat. Also, due to the remote environment and necessary run time, power consumption will be a major deciding factor in our design.

The design specifications defined in the following sections will be used to make decisions about the construction of the project, the components we will use and even the material we will choose. The following section lists these specifications and contains related tables. Aside from the design specifications, some other requirements must also be defined. Because the cooler must operate in rough terrain, a section on terrain requirements is contained here as well. Lastly a House of Quality diagram is constructed to compare the market and engineering requirements. This house of quality diagram is used as a reference when we, as a team, need to decide if a certain design aspect is more important to us as designers are if it’s more important to the end user.

2.1 Specifications

The following section lists the individual specifications for each subsystem of our design along with corresponding tables.

2.1.1 Housing Components Specifications

- 4 wheels
- Steering mechanism
- 2 USB ports
- Charging port for internal battery
- Mechanical solar panel support
- Powered drive motors at front wheels

Housing *(table 1)*

Feature	Spec
Internal Volume	13.6” x 7.3” x 9.5”
Total weight	100 lbs
USB charging ports	2 x USB 3.0
Internal battery charging ports	1 x 120v AC
Mechanical Solar Panel Support	18.1” x 13.8” x 1”

2.1.2 Drive-Module Components Specifications

- 2 x Drive motors
- MCU for user interface control
- Brushless DC motor controller

Drive Module *(table 2)*

Feature	Spec
Drive Motors	2 x 12 volt DC motors with internal position sensors
Motor-assist Reaction Time	100 milliseconds
Maximum speed	5 mph
PID controller	Project Controller (TBD)

2.1.3 Battery Charging Specifications

- 12 Volt Output

- Voltage Level Displayed
- Battery protection Circuit
- Low Voltage Warning System

2.1.4 Solar-Charge Module Specifications

- 12v Output
- Charge controller: Must be correct controller for specific battery

Battery and Solar Panel *(table 3)*

Feature	Spec
Operating Hours	10 hrs
Output Voltage	12v
Solar Panel	12v 130W
LCD	32*2
Current Sensor	0-30A
Voltage Sensor	0-25V
Project Controller	ATTiny85V

2.1.5 Power Distribution Components

- Route power to all modules with correct power level at each module
- Voltage regulated at multiple levels for different outputs: 5v, 12v, 3.3v

2.2 Requirements

While the specifications of the system are defined using quantitative values, the following section will contain other requirements that can't be easily quantified in a table. These are more abstract and qualitative requirements that must be explained and understood at a more functional level.

There are some main categories that most requirements will fit into. There are functional requirements, performance requirements, safety requirements, marketing and design requirements, even terrain requirements. The functional requirements are related to the functionality of the design. These will deal with the actual functionalities that our design must implement in order to meet the design goals. The performance requirements have more to do with how well the design will function. It doesn't matter if the solar charging function works, if it doesn't work well enough to keep the battery charged for our specified run time. The safety requirements are arguably the most important requirements of all. These are necessary to ensure that no user is hurt while operating the product.

In the following sections, the qualitative requirements mentioned in the above paragraph will be explained in detail. At the end of this section, a house of quality diagram showing marketing and design requirement comparisons is explained.

2.2.1 Functional Requirements

This project combines different areas of study including control, thermo-electric cooling, and energy harnessing. These all represent necessary functionalities that are required to operate in order for our design to work. The control system must accept a user input which will be translated into desired output at the wheel. The control system must also utilize feedback from the motors to ensure the desired wheel output is achieved. This control system is required to give the cooler forward and reverse motion as well as braking capabilities.

It is required of the system to provide cooling through the use of a powered refrigeration module. This is necessary to keep the contents of the cooler at a comfortable temperature for the user over long periods of time, where the ice may not be able to stay frozen. This system is of greater importance in our design than other coolers because we will be sacrificing some of the internal volume to fit the battery and circuitry. This reduction in internal volume means that less ice can be used in the cooler, also meaning that the ice will begin to melt faster.

Because our system will require a high level of energy, an added source of energy coming into the system is needed to support our specified run time. This energy source needs to reliably produce energy in the environment that it will be in. Not only does this source need to produce enough energy to keep charge in the battery, it also needs to be controlled so as to not damage the battery by providing too much energy.

2.2.2 Performance Requirements

Not only does the project need to function, but it also needs to function at a certain level of performance. Our project will still work, technically, if these performance requirements are not meant. These requirements are here to ensure the user satisfaction of our final project.

The user interface control system must react in a fast manner. There should be no noticeable oscillation or delay from when the user begins to direct the cooler and when the motor assist system kicks in. Also, the PID control system integrated in the motor assist should provide an adequate amount of damping to provide smooth transitions between speeds.

While it is meeting the functional requirement to have the refrigeration module providing some sort of cooling, the system is required to perform at a certain level that will keep the ice from melting within hours. The refrigeration module needs to operate at around freezing temperature for this performance requirement to be met.

The energy source that will be used to supplement the battery charge in the system must be able to produce enough voltage to charge the battery. This will not be much of an issue as the sun should provide more than enough energy to generate enough voltage. From a performance requirements perspective, we want the energy source to have the ability to turn on and off when necessary so that the battery doesn't become damaged from overcharging.

2.2.3 Safety Requirements

As was stated in the introduction to this requirements section, the safety requirements are among the most important. It doesn't matter how the project functions or performs if it is unsafe for the user. Most of the safety requirements will be taken care of in the motor control system because this could be the most dangerous system to the user. If safety measures are not taken, the cooler could very easily run over the user or knock the user over. For these reasons it will be required for some user presence to be sensed before the motors will engage. This presence sensor must not be able to be fooled by any other outside force and must be user friendly and easy to use.

Another safety hazard that can arise would be the threat of electrocution due to water pooling around the circuitry. For these reasons, it will be a requirement for the circuitry and battery to be properly sealed off from the cargo area of the cooler.

2.2.4 Terrain Requirements

The cooler must be able to traverse multiple types of terrain. Each terrain has certain characteristics that define them. There are two specific terrain characteristics that are important for this project: density and angle of repose. Angle of repose is considered to be the steepest angle at which a granular material can be piled without that material sliding down the angle. This is important because it relates to the traction that can be achieved in the material.

Density is related to the weight per volume of a material and can also be used to test traction as well as how far the tires may sink in the material. We need to define our terrain using these values in order to properly test and evaluate the success of our design. The following table contains three terrains and their corresponding density and angle of repose.

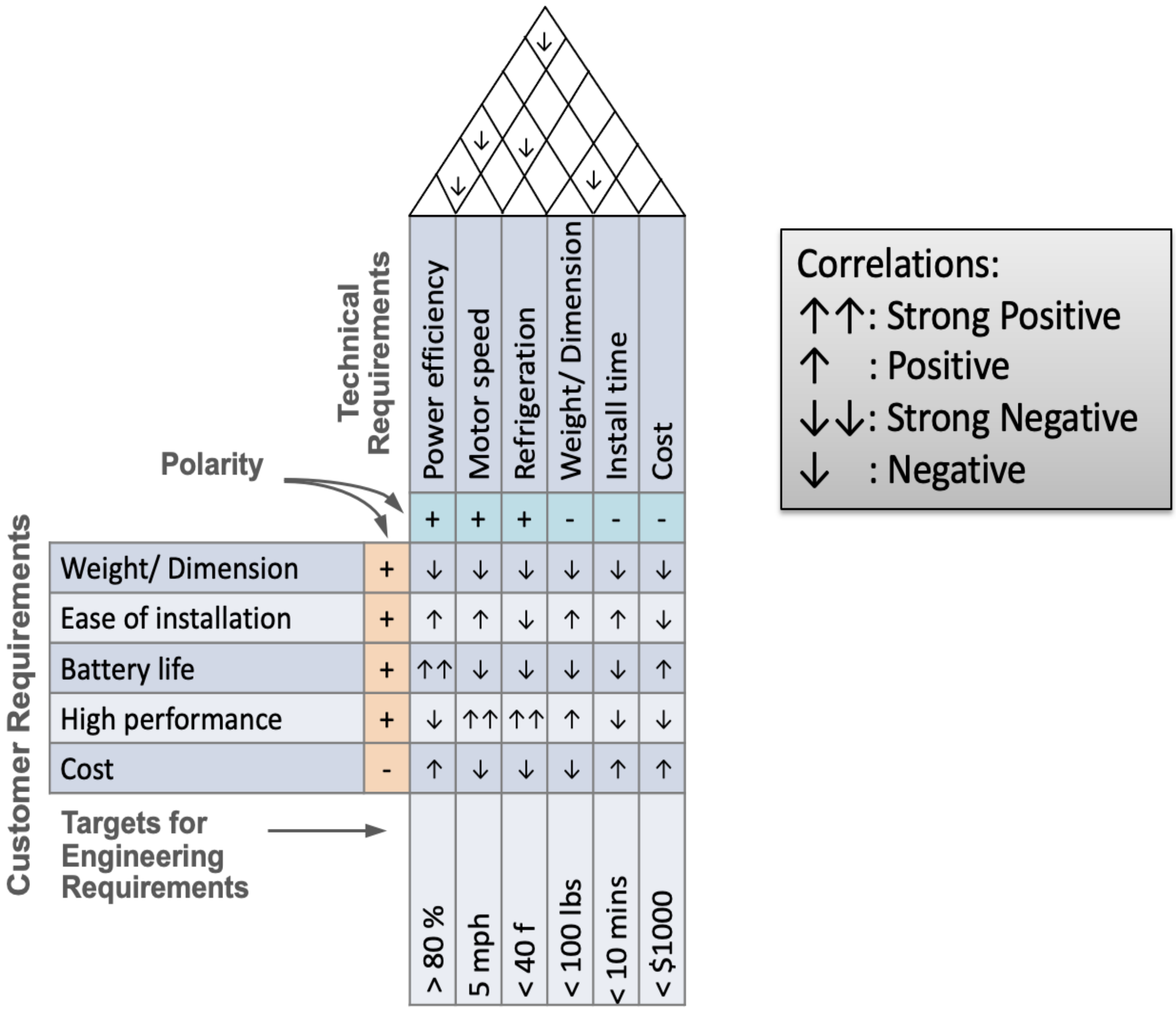
Terrain Requirements *(table 4)*

Material	Density (Kg / m^3)	Angle of Repose (degrees)
Sand (dry)	1631	35°
Sand (wet)	2039	45°
Earth (dry)	1220	30° - 45°

2.3 Marketing and Engineering Requirements

The house of quality shown in figure below is a product planning matrix to describe the relation of the customer requirements and the technical requirements so that the group project can come up with the best method to achieve those requirements. In addition to that, the diagram also specifies the numerical targets for engineering requirements based on designed experiments and analysis of some similar designs.

House of quality is useful to help the engineers anticipate the potential tradeoffs and determine the focus features for the product. In this project, we aim to design a portable electric iceless cooler and utilize solar energy as the main power supply. With the use of other group reports and similar products on the market, we were able to build a house of quality diagram that included the values and needs of the technical requirements as well as the customer needs.



(figure 1) *House of Quality Diagram*

Customer requirements are a set of what customers need and priorities to consider purchasing a product. In this diagram, we include weight/dimension as it is one of the main elements that the customers would like it to be lightweight and fit in most of the vehicles. Furthermore, ease of installation is also important. The customers would easily set up the cooler together with the temperature controller module. Besides, the wheels are operated by the motor drivers and the speed controller to simply make it move forward and backward effortlessly. As the power must be efficient enough to run both the cooler and the wheel controlling system, the selected batteries will make sure to have sufficient power to operate in a certain time. The cost mentioned in the customer requirements means the cost that the customers will pay for the product considering all the necessary features.

Technical requirements are the technical issues arising during the procedure of building and designing the product. Similar to the customer requirements, this section also involves the weight/dimension which would fit all of the required setups. The power supply has to be calculated correctly to provide the most efficient solution and follow safety rules at the same time. Moreover, the motor speed does not need to be significantly high since we will use the handle to pull them along while we are walking. Also, the refrigerator needs to reach a specific temperature range in order to cool the container inside the cooler. The cost in the technical requirements refers to the cost of purchasing the needed components and ordering the designed circuit boards. The time to assemble all of the parts together should not take too long after we have successfully tested separate components.

3. Project Definition Research

In these sections we will conduct research related to the design of our project. This research is of great importance because it allows us to make the best possible design choices later. The first subsection is research into the possible techniques that can be used to implement our desired functionalities. The following section contains our components selection research and explains why each component was chosen.

3.1 Relevant Technologies

The functionalities that have been defined in the earlier sections can be implemented in many ways. We want to design our project to meet the requirements in the most energy and cost-efficient way. For this reason, we researched the technologies that are relevant to our project and compared their effectiveness and efficiency. In the following sections we explain the techniques that can be used to implement our desired functionality and we defend the choices that are made in the final design.

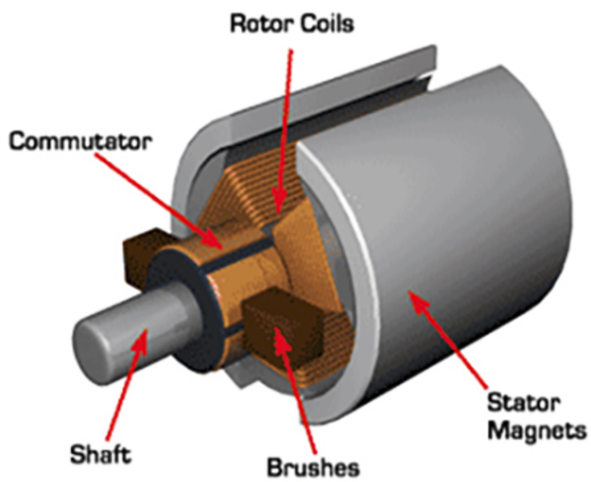
3.1.1 DC Motors

Before deciding on controls for the motor system within this project, it is first necessary to choose a type of motor to use. Because the project will be powered using batteries, DC motors are the best choice. There are different types of DC motors but the biggest difference, especially when it comes to the control of these motors, is whether they are brushed or brushless.

Both brushed and brushless DC motors work using the same principle. Internally, there are two magnets: the stator and the rotor. The rotor, as its name suggests, rotates within a magnetic field and is where the torque is delivered as the output to the wheels in this case. The Stator surrounds the rotor and does not move. One of these pieces will be an electromagnet in which the polarity will change, causing the rotation. The other piece will be a permanent magnet, but it’s polarity will remain constant. The difference between the brushed and brushless motors comes with how the polarity is changed in order to cause the rotational force.

For our project we will choose the DC motor type that will provide the greatest power efficiency and robustness. Position sensing is important for this project, so the motor type which allows the easiest position sensing will be favorable.

3.1.1.1 Brushed DC Motor

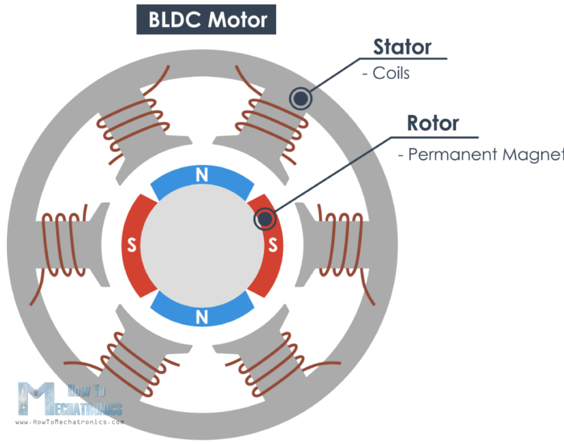


(figure 2)

The brushed DC motor has four parts: Permanent magnets as the stator, electromagnets as the internal rotor or armature, commutator rings, and brushes. The permanent magnets surround the armature. One side of the permanent magnets will be positive while the other side will be negative. The internal armature is made of a coil or series of coils and will rotate within the stator. The commutator is attached to the rotor and rotates with it. It will be in either two pieces for 2-pole configuration or four pieces for 4-pole configuration. The commutator rings

conduct charge delivered by the brushes into the armature coils. As the current runs through the coils, they become polarized and the rotor begins to spin. As the rotor spins, so do the commutator rings. Once they reach a certain point, they contact the opposite brush which then generates a current in the opposite direction causing the rotor to continue spinning.

3.1.1.2 Brushless DC Motor



(figure 3)

While a brushed DC motor uses the commutator and brush system to change the polarities of the magnets, a brushless DC motor uses an electronic controller to achieve the same goal. In the brushless DC motor configuration, the rotor is made of permanent magnets and the series of electromagnetic coils comprise the stator surrounding it. In order to achieve the rotational force, the electronic controller moves the positive and negative charge around the series of coils. The speed is regulated by how fast the positive and negative charges are moved around these coils.

In the brushed DC motor, the brush-commutator system generates some friction which reduces the rotational speed of the rotor as well as generates heat causing a loss in efficiency. The brushless DC motor does not generate friction in this way as none of the internal parts are contacting each other. This makes the brushless

motor more efficient and allows for even higher speeds. The brushless motor is also more robust, as the brushes will wear down and need to be replaced over time.

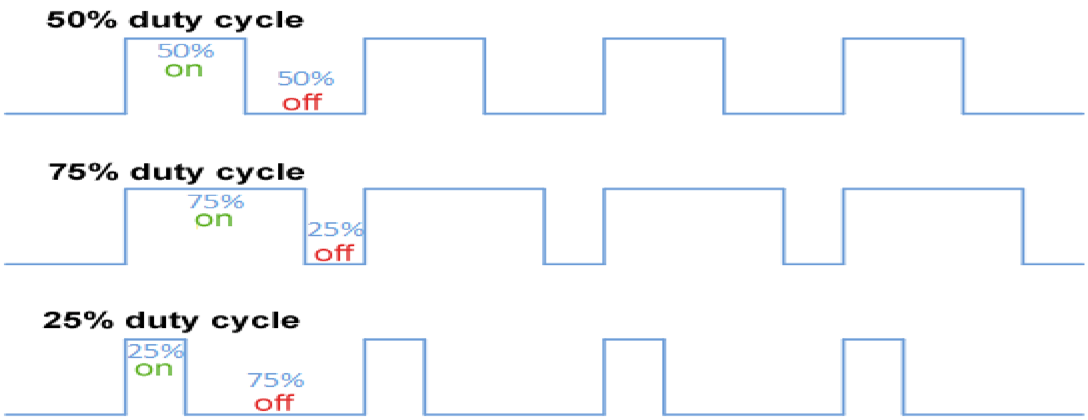
3.1.1.3 DC Motor Comparisons

For our application high speed is not necessary but position sensing is. While position sensing is embedded in most brushless DC motors in the form of hall effect sensors, brushed DC motors can also give position signals using encoders. Both motor types can provide the necessary torque, speed, efficiency and position feedback required for the project.

3.1.2 Motor Speed Control

Depending on the type of DC motor we choose for the project, either pulse width modulation will be used or an electronic speed controller will be used to control the speed of the motor. In the following sections the two control types are researched and will be compared for effectiveness, and ease of implementation. These factors will also have an effect on the motor type decision.

3.1.2.1 PWM Control

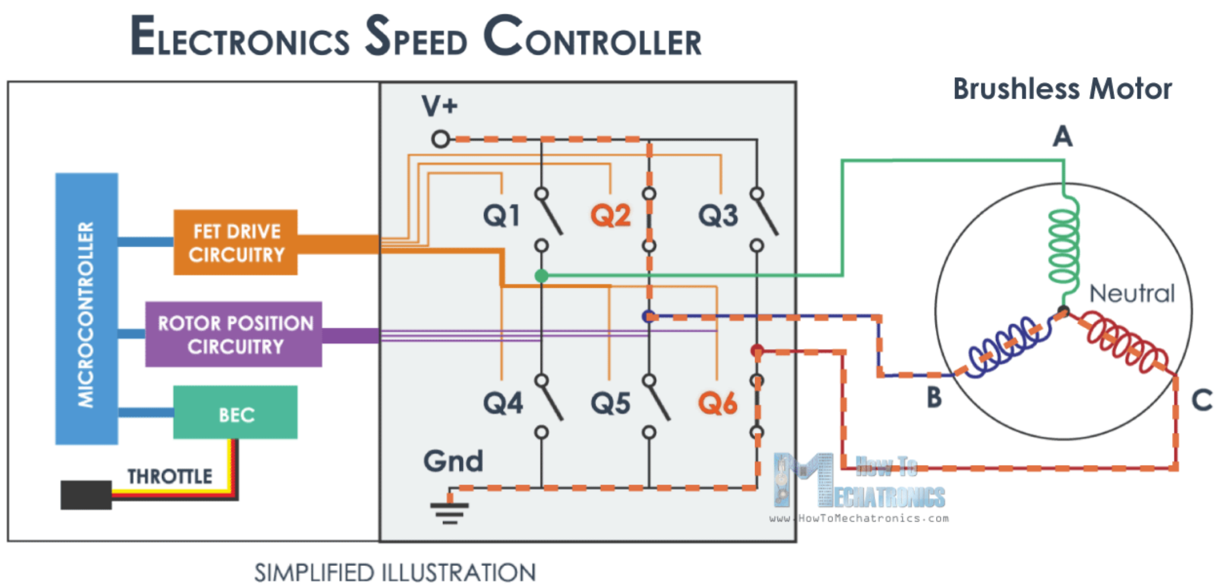


(figure 4)

While a brushed DC motor can operate with constant voltage applied across the terminals, this will only produce a full speed output of the motor and will also cause damage to the windings. In order to control the output speed of the motor

and avoid damage, pulse width modulation (PWM) is used. PWM reduces the average power delivered to a device without the need for an analog power source. A digital voltage is switched on and off at a high frequency to create an effective analog signal. The switching frequency controls the smoothness of the output voltage transitions. For a brushed DC motor, a frequency of between a few kHz and 10 kHz is normally desirable. Output voltage level is varied by changing what is called the duty cycle. Duty cycle refers to the percentage of the period in which the voltage level is at it's digital high (see figure). PWM control is achieved easily using micro-controllers, which usually have PWM generators built in.

3.1.2.2 Electronic Speed Control



(figure 5)

Unlike the brushed motor, an electronic speed controller or ESC is required to generate torque in a brushless motor. The ESC is responsible for providing current to the coils of the stator in the correct intervals. MOSFETs are used to control the current as shown in the figure. They need to be opened and closed in the proper sequence and timing in order to get the desired speed from the motor. The position of the rotor is needed to ensure that the controller is providing current to the right coils at the right time. This is most commonly achieved through Hall effect sensors

within the motor. These sensors report logic values based on the magnetic field it senses. A microcontroller will read these logic values and combine them with the desired speed to generate digital waveforms for each of the MOSFET switches.

3.1.2.3 Motor Speed Control Comparisons

Both of these strategies are effective solutions for speed control. There is a big difference in ease of implementation and simplicity however. While the ESC requires multiple control and sensing devices, along with the MOSFET switching circuit, PWM control can be done using a single microcontroller.

3.1.3 User Control

There are many ways in which our system may be able to receive control input from the user. The four control methods that are being researched follow.

3.1.3.1 Computer Vision

Computer vision is the technique of using camera pixel data to infer the presence of certain features in an image. This feature data can be used to make movement decisions. Computer vision can be done using classical programming, in which the software will always look for a certain feature. It can also be accomplished via artificial intelligence, where the target features are learned through repeated training. For the former strategy, the user would need to always wear an identifier that the system can detect which is distinguishable from all of its surroundings. For the latter, the system would be able to learn new features, however the system would have to be retrained every time and this is a very costly procedure.

While this technique has it's advantages, mainly the system being autonomous with the user not needing to control the vehicle, there are some concerns that arise. The vehicle will need to have an electronically controlled and powered steering system for navigation. A cpu and possibly even a gpu will be needed for processing. One or multiple cameras will also be needed. All of these concerns will require more energy from the batteries to operate. Because power efficiency is very important in

this project, we want to minimize these concerns as much as possible. There are also safety concerns associated with computer vision. Many computer vision algorithms can be tricked very easily. If the user is in a crowded location, like the beach or a football game, it is very possible for the algorithm to mistake somebody else as the user and begin to follow the wrong person.

3.1.3.2 Infrared Beacon

Another autonomous navigation strategy that can be used is the following infrared beacon. In this strategy two beacons are used, one on the vehicle and another on the user. Each beacon alternates between sending and receiving infrared signals so that the transceiver beacons do not get confused with reflections of their own signals. On each beacon, there are multiple IR transmitters and receivers facing different angles around the beacon. Proper navigation can be achieved by moving the vehicle in the direction of the receiver which has the strongest response. This strategy can be more robust than computer vision because it is much less likely for the sensors to be confused by noise in the area. Although, there is infrared light within sunlight which could possibly affect the receiver.

There are also some concerns related to this strategy. The steering, again, will need to be electronically controlled and powered. In order for this system to work, the user is required to have an IR transceiver on them with a clear line of sight to the vehicle. This requirement lends itself to the same use case issues as the computer vision strategy where large groups can cause the system to fail. The transceiver beacon that the user has will also need to be powered, requiring the design of a seperate battery powered, weather-proofed device.

3.1.3.3 Motor Position via Encoders

It is not necessary for our project to navigate autonomously. We want the motors to assist the user in moving the cooler, but the steering does not necessarily need to be powered. If a standard "wagon style" pivot point with a separate axle is used for steering, the only control which is necessary is the speed control of each of the motors. The user's intended speed is all that the vehicle needs to maintain. We want

the user interface to be as intuitive, simple, and safe as possible. We do not want to have the speed controlled by a simple throttle because this will not be intuitive to use while trying to also walk at the same speed. The cooler should automatically sense the user's intention and engage the motors in response.

A strategy that could be used to sense the user's intentions is the use of encoders within the motors that output the position of the rotor. Encoders can be implemented in a few different ways. Mechanical encoders use wheels attached to the rotor that make contact with leads or switches set at certain positions. Encoders can also be implemented using hall effect sensors embedded within the motor around the rotor magnet. These sensors detect the magnetic field as the rotor magnet moves inside the motor and returns a high value at a particular sensor which corresponds to a position. As the user begins to pull on the handle of the cooler, the wheels would move slightly. This change in position would be sensed by the encoders and sent to a controller which could then engage the motors.

While this strategy seems like a simple and elegant solution, there are some major concerns with its effectiveness. The biggest concern is the ability to distinguish between the user's input and other outside forces that can act on the cooler. This will also lead to some major safety concerns. It is completely possible that while going downhill, the controller would mistake the force of gravity as the user pulling harder. The controller would then increase the speed of the motors causing the cooler to possibly impact with the user.

3.1.3.4 User Pull/Push via Handle Position Sensors

We want the user interface to be intuitive and automatic, but the input needs also to be dependent solely on the user. For this reason, a novel approach is being considered. In order to keep the input based on the user only, this strategy would place sensors at the base of the handle. These sensors would work similar to the way an analog joystick works, using potentiometers and analog voltage to determine the position of the handle base. For this system to work, the base of the handle needs to be set in a frame that allows the base to slide linearly backward and forward only. The base would be held in a "zero" position by springs. An ADC

would be used to convert the analog voltage output by the potentiometers into a digital value. A feed-forward controller would then take this digital value and output a speed value to the motor controller. The controller will use the motors to try to keep the handle base at position "zero" at all times.

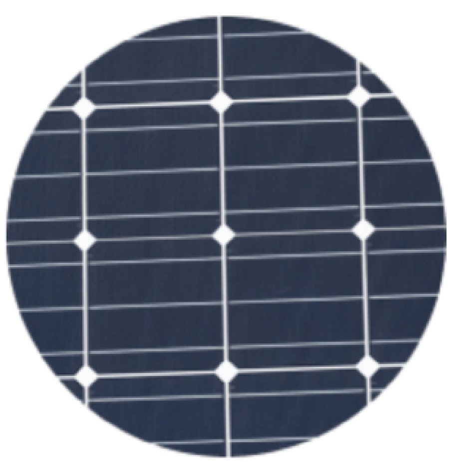
This strategy would overcome the problems posed by the motor encoder system. The motors will only engage when the user starts to pull the handle and will reduce speed or dis-engage completely when the handle is pushed backwards or held still. While going down a hill, for example, as gravity pulls the cooler down it will cause the handle to move backwards within the frame. This will cause the controller to reduce the speed of the motor.

3.1.4 Solar Panel

Solar panels are used to power a wide range of applications nowadays. They collect energy from sunlight and convert it to electricity which provides power for other electric loads. There are three major types of PV cells on the market: monocrystalline, polycrystalline, and thin-film. Each material has advantages and disadvantages with respect to the power efficiency, versatility and price. Due to the requirements of high-power usage, our project will consider the PV type that is the most affordable and provides high energy efficiency.

3.1.4.1 Monocrystalline

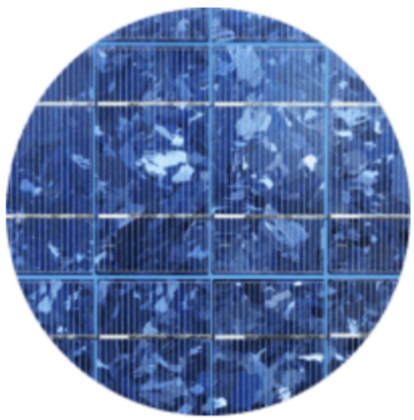
Monocrystalline silicon solar panels are made from a single pure silicon crystal cut into wafers; and then assembled together into rows and columns to form the rectangles with small gaps between them. As a result of silicon's high purity, this PV material has the highest efficiency levels, reaching above 20%. It is also less affected by temperature than polycrystalline panels and lasts longer than other solar panel types. However, there is a lot of silicon waste when manufacturing this solar panel. Although monocrystalline is the most popular one and capable of producing high output performance, this type of PV panels would perhaps be expensive for our project.



(figure 6)

3.1.4.2 Polycrystalline

Similar to monocrystalline solar panels, polycrystalline solar panels are made from silicon, but different samples of silicon crystals are melted together and poured into a square cast. This leads to the imperfect form of the crystal structure. This manufacturing process is less expensive and faster since it uses less material and energy than making monocrystalline panels. It decreases the overall output efficiency (approximately 17%) and causes shorter lifespan. Also, environmental temperature could affect performance of this cell material. Nonetheless, polycrystalline is considered as the most suitable one for our project as it is able to generate almost the same electricity as monocrystalline but with an economical solution.



(figure 7)

3.1.4.3 Thin-film

Thin-film is the newest technique developed for solar panels and offers a flexible and cheaper option. Its cells are much thinner than the crystalline wafers used in other solar panels. This type of PV panels is constructed from different materials: cadmium telluride (CdTe), amorphous silicon (a-Si), and Copper Indium Gallium Selenide (CIGS). One or more films of photovoltaic material is placed onto a substrate and topped with glass. Thin-film panels are the easiest one to produce since it does not require too many materials. The main issue of this type is that it is low in power efficiency and has a shorter lifespan than other solar panel types.

(figure 8)

Solar Panels (table 5)

Cell material	Power efficiency (%)	Temperature coefficient range (%/°C)	Average cost per Watt ($)
Monocrystalline	20	-0.3 to -0.5	1 to 1.50
Polycrystalline	15-17	-0.3 to -0.5	0.90 to 1
Thin-film	11	-0.2	0.70 to 1

3.1.5 Battery

Rechargeable batteries are becoming more popular and convenient for their power efficiency. They can be recharged to full strength whenever devices need more energy. They last longer than other primary batteries and help reduce waste. There are a variety of rechargeable batteries on the market with reasonable prices.

For battery selection of our project, we will consider the rechargeable battery with regard to its weight, dimension, power capacity and cost. Besides, we also look at the safety features and self-discharge rate of the battery. The solar panel will be connected to charge the battery. The battery has to be capable of distributing energy to supply both the Peltier cooler and motor's driver through voltage regulators. These following rechargeable batteries are the ones commonly used: Lithium-ion (Li-on), Lithium-ion Polymer (Li-po), Nickel-Metal Hydride(Ni-MH), Lead-Acid and Alkaline.

3.1.5.1 Lithium-ion (Li-on)

Li-on battery is light weight and popular for being used in plenty of portable electronics devices since it is feasible to satisfy the requirements involving weight and form factor. It has a high specific energy and specific capacity as well as a long cycle life. In addition to that, this battery type has a lower self-discharged rate than others and a wide range of ambient temperature. It is also compatible with fast charging technology. However, Li-on is expensive due to the manufacturing process and high demand. The battery needs extra protection since it will not function properly if overcharged or heated which causes capacity loss.

3.1.5.2 Lithium-ion Polymer (Li-po)

Li-po has twice the energy density compared to other battery types. Similar to Li-on, it is lightweight and meets precautions while performing charging and discharging. It also has a low self-discharge rate and can be manufactured in different shapes to adapt a wide range of packaging. Despite the fact that it is one of the most reliable batteries, Li-po is even more expensive than Li-on and also needs protection for overheating. It also has a short lifespan and can fail in two or three-year periods.

3.1.5.3 Nickel-Metal Hydride(Ni-mH)

Ni-mH battery also support higher capacity and energy density compared to standard NiCd batteries. It is considered as the most environmentally friendly battery since it consists of fewer toxic materials. However, Ni-mH has a very high self-discharge rate compared to other types of batteries. It cannot handle fast charging and generates considerably more heat while charging.

3.1.5.4 Lead-Acid

Lead-acid is the oldest type of batteries and also the most used one up to date. It can supply high surge current so that the cells would be able to maintain a relatively large power-to-weight ratio. It is low cost and used commonly in heavy-duty operations. Some of the major applications of lead-acid batteries are in powering automobile starter motors, electric vehicles and storage for power backup. This battery can be recycled and reused in new batteries. On the other hand, lead-acid batteries are heavy and bulky. It is not ideal for fast charging and needs proper care under hot climate conditions.

3.1.5.5 Alkaline

Alkaline batteries have high energy density, low self-discharge rate and longer lifespan than other types of batteries. It has lesser health and environmental impacts compared to lead-acid batteries due to the absence of heavy metals and ability to be recycled without special disposal methods. The rechargeable battery can be used roughly 100 times. It is cheap and also can function well even at low temperatures. Nevertheless, output performance can be reduced since it has a high internal resistance. The battery can explode if using the faulty charger. Besides, leaked material can cause severe damage to the devices.

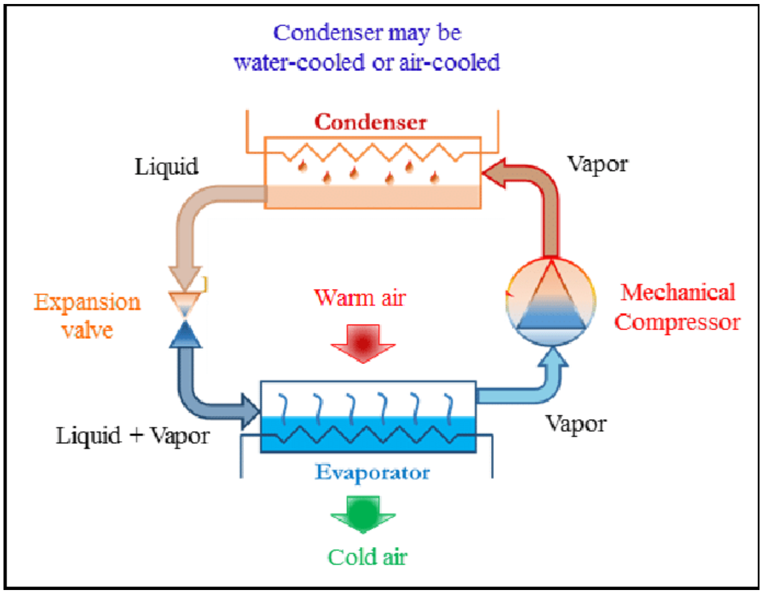
3.1.6 Refrigeration

Since its inception, refrigeration has been an integral part of our society. From keeping antidotes and vaccines at a cool temperature or simply storing food, it has truly made living for mankind a lot easier. But what exactly does it do and how does it work? Different types of refrigeration systems all involve transferring heat from one area to another which subsequently cools the former. There are four types of refrigeration methods that are the current standard, mechanical-compression, evaporation, absorption and thermoelectric with different attributes for all of them.

3.1.6.1 Mechanical-Compression

Mechanical compression is the most common and widely used of the four refrigeration methods and is mainly used for commercial and industrial refrigeration systems and air conditioning units. This process is done by mechanically compressing refrigerant into a low-pressure side with cold liquid and moving it inside a closed system and expanding it into a high-pressure side into hot gas.

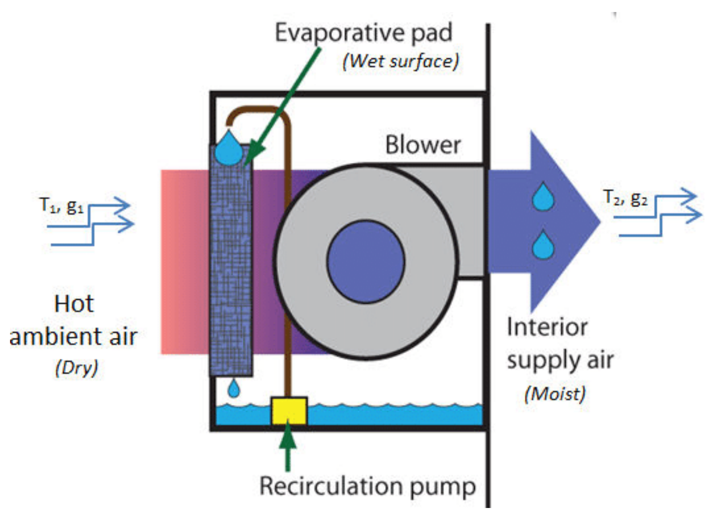
In this instance the refrigerant absorbs heat when it is boiled into a gas and releases the heat and goes back into its liquid form.



(figure 9)

3.1.6.2 Evaporation

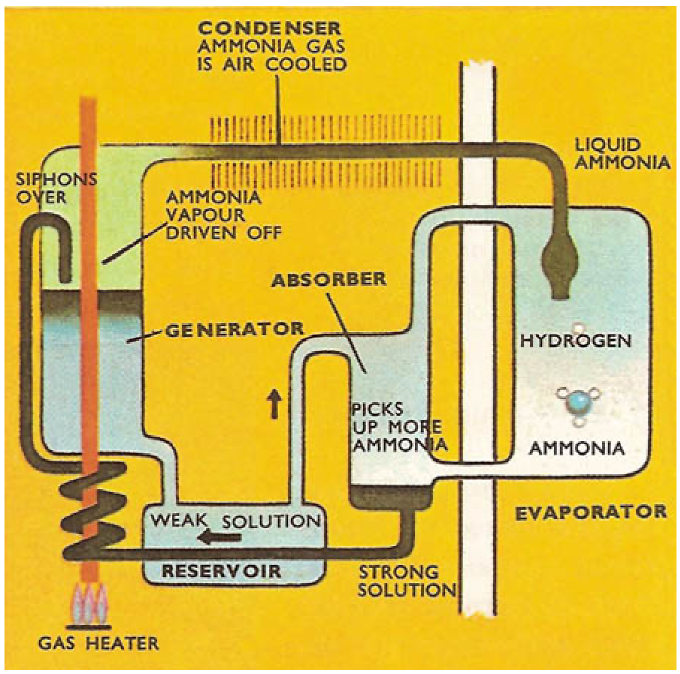
Evaporative cooling is the least popular amongst the three due to the process of how it works. This method of cooling gathers the warm air from outdoors and moves it through damp/water soaked pads. Much like the refrigerant it absorbs the heat from the air and evaporates it thus creating cooler air. But this is also the crux of this method. The temperature of dry air can be dropped significantly through the phase transition of evaporation(from liquid to vapor). It does not work as efficiently in humid climates and is best suited for dryer areas of the world.



(figure 10)

3.1.6.3 Absorption

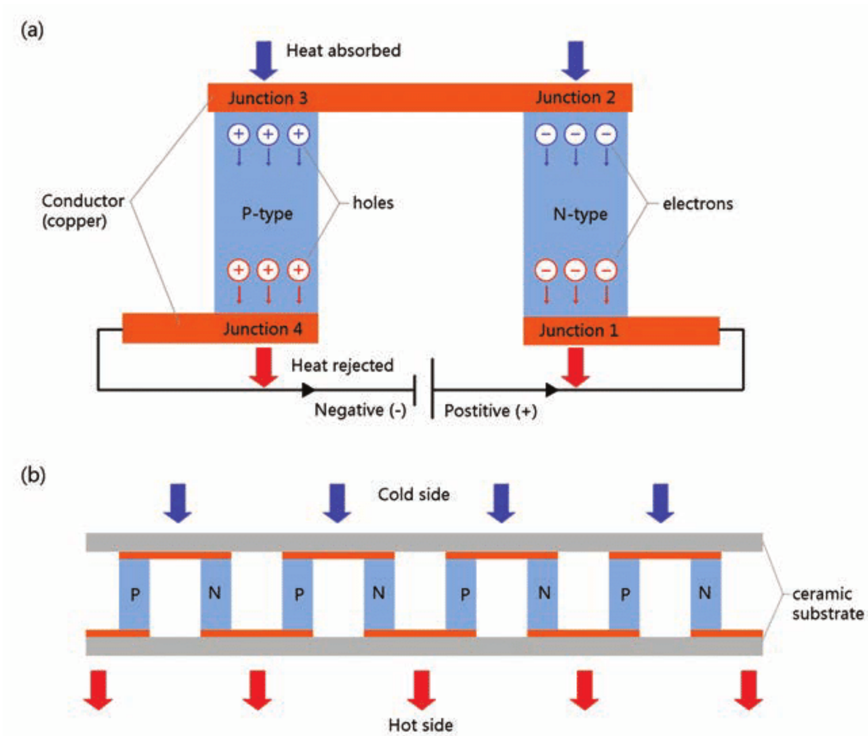
This process uses heat transfer by compressing and expanding a liquid but does not use a mechanical compressor to do so but instead uses other substances. Most residential HVAC chillers often use ammonia as the refrigerant and water as the absorbent. This is done by the absorber which is a component that contains the water where it separates the ammonia from the low-pressure side and removes the heat while absorbing it and boils to separate the ammonia and water before sending it to the high-pressure side.



(figure 11)

3.1.6.4 Thermoelectric

This process is the most unique from the previous three methods of refrigeration. Thermoelectric refrigeration does not require the use of a refrigerant or water for the cooling process but rather uses a thermocouple and an electrical current to reduce temperatures. The thermocouple is composed of two different metal wires and connected at both ends with some insulation separating these two. Then a current is directed onto the wires heating one up while the other cools down. Then if the current is in the opposite direction, it will reverse the hot and cold areas.



(figure 12)

3.1.7 Power Technologies

Power supply plays an important role in supplying and transferring power to different electronic devices. It is designed to convert electric current coming in from a power source to the type of desired electricity, known as DC and AC. Therefore, DC and AC power supplies are the two common options to be considered in the market. Knowing the differences between them will help us make an informed decision when we make a purchase. There are some distinct features of these two types of power supplies that will be discussed specifically.

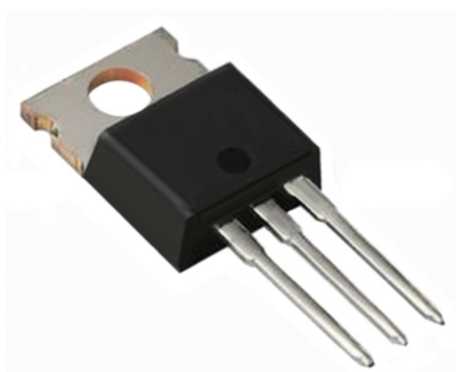
3.1.7.1 AC and DC power

AC (alternating current) power is the standard electricity that takes the voltage from the wall outlets. The alternating current is able to reverse its direction periodically between positive and negative polarity depending on the behaviors of

the wave-like current. Alternator is a special type of electrical generator, which is designed to generate AC current, and contains a wire loop rotating inside a magnetic field. AC flows through the high-voltage transmission line and need to be stepped down when it is needed for household uses.
Unlike AC power, DC (direct current) power has the current flow in one direction between positive and negative terminals. Direct current is produced by the chemical effect in cells, batteries and generators with commutators. DC generation is limited in some small-scaled applications.
In our application, we are attempting to develop a sustainable solution by utilizing solar panels as the main power source to charge the rechargeable batteries so that it will distribute energy over several subsystems. On the other hand, we try to provide an alternative method to charge the pack of rechargeable batteries by using the AC outlets connected with an AC to DC converter.

3.1.8 Voltage Regulator

Voltage regulator is an integrated electrical circuit that can maintain a fixed DC output voltage regardless of the changes to the voltage of input and loads. It is able to adjust the current flowing through the load by comparing the output of DC supply to a programmed internal reference voltage. Linear regulators are usually attached with a heatsink to optimize the temperature range.



For our device, the voltage regulator will help adjust the voltage going in the MCUs, LCDs and sensors. We will consider selecting the IC voltage regulator to step down the 12V battery to a lower voltage range for operating those low-power devices. In order to pick up the most efficient ones, we will focus on some aspects of the regulators, such as appropriate input/output voltage, load current and minimum dropout voltage. Voltage regulators are cheap and simple to manufacture so we do not have to worry about the cost. There are two typical types of voltage regulators: Linear voltage regulator and Switching voltage regulator.

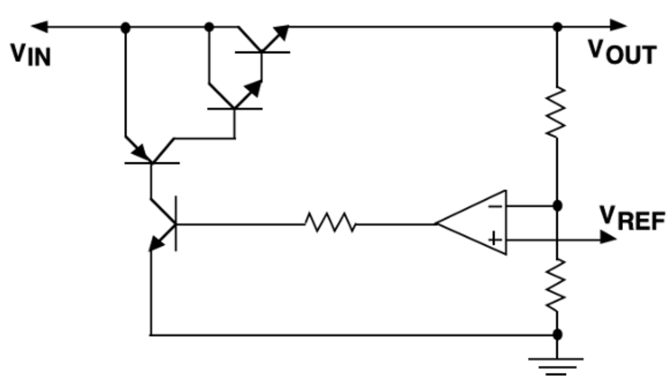
3.1.8.1 Linear Voltage Regulator

Linear voltage regulators work as a step-down converter because by definition, the input voltage is always higher than the output voltage. A voltage-controlled current source was used to draw a constant voltage to appear at the regulator output terminal. The difference of input and output is lost by converting it to heat. The power dissipation of this regulator is relatively high causing its low efficiency (50% or lower). Dropout voltage is important to the linear regulator since it can influence the overall efficiency of the regulator. For some classic linear regulators such as LM317 and LM78XX, their dropout voltages are roughly 2V. Meaning that the input voltage must be 2V higher than the output voltage for the regulator to function properly. On the other hand, linear regulators are easy to design and offer low output noise and low voltage ripple.

There are 3 basic types of linear regulators: Standard (NPN Darlington) Regulator, Low Dropout or LDO Regulator and Quasi LDO Regulator

1) Standard (NPN Darlington) Regulator

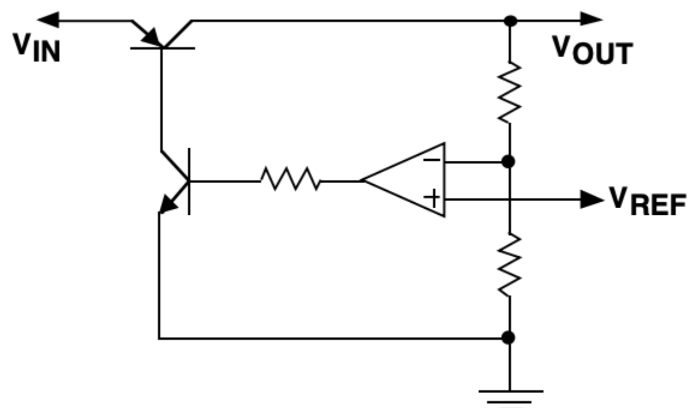
NPN Darlington regulator was the first IC voltage regulator type designed for the pass device. It is an arrangement of the standard of NPN or PNP bipolar junction transistors. The base of a transistor is connected to the emitter of the other transistor to generate high current gain for effectively functioning some applications where switching and current amplification is required. The temperature range of this type of regulator is from -55°C to +150°C. Besides, it has the minimum voltage requirement range from 2.5V to 3V in order to operate properly. Its dropout voltage is considered the worst (1.5V to 2.2V) in comparison to other IC voltage regulators. However, it has the lowest ground pin current since it is not required to drive the base of the transistors.



(figure 13)

2) Low Dropout (LDO) Regulator

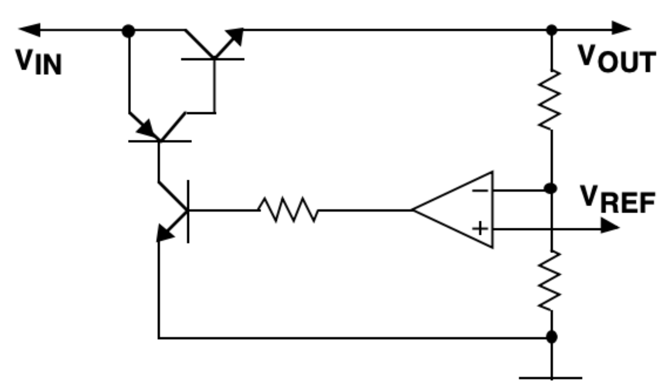
The difference between the low dropout regulator and the standard voltage regulator is that the LDO regulator is composed of only a single PNP transistor. LDO regulator is capable of providing a stable power supply voltage with the lowest dropout voltage rate. The maximum dropout voltage of this regulator is usually in the range of 0.7V to 0.8V at full current. LDO regulator is popular in operating battery-powered applications because it can amplify the input voltage and ensure high power efficiency. On the other hand, it has the highest ground pin current out of three types of regulators mentioned. Minimum voltage across the LDO regulator is the voltage at the PNP transistor



(Figure 14)

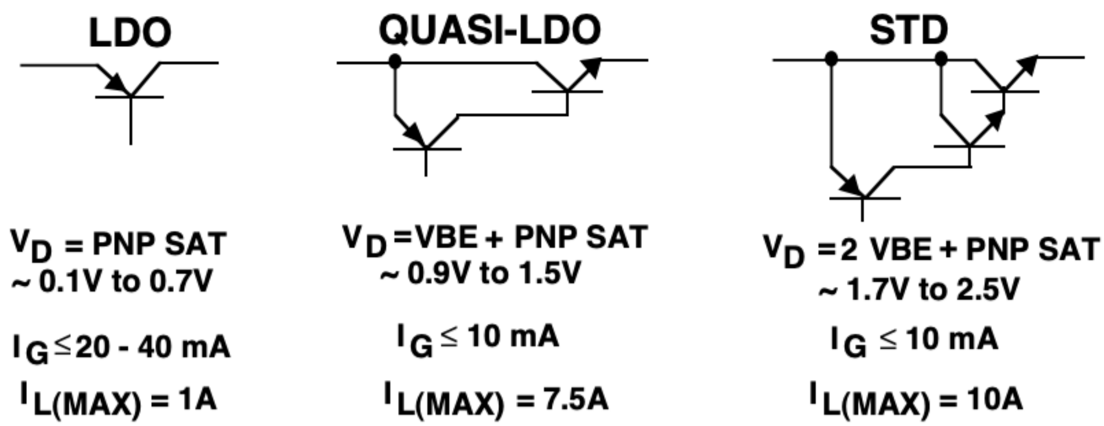
3) Quasi LDO Regulator

Quasi LDO regulator is a variation of the standard voltage regulator that uses both NPN and PNP transistors as the pass device. The dropout voltage of this regulator is relatively high and specified around maximum 1.5V, which is lower than the standard voltage regulator and higher than the LDO voltage regulator. Its dropout rate depends on the temperature and the load current. Also, it has a fairly low ground pin current, which is less than 10mA for full load.



(Figure 15)

The figure below has shown a summary of the features regarding the three IC voltage regulators. The LDO regulator seems to be the most suitable regulator to use for the applications with battery as the primary power supply. The number of battery cells can be reduced since the dropout voltage of LDO is the lowest so it could save quite a lot of waste energy. Moreover, if the difference between input and output voltage is not too much, the LDO could help decrease the rate of dissipation of energy resulting from the load current and input-output.



(Figure 16)

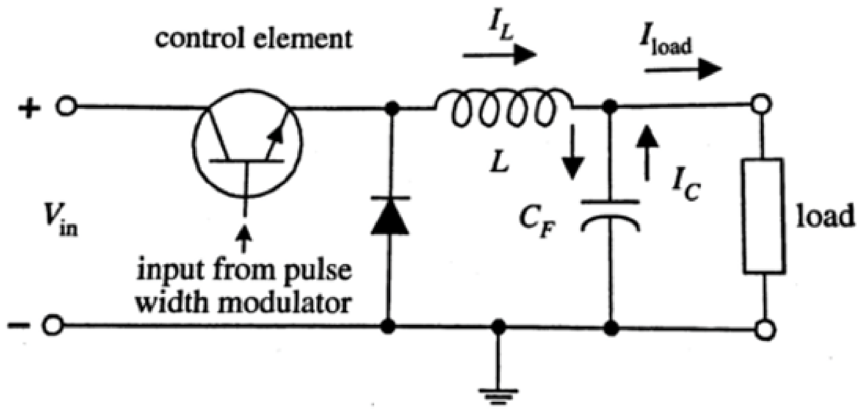
3.1.8.2 Switching Voltage Regulator

Switching voltage regulator can convert the DC input to a switched voltage turning on/off rapidly at high frequency. The on/off pulses are controlled by a PWM network, so the output remains unchanged regardless of the variation of input voltage and load current. This regulator can achieve the power conversion rate exceeding over 85%, which is much higher than linear-voltage-regulator efficiency. Additionally, they have a wide current and voltage operating range as well as can be configured in some desired configuration such as step up or down to serve different circuitry purposes. They are beneficial for those applications needed a large step-down voltage. However, the switching regulator is more complicated to design compared to the linear regulator since there are requirements for tuning control loop, layout design and selecting external components.
There are three common types of switching voltage regulators: Buck, Boost and Buck-Boost (Invert).

1) Buck Regulator

Buck regulator or step-down voltage regulator is used when the DC output voltage needs to be lower than the DC input voltage. The current is flowing through the output during the entire cycle only in buck mode. The higher the current being, the more power dynamic the circuit can achieve. Buck regulators are popular in a plenty of cool applications used in electronic devices. The converters are designed to have efficiency of 90% and offer optimum power loss. Some of the other

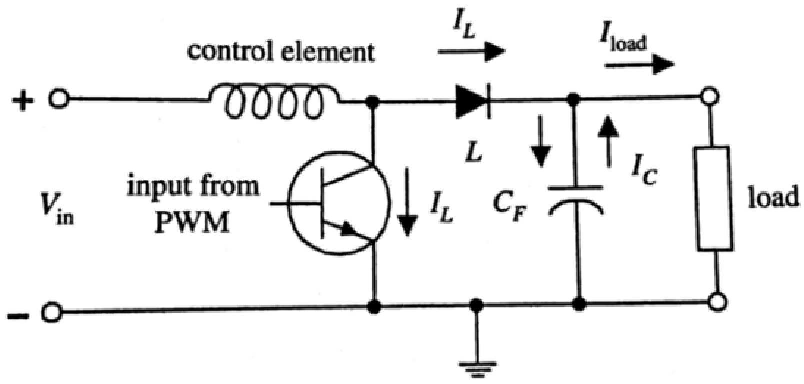
advantages of buck regulators are heat reduction and battery life extended ability. They are used commonly in some low input voltage applications as modern microprocessors, smartphones, tablets, etc. However, this regulator can only operate in one mode and step down the input voltage.



(Figure 17)

2) Boost Regulator

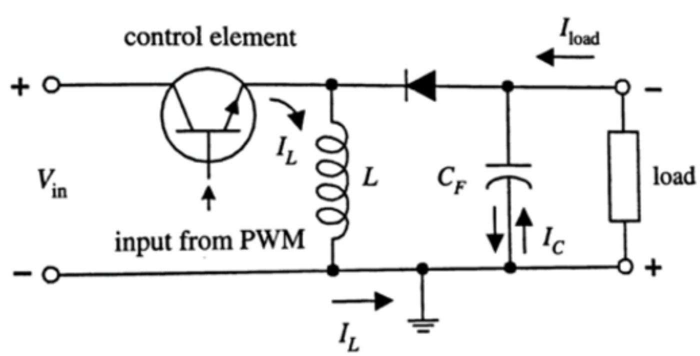
Boost regulator or step-up voltage regulator is used when the DC output voltage is designed to be higher than the input voltage. In contrast to the buck regulator, the boost converter will step up the output voltage to meet the requirements of some amplifier applications and hybrid electric circuits. There is less component count needed to build this regulator than other switching regulators. The input current of the buck regulator is continuous, which is more beneficial for PV panel and battery sources. Similar to the buck regulator, the boost regulator can only step up the input voltage.



(Figure 18)

3) Buck-Boost (Invert) Regulator

Buck-Boost or inverting regulator is designed to take the DC input voltage and then produce the output with opposite polarity to the input. The input and negative output voltage can have different magnitudes. It also offers a lower operating duty cycle. Unlike the other two regulators, this regulator is able to work in two modes to step up and step down the input voltage with minimum component count in order to save cost. However, they cannot achieve high gain; and have complex sensing and feedback circuits due to inverted output.



(Figure 19)

3.1.8.3 Comparison of linear and switching voltage regulator

The linear voltage regulators and switching voltage regulators have several benefits and drawbacks if we would consider one of them to use in our project. The table below shows the different features of these regulators and based on that we can select the one that can best fulfill the requirements of our design.

(table 6)

Features	Linear Regulator	Switching Regulator
Definition	Regulator uses non-switching technique to regulate the constant output	Regulator uses switching technique to transform the supplied power into a pulsed voltage
Efficiency	Low to medium for low differences between input & output voltages (50% or lower)	High (over 85%)
Design Flexibility	Buck	Buck, Boost, Buck-Boost
Complexity	Low	Medium to high
Cost	Low	Medium to high due to external components
Size	Small to medium	Small to medium
Noise generated	Low	Medium to high

As we can see, the switching regulator can provide a significantly higher efficiency than the linear regulator in the process of regulating the output voltage. It also could be constructed in several modes for different designing purposes. However, we might have to worry about the extra external components needed for this one as those parts will lead to increased cost. Also, as the fundamental working principle of switching regulators involves oscillating the clock frequency and harmonics, the noise could increase up to hundreds of microvolts, which is intolerable for some applications. If there are some loads being sensitive to supply rail noise, the system may suffer unexpected problems. On the other hand, as linear regulators do not have a time clock, the device is free of noise and ripple voltage. Nonetheless, they are considered to be inefficient since they dissipate the power regardless of the power still being delivered to the loads. The complex of heat generation produced by the regulator also will arise if the difference of the input and output is a lot and there would be a need of a heatsink attached to the regulator.

Since efficiency is the key to our device, we might consider the switching regulator to use in this project. Although the problem of the switching regulator is producing more noise than the linear regulator, that would not drastically impact our device performance. We will need to build a DC/DC conversion circuit which connects the battery and the main PCB board. The 12V DC battery will be stepped down to either 3.3 or 5V to supply power for the board. We use the Texas Instrument Webench to find the most suitable converter for our project. The specific design and schematic of the regulator will be discussed in the hardware design section.

3.1.9 Solar Charger Extra Features

Our plan is to add as many features as we can in a limited budget to make the solar part smart as well as project. There are different features that we are planning to add to it.

3.1.9.1 Display

There are different options to display battery data, either LCD or pixel display. Pixel display is expensive compared to LCD. We do not have a lot of information to display and are planning to go with an LCD option. But it can be changed to pixel display later on if needed.

3.1.9.2 Current and Voltage measurement

It is planned to display real time current and voltage values on display. So the user can see what is the voltage level of the battery and current drawn by load. Since it is a dc voltage and current that needs to be displayed. Potential and current transformers are not the option to use and even the rating of these values are not so high and we can achieve the desired task using DC sensors. There are different sensors of high measurable values available in the market and any of them can be

used in our project. The particular name and brand have not been decided yet but will be chosen based on research later on.

3.1.9.3 Overload Protection

There are chances of putting more weight on the cooler than the required rating from the user side. To avoid failure or motors by drawing more current in case of overloading we are planning to do some protection in our system. The protection will be done by means of some automatic switching. It could be relay or any other under budget and reliable technology. The controller of the system will monitor the current and make decisions based on current coming out of the battery. We will not let the user drive cooler as long as it is overloaded. The protection switch will disconnect incase of overloading.

3.1.10 Different Types of Charge Controllers

The purpose of the charge controller is to regulate the voltage and current and avoid batteries from overcharging. For example, a 12-volt battery needs around 14 volts to get fully charged. The normal 12-volt panel gives 16 or a little more voltage on it, if the voltage is not regulated before going to the battery, then it could damage the battery by overcharging it.

If the system is small and the charge panel is not putting out more than 5 watts, then normally controllers are not used and the battery is charged directly from panels. But it is not a good approach, there should be a bridge between panel and battery.

After doing a lot of research it is found that we cannot use a panel which gives 12 volts all the time. Even these types of panels are not in the market. Panels always give more voltage than their rated value. The reason is that, if the panel is designed for 12 volts only then we get power output in standard condition and will not get any output in the case of low sun, cloud or high temperature. A fully charged 12-volt battery shows 12.7 volt on its terminal. And in case of under charging it is between 13 to 14.6 volt. Panel needs to provide at least this amount of voltage for the battery to get fully charged.

The Market does have charge controllers of different shape sizes and features. Normally their current range is from 4 to 80 amp. There are some controllers that go beyond the 80-amp limit for some big scale projects. Based on design and structure there are three different types of controllers available.

3.1.10.1 Simple 1 or 2 stage controllers

It is a very old technology of controllers where they control the voltage with the help of a transistor switch. Since they are not so common but can be found in old systems as well as online for cheap solutions. They do have one benefit of reliability. Since the circuit is not too big or complicated and it is very rare for them to break. The basic principle of working is that they just disconnect the battery from panels when it reaches a certain voltage level.

3.1.10.2 Three stage or PWM

There are few names of them in the market like Morningstar, Xantrex, Blue Sky, Steca, and many others. They are also used as a standard by many industries. There is not much difference between the three stage and maximum power point tracking controller. As the name suggests there are three main settings of this type of controller bulk, absorption and float. In the bulk stage the battery is getting as much energy as it can while maintaining the low temperature of it. The absorption controller will try to maintain the voltage which is required by the battery for charging and last float try to reduce the current when the battery is about to charge and it will keep the battery fully charged all the time.

3.1.10.3 Maximum Power Point Tracking

The maximum power point tracking (MPPT) charge controller is that converts the higher voltage DC voltage to lower value to charge the battery. It is basically a bridge between a solar panel or wind generator and battery.

Most of the solar panels that are available in the market are designed for nominal voltage of 12V, but in actual they are capable of putting out voltage between 16 to 18 volts. On the other hand, batteries nominal and actual voltage do not have much difference. For example, a battery with nominal voltage of 12 volt has an actual voltage between 10.5 to 12.7 volt. And a battery requires a voltage of 13.2 to 14.4 to get fully charged.

Now let us talk about rated power. If a solar panel has a power of 130W, it means it is capable of giving that power at a particular voltage and current values. For example, a 130-Watt Kyocera KC-130 is rated at current of 7.39 and voltage of 17.6 volts. Which is 7.39*17.6 = 130W.

Let us suppose we have a panel of 130W, and it has a rated current and voltage values as 7.39A and 17.6V. When it is connected with a battery of rated voltage of 12V, the watts we get are 7.39*12 = 88.8 watts. We almost lost 41 watts this way. Where did this power go? Actually, that power is not used by the charge controller and converted into heat.

One solution is to get a solar panel of lower voltage level. But does a 130watt solar panel always give its rated voltage of 17.6 or not? It does not, it all depends on the sunlight and the temperature of the solar panel. If solar panel temperature increases due to some factors, then the output voltage getting out from solar will be reduced and what if this voltage is reduced to the point which is lower than battery rated voltage. In that case we will not have enough voltage to put charge on the battery.

Here designing and implementation of maximum power point tracking charge controller starts and plays its part to maximize the available power usage.

Maximum power point tracking controller is the electronic circuit. The job of it is to look at the output of the panel and compress it to the battery voltage. The controller circuit checks the best output power that can be taken from the panel and gives it to the battery for maximum Amps. The available controllers are about 93 to 97% efficient. And overall efficiency and performance also depend on weather,

temperature, battery state and others. Since we are designing systems for mobile coolers, our main job will be to provide a cheap solution that is capable enough to do the job and meet the customer's demand.

If maximum power tracking is implemented, then the maximum power point will be different from the standard conditions because the weather condition changes all the time. For example, in winter the panel will be able to put out more power than its rating while on the other hand it will reduce its rated power in summer due to increase in temperature. It is very important to track the maximum power point to get more power output and store it.

The job of the tracker is to take the input from the panel, convert it to the high frequency A.C and then convert it back to different DC voltage and current for the battery. Since it is working on a very high frequency the design could be very tricky due to noise and other factors.

There are also linear maximum power point trackers available in the market but they are not as efficient as digital one. It is very easy for them to lose their tracking point especially when clouds come and go back, the linear circuit loses its control of finding maximum point and goes far away from its accuracy. Solar charge controller needs to be smart enough to work smartly when light, temperature and battery voltage changes throughout the day.

The recent maximum power trackers are microprocessor based. The main reason for microprocessor-based trackers is that they have become so cheap. They are even cost effective even for systems of less than 1KW. There are several companies who make microprocessor based maximum power point tracking charge control, such as Outback Power, Xantrex XW-SCC, Blue Sky Energy, Apollo Solar, Midnite Solar, Morningstar and a few others.

3.2 Project Components Research

In this section we will research the possible components that will be used on our project. Multiple parts and manufacturers will be researched for each component. The parts that provide the best performance with the lowest energy consumption and cost will be the favorable choices. The manufacturing company will also be considered because it is very easy for electronics to be damaged or otherwise not working if they are not manufactured well. After the best suited parts are compared, the best one will be selected based on the relevant criteria.

For this project there are two main components that will be consuming most of the power. These components were researched first in order to make decisions about the components that are needed to provide power to the main consumers. The two main energy consumers are the motors used to move the chassis and the refrigeration unit. After, the rest of the necessary components that will be purchased are researched.

3.2.1 DC Motors

Some assumptions and calculations are made to decide which motor is best suited for this project. The specification that we have decided for the top speed of the cooler is 5 mph. Assuming an 8-inch diameter wheel, the motor will need to spin at a maximum of 210 rpm's. This is a low number when looking at the rpm ratings of DC motors meaning that almost any motor, we choose will be sufficient for this specification. The weight specification we have chosen is set at 100 lbs. For these reasons, we believe that two 12-volt drive motors will be sufficient for this project. The parameters that we are most interested in are the voltage rating, power rating, size, weight, and of course cost. Because the motor position sensing is necessary, only motors with position sensing will be considered.

The best suited brushed and brushless DC motor will be evaluated and compared, finally the best suited motor of the two will be chosen for the project.

3.2.1.1 Tebru Brushless Sensored Motor

Motor Specifications (table 7)

Parameter	Value
Voltage Rating	11.1 - 36 V
Power Rating	2500 W
Length	60 mm / 2.4 in
Diameter	~ 50 mm / 2.0 in
Weight	~ 500 g
Cost	$ 59.26
Position Sensing Type	Hall Effect

The voltage rating of this motor is a little high for our project. The minimum voltage is 11.1 which will work for us, although it is unclear how fast the motor will spin at this voltage. Because we are not interested in high speed, but low speed and high torque this may not be an issue. The power rating for this motor is well above the necessary rating needed for this project. Size and weight are also very desirable for our situation as this motor will fit easily within the cooler chassis and add a very small amount to the overall weight helping us stay within the 100 lb specification.

3.2.1.2 12V, 313RPM 416.6oz-in HD Premium Planetary Gearmotor w/ Encoder

Motor Specifications (table 8)

Parameter	Value
Voltage Rating	12 V (6 - 12 V)
Power Consumption	24 W

Length	85.6 mm
Diameter	38 mm
Weight	~ 330 g
Cost	$ 59.99
Position Sensing Type	Hall Effect Encoder

This motor checks all the necessary boxes for this project. It operates at 12 volts, the size will fit perfectly in the cooler, and it has a high torque rating of 10 kgf-cms. The only worry about this motor may be the power consumption, however we believe that this is a necessary part of a motor that is powerful enough to move our 100lb vehicle as per the original requirements. Based on the information seen in the table and the above ratings, this motor will be chosen for the final design.

3.2.2 Commonly used batteries for Solar Electric Systems

There are many different battery technologies that can be used in the solar system. If we talk about the led acid battery these are the commonly used automobile batteries. The deep cycle normally used in golf carts can last up to 3 to 5 years. The new AGM technology in lead acid batteries made them one of the best batteries for solar systems. AGM is an absorbed glass mat battery. The tight ultra-glass fiber tight fiberglass between the plates makes them immune to the vibration and increase its performance. But the cost of these batteries is high, and we will see our budget before planning to buy a battery of that technology. However, these are the best for solar or other applications as well.

Nickel cadmium batteries are also seen in solar charging systems, but they are pretty much expensive, contain very hazardous material, low efficiency and they also have nonstandard voltage and current which makes them difficult to use with other circuits.

Nickel iron is also used but they also have low efficiency, high water consumption, causes large voltage drop across the cells, and also can reduce the efficiency of the system up to 25%. Considering all these factors nickel iron is not a good choice.

Lithium batteries are also commonly found in solar electric systems due to its long cycle life and highly charge and discharge rate. One of the advantages of lithium batteries over lead acid is that there is no danger of explosion. These batteries do not need to be fully charged, like in other batteries for example lead acid if they do not get fully charged on a regular basis then its cause of plate degradation. The round trip efficiency of it is up to 95 to 98 percent while lead acid is 80 and other technology is less than that.

Considering all the factors and our priority of safety and cheap solution it is decided that lithium batteries will be the best choice for our project and meet the demands but if it is way too expensive for our project then we can think about other technologies and provide some safety mechanism for the design.

3.2.3 Solar Charging Control Circuit

As discussed in previous there are different approaches to design charging circuits. From cheap to expensive and from simple to complicated. Since the solar part in our project is not playing a crucial role and we must limit the budget of the overall project. The idea is to provide a solution which is not too complicated and expensive but meet the required demand and make the system reliable as well.

At this stage it is still in the plan to design a circuit by using the maximum power point tracking logic but if it seems to be more time consuming and costly then we may move to a simple three stage charging circuit. Research of designing them still needs to be done and after careful consideration a decision will be made. But the point is to give more money and time constraints to the main control part of the project and use the rest of the budget for providing solar charging solutions for the cart.

It is obvious that the battery will have a circuit that can be used to charge the battery before leaving, and the solar part will accommodate if the customers stay outside for a longer period of time then solar charging will maintain the battery charge and the cooler can be used as a mobile for a longer period of time.

In designing the circuit it will make sure the battery reliability does not compromise and our design does not damage it so it can be used for a long time and users do not need to worry about its replacement at least for a couple of years.

3.2.4 Load and Source Analysis and its Calculations

The total load that we need to run on a battery at a time could include two motors, refrigerator and charging ports. Since the actual parts are not decided yet the following part will discuss the proper selection of battery and solar panel on the bases of 100-watt load. If the actual design needed more power, then calculations will be done again for proper selection of battery and as well as solar panel.

Since batteries are expensive and right now for the prototype we decided to use what we already have. We have two 12 volt 9 amp-hr batteries. And if we connect them in parallel then they should be good for at least 2 hrs. If we need more time duration or available batteries do not meet the requirements then the plan is to buy two 12 volt 16 amp-hr. And in theoretical calculations, it shows a duration time of 3 hours for the output current of 10 amp.

Actual duration and rating may be changed based on battery data sheet and other constraints. For example, the battery won't need to give output current of 10 amp all the time, we only draw maximum current when the cooler is moving and we also need a refrigerator for cooling, we will also have a solar charging circuit which will charge the battery and power will be available to use.

The available lead-acid battery is designed to have a high power density composed of lead and calcium tin alloy grid. Some major advantages of this battery is that it is capable of operating in a wide temperature range and maintaining high performance in sudden temperature change conditions. Additionally, it has a characteristic low self discharge rate, which can help the battery have a longer service life. This is a rechargeable battery that can be mounted in any position and has a built-in resist shock and vibration. Nevertheless, it has a deep discharge rate so it should not be discharged past roughly 50%; otherwise, negative impacts could happen to the battery lifespan. The lifespan of most of the lead-acid batteries is relatively short, which is not an efficient solution to the devices that are used frequently.

On the other hand, Lithium Ion Phosphate battery is considered as another battery option that is more efficient and has a higher efficiency percentage compared to the lead-acid-type battery. This battery can be fully discharged without risk and loss of further capacity. It has a significant flat discharge curve which means the battery can sustain power to the end of the cycle . Lithium batteries also have a longer lifespan than the lead-acid type. While this lithium-based type seems to be the better choice, we would use the available battery to perform testing to save cost and decide whether it is necessary to buy another type of battery after that.

The available batteries are lead acid but if we decide to buy them then they will be lithium ion technology.

(table 9)

Parameter	Value
Technology	Lead Acid

Voltage	12V
Ratings	9 Amp-hr
Quantity	2
Cost	29.99$

(table 10)

Parameter	Value
Technology	Lithium Ion Phosphate
Voltage	12V, nominal 12.8V
Nominal Capacity	16 Ah @ 0.2C
Energy	204.8 Wh
Internal Resistance	70 < mΩ
Charge Voltage	16.6 ± 0.2V
Charge Current	10A - 40A
Max Continuous Current	42A
Discharge Current	42A
Discharge cut-off voltage	10V
Dimension (L x W x H)	151 x 99 x 94 mm
Weight	1.8 kg
Charge Temperature	0°C to 45°C @ 60 ± 25% Relative Humidity
Discharge Temperature	-20°C to 60°C @ 60 ± 25% Relative Humidity
Ratings	16 Amp-hr
Quantity	2
Cost	59.99$

3.2.5 Micro Controllers

Multiple microcontrollers will be needed for this project. To make the best choices for each use case, certain parameters will be researched. The parameters of most importance are the supply voltage, power consumption, the list of peripherals / features, how it's programmed, clock speed, and price.

3.2.5.1 MSP 430 G2553

(table 11)

Parameter	Value
Supply Voltage	3.3v
Power Consumption	5 milliWatts (active) @ 1MHz 1.1 microWatts (standby)
Clock Speed	Up to 16 MHz
MSP430G2553IPW28 cost	$3.25

The MSP 430 G2553 includes the following features: 5 power saving modes, two 16-bit timers with three capture/compare registers, 24 I/O pins, a Universal Serial Communication Interface, an on-chip comparator for analog comparisons, a 10-bit analog to digital converter, and 3 different clocks with varying frequencies. This microcontroller uses a 16-bit RISC architecture which is programmed using the C or C++ language in a development environment named code composer studio. The peripherals are controlled by manipulating and reading certain registers within the microcontroller. While the programming may not be as straightforward as some other microcontrollers, it does allow for complete control over the resources available, making it possible for total utilization.

3.2.5.2 ATMEGA328-P

(table 12)

Parameter	Value
Supply Voltage	2.7 to 5.5v
Power Consumption	4.5 milliWatts (active) @ 3v & 4 MHz 3 microWatts (standby) @ 3v
Clock Speed	0 to 8MHz at 2.7 to 5.5v 0 to 16MHz at 4.5 to 5.5v

ATMEGA328P-15MZ cost	$4.50

The ATMEGA328-P includes the following features: two 8-bit Timer / Counters with separate prescaler and compare mode, one 16-bit Timer / Counter with separate prescaler, compare mode, and capture mode, a Real time counter with a separate oscillator, six PWM channels, an 8-channel 10-bit analog to digital converter in the TQFP and QFN/MLF package, a programmable serial USART, SPI interface, I2C interface, and an analog comparator. This microcontroller uses an 8-bit RISC architecture which can be programmed in C / C++ using a development environment named Atmel Studio, however it can also be programmed using the much easier to use Arduino IDE. Arduino sketches can even be used in the Atmel Studio IDE as well. This is preferable to the TI microcontroller because it allows for the ability to gain full utilization of the resources when necessary and the ability to program high level functions without the need for such laborious programming when full utilization is not necessary. There is a concern with using this microcontroller. The ADC provided for the microcontroller is only available in certain packages. As of now, we have not been able to actually find these certain packages in stock. This is a concern because the ADC will be necessary for this project in order to sense the user input.

3.2.5.3 ATMEGA48PB-AU

(table 13)

Parameter	Value
Supply Voltage	1.8 to 5.5v
Power Consumption	0.63 milliwatts (active) @ 1.8v & 1 MHz 0.414 microwatts (standby) @ 1.8v
Clock Speed	0 - 4 MHz at 1.8 - 5.5v 0 - 10 MHz at 2.7 - 5.5v 0 - 20 MHz at 4.5 - 5.5v
ATMEGA48PB-AU cost	$1.13

The ATMEGA48PB-AU includes the following features: two 8-bit Timer/Counters (TC) with separate prescaler and compare mode, a 6-bit Timer/Counter with separate prescaler, compare mode, and capture mode, a real Time Counter (RTC) with separate oscillator, six Pulse Width Modulation (PWM) channels, an 8-channel 10-bit Analog-to-Digital converter (ADC) with temperature measurement, an SPI interface, an I2C interface, and an on-chip Analog Comparator (AC). This microcontroller, like the other atmega, uses an 8-bit RISC architecture and can also be programmed using the atmel IDE as well as the Arduino IDE. Also, the ADC is available in the listed package and there are available chips in stock at this time.

3.2.5.4 ATTINY85V-10SHR

(table 14)

Parameter	Value
Supply Voltage	1.8 to 5.5v
Power Consumption	.54 milliwatts (active) @ 1.8v & 1 MHz 0.18 microwatts (standby) @ 1.8v
Clock Speed	0 - 4 MHz at 1.8 - 5.5v 0 - 10 MHz at 2.7 - 5.5v
cost	$1.26

The ATTINY85V-10SHR includes the following features which are necessary for this project: 8 K Bytes of programmable memory, an 8-bit timer/counter with prescaler and two PWM channels, a 10-bit ADC, and six IO lines. This microcontroller has all the peripherals needed for the motor control / user interface subsystem, while also having the least power consumption and smallest physical size. For these reasons, this microcontroller will be used in that part of the project.

3.2.6 Mosfet Driver ICs

To properly power the DC motors, MOSFET transistors will be used to switch the power from the 12-volt source to the motors based on a PWM signal generated from a microcontroller. Because we also want bidirectional control, it is desirable to have an H-bridge MOSFET driver between the MOSFET circuit and the microcontroller. The driver will take inputs from the MCU and based on the voltages received will switch two out of four MOSFETs resulting in the desired direction of the motor. The following sections compare two different MOSFET drivers and finally chooses the best IC for the project.

(table 15)

Part #	IR2104	ISL83204A
Operating Voltage	10 – 20 V	9.5 – 15 V
Output Current(Max)	120 mA	4.1 A
Packages	SOIC, PDIP	SOIC, PDIP
Delay Time	540 ns	140 ns (Max)
Cost	$4.56 x 4	$4.11 x 2

MOSFET Driver Comparison

3.2.6.1 IR2104

This driver is a simple half-bridge design. The half-bridge has some advantages in that they are smaller, and simpler to use. The disadvantage is that two of them are needed for each motor. More careful programming within the microcontroller is necessary to ensure that the two drivers per motor are never supplying current in the same direction, this would cause a catastrophic failure. As can be seen in the figure, the current sourcing capabilities are rather low when compared to the other driver. The delay time is also much longer. This will become an issue as the PWM frequency increases. It can also be seen from the figure that it will cost twice as much to implement this IC.

3.2.6.2 ISL83204A

This driver is a full-bridge driver. The first obvious advantage is that only one of these ICs are needed per motor. The disadvantages are that the internal structure of the IC is much more complicated which can lead to internal problems. It can be seen in the figure that this driver can supply a much higher current than the other one. The propagation delay time is also much less, which will allow us to use a higher frequency PWM if necessary. The last benefit for this IC is that it will cost half as much to use.

For the above reasons, we have chosen to go with the ISL83204A full-bridge MOSFET driver for this project.

3.2.7 MOSFETs

The MOSFET transistors are used to send the high current needed to power the motors without damaging the surrounding integrated circuits. The most important aspects for our project related to the MOSFET transistors are the maximum operating voltage, maximum operating current and internal resistance. While the maximum voltage and current ratings are obvious necessary parameters, the internal resistance is also needed because the higher that value is, the more voltage will be generated within the transistor as well as more heat. Because we need high current to power the DC motors, this heat generation will lead to major issues if the internal resistance of the MOSFETs is too high.

(table 16)

Part #	IRFP048NPbF	IPB50N10S3L-16
Operating Voltage(Max)	55 V	100 V
Operating Current(Max)	64 A	50 A
Internal Resistance	16 mOhm	15.4 mOhm
Cost	$ 0.65	$ 0.75

MOSFET Comparison

3.2.7.1 IRFP048NPbF

It can be seen in the figure that this transistor is able to handle the voltage and current necessary to power the DC motors for this project. While the max voltage is about half of the other choice, for our system the most voltage that will be applied is 12 volt, so the maximum current being higher is an advantage. The disadvantage of this choice is the higher internal resistance.

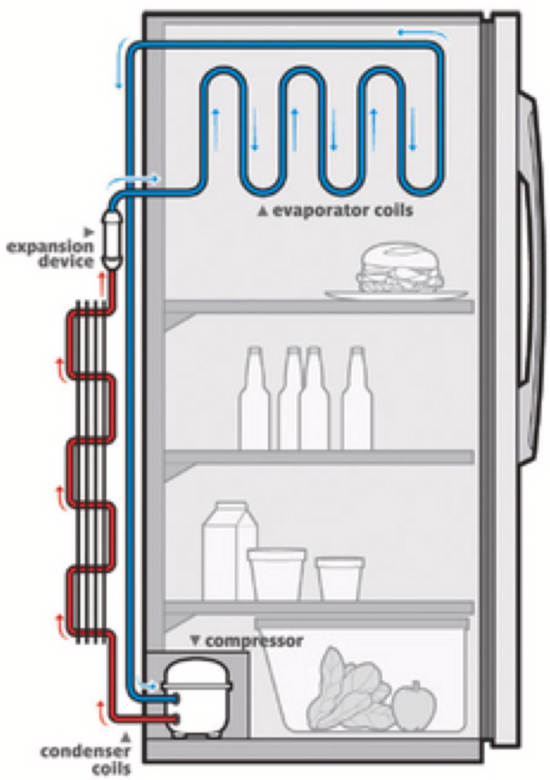
3.2.7.2 IPB50N10S3L-16

This MOSFET has a higher maximum voltage but a lower maximum current. Because our motors are 12-volt, the current draw will be higher, although 50 Amps should be plenty. The biggest advantage in this choice is the lower internal resistance. While only being 1 mOhm less, this can possibly make a difference as the current rises.

While there are better MOSFET choices out there, with the supply shortage in the market now, we believe these to be the best available choices. Given the information above, we have chosen to go with the transistor because it offers a higher current rating and is slightly cheaper.

3.2.8 Choosing the correct Refrigeration Method

So after looking at the four current standards we can see that the evaporation cooling method is not suitable for us in our higher than average humidity here in Florida, which leaves us with the other three methods, mechanical compression, absorption, and thermoelectric, for our design. We will be taking a closer look into each of these techniques to see which ones best suits our needs.



Mechanical Compression, as stated above, is the most widely used of the remaining three methods of cooling. But this method is also most commonly used in a more stationary setting such as air conditioning units and home refrigeration units. Mechanical compression relies on four stages to make it work, which makes it a bulky design.

From the figure on the left, we can see a more visual detail of the four stages that are required for cooling a refrigeration unit in most homes around the world. At the bottom of the figure, we see that a compressor is being used. There are three types of compressors that are most commonly associated with these types of designs, centrifugal, reciprocating and rotary. Which is connected to condenser coils which are placed in the back of the unit. From there, the expansion device or "valve" converts the liquid to vapors. And finally the evaporator coils produce the cooling feature to the machine.

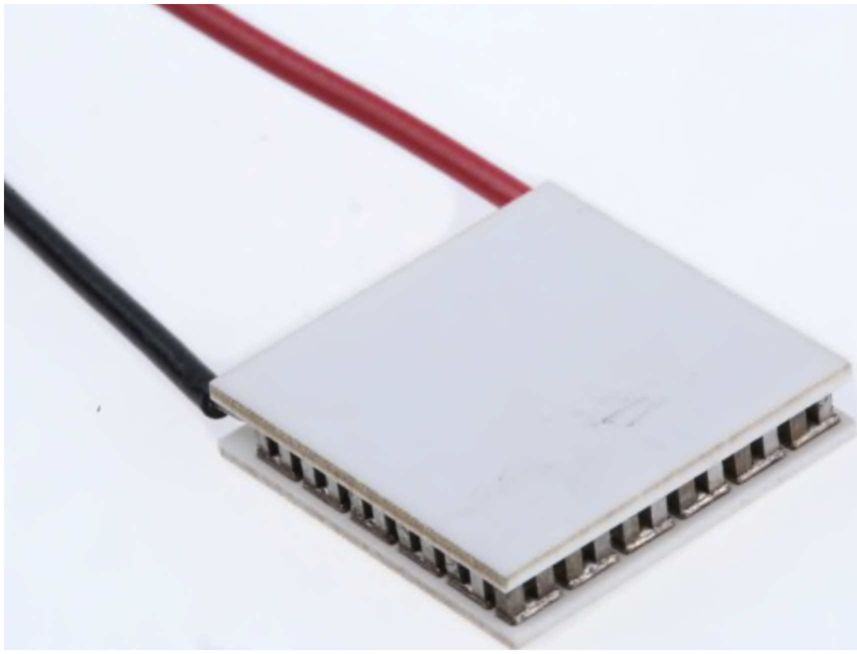
But these four components would not be as effective as they are without the use of refrigerants. The most commonly used refrigerants used in this capacity are chemically composed of Chlorofluorocarbons (CFCs), Hydrochlorofluorocarbons (HCFCs) and Hydrofluorocarbons(HFCs). All of these are categorized in two areas, their Ozone Depletion Potential (ODP) and Global Warming Potential (GWP).

There are many comparable designs out on the market that utilize this method but none of them have it attached to a motor assisted device to make it easy to transport from your car to your destination. We took that into consideration when deciding to use this version but since we did not want to increase the load of our motor assisted support on the cooling system but rather on the amount of items we wanted chilled as well as the environmental impact with the chemical refrigerants, we have determined this method was not going to be used.

This leads us into our next cooling method, absorption. Unlike mechanical compression, there are no moving parts other than the liquid components of the systems. This liquid is moved around by rapidly boiling a refrigerant from liquid form to gas which is then cooled back into its liquid form to repeat the cycle. This process of cooling the gas to liquid is what makes the absorption method work. But much like mechanical compression systems, it uses ammonia and water as the refrigerant rather than the chemicals stated above. Although ammonia is not as harmful to the environment as the other refrigerants since it is a naturally occurring chemical found in almost every living entity, it is still corrosive. High concentrations of it to humans can cause damage to your eyes, nose, throat and lungs and can even lead to death. This factor along with its bulky design we can conclude that this method will not be used.

Which brings us to our final method, thermoelectric cooling. This process, unlike the two mentioned, does not have any moving parts at all. Instead of moving any form of liquids around, it uses an electric current to cool the targeted area. This is done by having dissimilar semiconductors in a circuit that has an attached battery that is connected to a piece of copper wire and a bismuth wire. The junction where the current passes through the copper to bismuth, a heat rise occurs while at the junction of the bismuth to copper, a temperature drop happens. This process is known as the “Peltier effect” which was discovered in 1834 by French physicist Jean-Charles-Athanase Peltier. Along with the discovery made in 1821 by German physicist, Thomas Johann Seebeck, known as the Seebeck effect, which is used to measure temperature and generate electricity, to create thermoelectricity.

Modern Peltier devices are built using semiconductors that have alternating P and N types that are arranged in a matrix which are sandwiched between thermal conductive plates which are usually made from ceramic like the figure below.



(Figure 21)

(table 16)

Parameter	Value
Voltage	12V
Dimensions	40mm x 40mm x 3.2mm
Cost per panel	$7.00 - $12.00

This Peltier device alone is not an efficient design since the hot side of the unit gets extremely hot in a short time and will cause damage to the entire instrument. Because of this a heat sink is necessary to dissipate the heat to use this device for long periods of time which we will be able to add to our design like the one below.

(Figure 22)

(Table 17)

Parameter	Value
Dimensions	varies
Cost	Depends on dimensions

Due to its portability, environmental impact and cost effectiveness, this method was chosen to incorporate into our design.

After some research on Peltier devices, we came across products that incorporated a Peltier device, a heatsink and added a fan to cool an empty space. With this discovery, we have decided to investigate more of these types of designs and implement them into our own project.

3.2.9 Thermoelectric Peltier Refrigeration Cooling Systems

After some research of Peltier Cooling applications, we have found there exists products on the market today that use Peltier tiles in conjunction with a heatsink and fan to cool the target area more effectively and efficiently. The following are some of the systems that we have looked into and their specifications.

3.2.9.1 The Wavefront Semiconductor Refrigeration Device

(Figure 23)

(table 18)

Parameter	Value
Voltage	12V
Current	6A
Dimensions	175mm x 100mm x 98 mm
Cost	$48.99

During testing of this device, it got a 300mm x 200mm x 250mm cooler to reach 19 degrees cooler than the ambient temperature in 10 minutes. So in a short amount of time, we can get the contents of our cooler to a relatively lower temperature within a matter of minutes. If we left this unit on the way to the beach, all the drinks and food items should be at a cool temperature in the hot sun.

3.2.9.2 Esumic Thermoelectric Peltier Cooling System

(Figure 24)

(Table 19)

Parameter	Value
Voltage	12V
Current	4A
Dimensions	120mm x 100mm x 80 mm
Cost	$23.99

This device states that the maximum cooling space is 10 liters which is roughly 300mm x 180mm x 200mm volume. While we still need to do more research into what dimensions that our cooler will be, this model is certainly in the running for our final design plans. Just like the previous unit, it requires only 12 volts but only needs 4 amps instead of 6, which moves this up our list.

3.2.9.3 The Partgry-T DIY Thermoelectric Peltier Refrigeration Cooling System

(Figure 25)

(table 20)

Parameter	Value
Voltage	12V
Current	12A
Dimensions	100mm x 100mm x 40 mm
Cost	$47.89

This device uses two units attached to each other which is like the first one we looked at but also needs twice the amount of current. While this unit might be able to double our cooling potential it all needs more current to do so. At this point in time, we are unsure of what battery we might need to operate all our design features and might not be able to use this model due to the current it needs but will still be considered if we have enough power to run this or the alternative would be to add a additional battery to help with the cooling.

3.2.10 AC Battery Charger Selection

To provide an alternate power source to charge the two batteries as the main power supplies, we choose the AC source to back up for the solar panels when there is not enough sunlight.

The AC battery charger will be plugged into any AC socket range from 120V to 240V and connected to the batteries. The battery charger/maintainer is considered the NOCO GENIUS1, 1-Amp fully automatic smart charger designed for 6V and 12V lead-acid and lithium-based batteries. There are four different modes to charge different types of batteries and force mode to manually control and charge the dead batteries. An integrated thermal sensor can detect the ambient temperature and alter the charge to prevent overcharging and undercharging in hot or cold climates. The charger also comes with the battery clamps and integrated eyelets to hook up to the batteries.

(Figure 26)

The size of the battery in Ah and depth of discharge has a great impact on the charging time. The regular discharged battery can be charged in the time duration associated with 50% of dept of discharge. Moreover, since the temperature can affect the charging time, the charger is equipped with the thermal compensation feature to adjust the charging profiles. The estimated time to charge a battery based on its capacity is shown in figure below:

Battery Size Ah	Approx. Time to Charge In Hours 6V	12V
8	6.0	6.0
12	9.0	9.0
18	13.5	12.0
24	18.0	18.0
30	22.5	22.5

(Figure 27)

The technical specification of this battery charger is shown in table below:

(table 20)

Features	Parameter
Input Voltage AC	120-240 VAC, 50-60 Hz
Output Power	15W max
Charging Current	1A (12V), 1A (6V)
Low-Voltage Detection	1A (12V), 1A (6V)
Back Current Drain	< 5mA
Ambient Temperature	-20°C to +40°C
Dimension	3.5 x 2.3 x 1.3 inches
Weight	0.77 Pounds
Battery compatible	Lead-acid and Lithium batteries

3.2.11 Solar Panel Selection

The selection of panels is a critical task. We do not want a bigger size but at the same time need enough power to charge the battery. The overall rated capacity of batteries is 18 amp-h, when connected in parallel.

(table 21)

Parameter	Value
Battery Size in Amp Hours	18 Amp-hrs
Recharge Time in Hours	6 hrs
Charge Current	3 Amp
Maximum System Current	10 Amp
Total Current Required	13 Amp
Panel Size	130 Watt

It is assumed the following size of panel will be good for our battery. But one of the main constraints in our project is the dimensions of the panel. If we could not find a panel of 1 by 2 feet of the same size we may reduce the size of the panel and compromise on charging time of the system.

We have considered the 130W 12V monocrystalline solar panel from the brand Eco-Worthy to use in our project. This panel is able to satisfy all of the requirements for power usage and its cost is relatively low among those of the same type.

The table below has shown the technical specifications of the chosen solar panel:

(table 22)

Parameter	Value
Solar Panel Rated Power	12V, 130W
Maximum Current	6.48 A
Open Circuit Voltage (Voc)	23.36 V
Short Circuit Current (Isc)	6.84 A
Maximum System Voltage	1000 V
Operating Temperature	-40° C ~ + 70 ° C
Cable Length	900 mm
Weight	4.62 lbs

Dimension	40.55 "x 27.16" x 0.15 "
Price	$119.94
Technology	Eco monocrystalline

3.2.12 Solar Charger

We are planning to build a more efficient charging circuit for our solar system and the first approach is to design on the basis of maximum power point tracking.

Since the maximum power point tracking approach will be implemented. The design will include a buck boost converter. The voltage coming from the solar panel will be adjusted using buck boost so the battery gets appropriate voltages for charging to avoid any damages incase of high voltage. And it will be capable of providing enough voltage to the battery to charge when the sky is not clear or intensity of light is less.

Other than this charge circuit a 16*2 LCD will be used to display battery voltage and outgoing current. To avoid overcharge protection, battery state will also be monitored and it will disconnect the solar panel from the battery when it is fully charged and reconnect it when voltages are low.

It is also in a plan to read the outgoing voltage and current and disconnect the load from battery source incase of overloading and battery draw more current than normal range to avoid any kind of damage.

Two microcontrollers will be used, one for the switching of buck boost converter while the other one is for protection and display circuit.

3.2.13 Temperature Gauge and Control

We have now established a way of cooling down our cooler but should the Peltier device be running the whole time? There are many disadvantages of having this mechanism running the whole time, such as overheating the unit and draining the power source, in our case a 12 volt battery. So the way we are going to be able to control this is by way of a relay mechanism. The approach that we are taking is by using a thermostat to set a certain temperature inside of our cooler. This helps us in two ways instantaneously, the first being the ability to control the temperature inside the cooler and secondly, to see what the actual temperature is inside!

3.2.14 Thermostat Options

There are many different ways to measure temperature. For instance, when your mother is checking to see if you have a fever, she would use the back of her hand to check for a relatively higher than normal body temperature and then move on to a thermometer that went under your tongue. Another more accurate way is to use a probe to check the internal temperature of different types of proteins to make sure it is safe throughout even the thickest part of it to prevent food poisoning. For our project, we will be looking at a variety of thermometers and the specifications that are suitable for our design goals.

Large Dial Thermometer

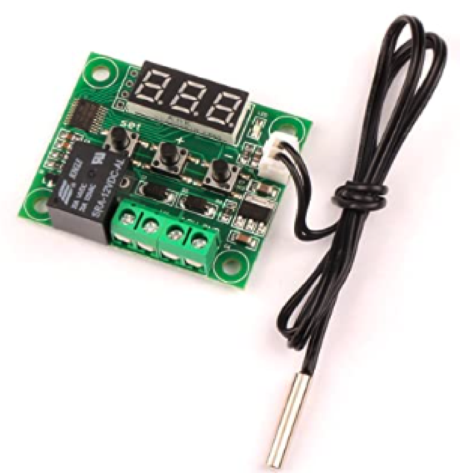
(Figure 28)

(table 22)

Parameter	Value
Temperature Range	-20 to 80 degrees F
Material	Stainless steel
Power-Supply	n/a
Cost	$9.99

This is a very basic thermometer that measures the temperature of wherever the unit is inside, such as inside a freezer or industrial refrigerator. It is made from stainless steel which means that if kept in condition, it could possibly last a very long time. Another thing that makes these little gadgets great is the fact that it does not need any power source for it to work which makes this very appealing. Unfortunately, for our design, we envisioned a way to see the internal temperature without having to look inside of the cooler itself which this particular device needs to stay to accurately gauge the temperature. Furthermore, the display for our temperature reader was imagined to be on the side or on top of our cooler for easier visibility to check if everything inside is okay. In addition to the visibility, we also wanted a way to be able to turn off our cooling device when the internal temperature of our cooler reached a certain value which makes this type of thermostat unusable but was considered in our early design phase to keep energy usage to a minimum.

RioRand Digital Thermostat



(Figure 29)

(table 23)

Parameter	Value
Temperature Range	-58 to 230 degrees F
Power-Supply	12V DC
Weight	.35 oz.
Cost	$9.99

This particular thermometer is vastly superior to the large dial mentioned above. Instead of a rotating dial to tell the temperature, it uses a digital LED panel to do so for clearer visibility without the need of another light source. In addition to the improved LED screen, this thermostat has a built-in relay which we are able to set the temperature which allows it to turn on or off our cooling system if the correct temperature has been reached. Also unlike the dial thermometer, which gauged the temperature by being inside the cooler, this model has a temperature sensor lead which means we are able to attach the panel to the outer part of our cooler. The only downside of this thermostat appears that it actually measures the temperature in Celsius rather than Fahrenheit which is a unit of measure used the majority of the time here in the United States. While this isn't an issue for users with knowledge of the difference it might be too confusing for most, which brings us to our next thermostat.

Inkbird ITC-1000

The thermostat to be used for our cooling system must be able to be mounted on the outer surface of the cooler itself. For our design, we would like to mount this device on top of the cooler for ease of access and visibility for the user. Another aspect of the thermostat is the ability to turn the cooling device on and off as if our refrigeration system is sealed correctly, we will not have to rely on the device running continuously and drain the battery faster than expected. For the above two reasons, we have selected the Inkbird ITC-1000 (12V).

(Figure 30)

(table 24)

Parameter	Value
Temperature Range	-50 to 210 degrees F
Power-Supply	12V DC
Cost	$13.99

Just like the RioRand above, the Inkbird comes with a temperature probe as well as an LED screen for monitoring the contents of our cooler as well as a relay to automatically shut off the power to our cooling device. It also is a lot more user friendly than the previous one with four easy to push buttons as well as displaying the temperature in Fahrenheit. For these reasons, we have chosen this specific thermostat to control our temperature and cooling unit.

3.2.15 The First "Portable Ice Chest"

The first iteration of a cooler was called "The Refrigeratory" and was created by a farmer from Maryland named Thomas Moore in 1802. The outer shell was was constructed from cedar wood with a tin rectangular box residing inside, with rabbit fur lining the sides of the box to keep things cool. Fast forward to 1944 during World War II, a chemical company called Dow Chemical was looking for a way more cost efficient alternative to rubber to help the war effort where an engineer by the name of Ray 'Otis' McIntire invented Styrofoam. This was done by pressurized polystyrene, a chemical with great durability and insulation properties. The material it is made from has over a billion little air pockets making it a great insulator and very light in the process. This invention is so great, it is still used today. Move ahead 12 years to 1953 where Richard C. Laramy filed a patent for the "Portable Ice Chest and the Like". This patent was sold in 1957 to the Coleman Company, who then changed the patent name to cooler. The original models for the cooler were made from steel which consumers found too heavy to carry around which they later changed to plastic which made them increasingly popular and now a very well known brand.

3.2.16 The Cooler Options

In today's market, there are literally hundreds of different types of coolers available for consumers. They come in all different shapes and sizes, from plastic to metal outer shells, but all with some type of insulation to keep the contents of the cooler nice and cold. Below we will compare and contrast some of these options and see which one is right for us in our design.

Coleman Reunion Steel Belted Cooler

(Figure 31)

(table 25)

Parameter	Value
Capacity	54 quarts
Weight	18 pounds
Exterior Dimensions	26 x 17 x 17 inches
Interior Dimensions	25 x 16 x 16 inches
Cost	$199.99

As the forefather of modern day coolers, we can see that Coleman has stood the test of time and is still relatively popular to this day. The model we have on display has a stainless steel exterior while its interior consists of plastic as its insulation. This particular model comes with a latching mechanism to lock and unlock the lid which is connected by one long hinge. A bonus feature of this cooler is the attached bottle opener for more adult libations. Upon further inspection of what our design for our cooler should be, this sleek design played a role for aesthetic purposes but when it came to the necessary modifications that needed to be implemented is where it fails. Due to the stainless steel exterior and the tools that might be required to attach a thermostat on it as well as the price point of this cooler, this model might not be used but still in consideration.

Tundra 45 Hard Cooler

(Figure 32)

(table 26)

Parameter	Value
Capacity	45 quarts
Weight	23 pounds
Exterior Dimensions	16 ⅛" x 15 ⅜" x 25 ¾"
Interior Dimensions	9 ⅜" x 10 ⅝" x 18 ⅜"
Cost	$299.99

And here we see the top tier model of a cooler in the Yeti Tundra. From the advancements of technology, scientists have come up with a new way of molding plastic known as rotational molding or rotomolding for short. This process involves high-temperature, low pressure plastic forming process that uses heat and biaxial rotation to produce hollow, one-piece parts in most Yeti brand coolers. Whereas some cheaper coolers use the same old plastics from years gone by, Yeti coolers use the rotomolding in conjunction with the polyurethane foam insulation to keep its contents cooler for way longer than the older coolers. As you can also see the interior dimensions for the Yeti cooler is significantly smaller than the other two mentioned here, which means that there is that much more of the insulating foam in them which results in longer cold temperature retention. So why don't we use this cooler? Well out of the three this is by far the most expensive option. Upon further investigation as well, our plan is to put in most of our required materials such as our batteries and wiring inside the cooler not to mention our cooling device as well but with such a small interior, it does not seem feasible for us to go in this direction.

Igloo Marine Ultra Cooler

(Figure 33)

(table 27)

Parameter	Value
Capacity	48 quarts
Weight	8.8 pounds
Exterior Dimensions	26.08” x 14.63” x 14.5”
Interior Dimensions	21.25” x 11.5” x 11.25”
Cost	$47.99

Last but not least, we have the Igloo Marine Ultra cooler. This particular version resembles the coolers of yesterday with some few upgrades. This cooler has UV shields to keep it safe from the sun to not warp the plastic and create discoloration. Out of the three, we can clearly see that this cooler is the lightest of them all as well as the cheapest which is a huge plus. It is also the easiest to modify for what we need such as attaching the thermostat on either the lid or side for constant temperature monitoring. The factor of the weight is also important due to the maximum pushing and pulling capacity of our motors as we do not want to burn them out. All in all this is probably the cooler our group will be choosing for our project design.

3.2.17 The Base

Now that we have completed our refrigeration systems, how will we transport our unit full of our cold refreshments? For our project design, our aim was to allow the user to push and pull our cooler with little force to move it around. For this concept, we needed a rugged cart to be able to move across many different terrains such as concrete, grass, sand etc. We will go over some carts that meet these criteria

Kintness Garden Utility Cart

(Figure 34)

(table 28)

Parameter	Value
Weight	32 pounds
Dimensions	37” x 20.8” x 8”
Towing Capacity	570 pounds
Cost	$89.99

From our choices of coolers from the previous section, we see that we need at least 26 inches of space to place it on top of. The Kintness cart offers more than enough room for any of our cooler selections. It comes in at 32 pounds and can tow up to 570 pounds by the handle attached to the front wheels. The handle itself is covered by a soft mesh material for an easier grip as well as a 180 degree turning radius for easy maneuverability. This specific cart also offers a dump feature that we do not need and will have to disable for our purposes.

Gorilla Carts GOR400-COM

(Figure 35)

(table 29)

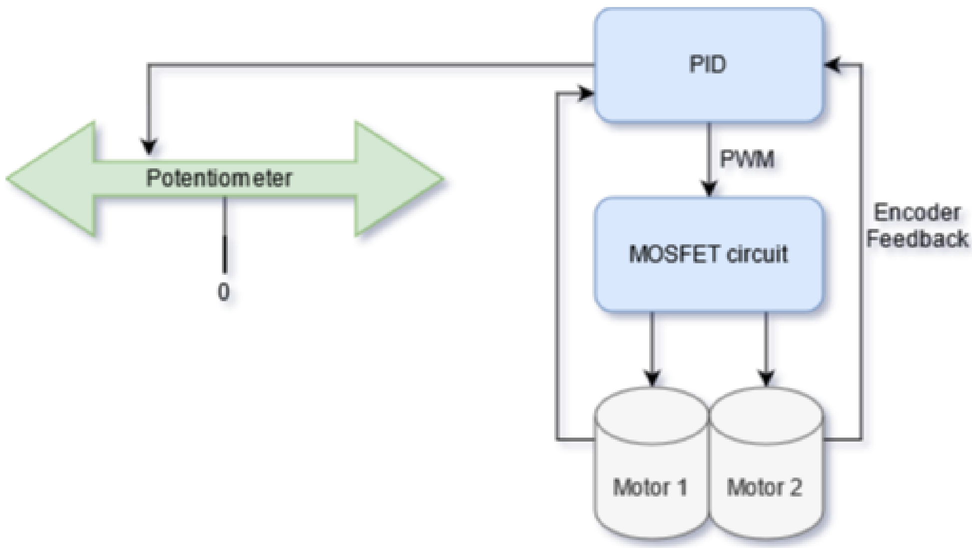
Parameter	Value
Weight	37 pounds
Dimensions	41 x 19 x 37 inches
Towing Capacity	400 pounds
Cost	$104.99

This handcart comes with a paddled handle for a better grip for the user and has a turning radius of 180 degrees for excellent mobility. The frame itself is made from steel and the wheels are 10 inch pneumatic tires made from rubber.

3.3 Possible Architectures and Related Diagrams

Before deciding on a final design, it is helpful to create a few different possible designs in order to compare their different pros and cons. It can also be useful if some of the components that are chosen can not be obtained or do not perform as intended. In the following section, different design options are explored.

One of the most crucial components in this design is the user input sensing. This user input can be implemented in many ways but for our project scope, we are prepared to design two systems.



(figure 36. Possible Design)

The first, and current expected design, is the use of a potentiometer and simple handle mechanism. The potentiometer output voltage will change as the user applies pressure to the handle. A lateral sliding potentiometer will be used. This component is a standard component and as such is not included in the components research section. A PID controller will be implemented in a microcontroller which will provide a PWM signal to a MOSFET driver to move the cart to keep that potentiometer centered on the base of the handle. In this way, the user will only have to apply enough pressure to slide the potentiometer and the control system will do the heavy lifting.

The second possible design to solve the motor control problem is a simple throttle attached to the handle. This can be implemented with a potentiometer as well. The designs are similar, in theory but implemented in very different ways.

3.4 Parts Selection Summary

The following table is a list of the selected major components for the project. The decisions were made based on the research completed in previous sections.

(table 30)

Item	Part #	Manufacturer	Cost
DC Motor	638280	ActoBotics	$59.99 x 2
Battery	LFP16AH	Miady	$59.99
Microcontroller	ATTINY85V-10SHR	Microchip	$1.26
MOSFET Driver	ISL83204A	Renesas	$4.11 x 2
MOSFET	IRFP048NPbF	Infinion	$0.65 x 8
Refrigeration Module	Tec1-12706	Esumic	$23.99
Refrigeration Control	ITC-1000	InkBird	$13.99
Solar Panel	L02AM130W18V-1	ECO-Worthy	$119.94

4. Realistic Design Constraints and Related Standards

When designing a solution for any problem statement, constraints need to be observed and defined to ensure that the design solves the problem. In the engineering profession, industry standards are also observed to ensure that your product will be accepted into the market and will be able to perform as well as other products in the market. In the following sections, we will define the constraints and standards as they apply to our design. Finally, their effects on the design will be explained.

4.1 Constraints

The constraints of a system are the limitations imposed on the design. There are many factors that cause design constraints, some coming from the world in which the design is meant to function, while others come from the design itself. In the following section, we will mention the realistic design constraints that we are aware of and the impact they will have.

4.1.1 Environmental, Social, and Political Constraints

Because our project is meant to work outside in a rugged environment, the constraints applied by that environment will have a major effect on the success of the design. According to the original requirements, the motor-assisted solar charging cooler will have to operate in harsh, soft sand and dirt trails. It must also operate in extreme heat. These constraints mean that the wheels of the cooler must have a certain amount of traction, the electronics must be sufficiently insulated from the heat, and the electric motors must be properly sealed to protect against dirt and sand. This also means that the internal components must be well secured to the structure to avoid breakage due to rough terrain and the handle-sensor mechanism must be similarly secured.

There seem to be no social or political constraints applied to our design.

4.1.2 Economic and Time Constraints

Everything has a cost associated with it. Unfortunately for us, we are amidst a pandemic which mankind has never seen. The world is slowly getting back to where it was before this catastrophe but not soon enough. During the past year, many supply chains have been severed due to either the lack of import and export goods, halted production lines, loss of labor and the list goes on and on. What this means for our group is that everything is more expensive than it was before which does not bode well for us. On top of the pandemic, we are taking Senior Design during the summer semester which currently doesn't allow us to see some sponsored projects that provide funding from local businesses and engineering firms. This means that this project will be entirely funded out of pocket from our team.

With that being said, striking the balance between cost and quality has been very important to us. We have set a budget of $1000 to try and complete our project. To try and not incur any additional costs, we will be using some materials that we have around in our prospective domiciles as well as research many different types of components that will help us in our endeavor.

As stated before, everything has a cost and there is none higher than that of time. From the beginning of Senior Design I until early December in Senior Design II, our team has been on a clock to design and develop a working Motor-assisted Cooler. Time is something no one was extra of and our team of college seniors is no different. From our different class schedules, to part time jobs we have, allocating enough time to successfully deliver a working project is quite possibly our greatest hurdle.

To help in overcoming this constraint, as a team, we will make a very regimented schedule to meet requirements related to our project in a timely manner to ensure the completion of our project. The scope of our project is pretty wide but we are ready and confident to finish our college careers this fall.

4.1.3 Ethical, Health and Safety Constraints

It is important to perform testing and evaluate the accuracy of each device before incorporating them into a whole. Since we will order the parts from different online suppliers, some of the components will not be able to work perfectly. If there is any part that cannot satisfy the safety requirements, we will replace them with a better solution.

Battery and solar panels are the crucial power to our project. However, they also contain a lot of toxic chemicals that can be harmful if we do not handle them with care. In our project, the chosen batteries will be stored in the recommended environment to prevent any potential chemical leaks. The contact points of the battery will be insulated when they are not in use so as to avoid any risk of electrocution. Similarly, when we do not use the solar panels, they will be covered and stored in the no-light room to block them from the sunlight. The sun energy can generate electricity to the panels and can cause injuries because of electric shock and arc-flash. Furthermore, as our project involves soldering and assembling electronics components on the PCBs, there are several safety guides that need to be followed closely to prevent serious health risks. The hot gun and soldering station have extremely hot elements when operating so we have to be careful not to get burned while using them. Moreover, exposure to lead and solder flux may cause eye and throat irritation, headaches and skin sensitization. If directly soldering the components, we should be wearing gloves to protect our skin.

4.1.4 Manufacturability and Sustainability Constraints

Just like our economic and time constraints, our manufacturability constraint is also affected by the Covid-19 pandemic. More specifically to the availability of certain components that our project requires might be harder to come by during these unprecedented times. This will be something that we will take into consideration when picking parts such as microcontrollers that are currently available to us in the coming months to be able to effectively produce.

Luckily for us, in today's modern world, 3-D printers are more accessible than ever. One member of our team has a 3-D printer at his disposal and the University of Central Florida gives us access to these amazing machines.

Which brings us to our next constraint, sustainability. In today's world, we are more conscious than ever about reusability and not being so wasteful with our materials that we have. With that being said, our design will depend on a power source in the form of a battery. The two products that are currently viable for our design are either Lithium or lead-acid batteries. Lithium batteries can last from two to three years of use while lead-acid batteries last from three-five years. Since we are integrating solar charging into our design, charging time was also considered during our decision making. While the lifespan of a lead-acid battery is longer, the time to fully charge the battery was its downfall. Lead-acid batteries require up to eight hours to fully charge while Lithium only takes one to two hours.

Another sustainability constraint are the rubber tires that are being used in our design. Our current design uses pneumatic tires which require air inside to be functional at 100% capacity which could hinder the amount of force necessary to operate.

Not only that, our entire model will be exposed to mother nature being that it is a portable cooling system which will degrade overtime weathering all it has to offer from rain to sand and salt.

With all of this taken into account, our aim in this design is to also make it weather-proof to increase the lifespan of our product.

4.2 Related Standards

Almost every product out on the market today is itself regulated by an official standard or has parts that are regulated by an official standard. For our design, we want to investigate the standards related to the battery choice, solar panel charging system, software and system design and finally the testing procedures to ensure that we meet all the criteria needed for a product to join the market.

4.2.1 System, Software, and Hardware Validation Standard

IEEE 1012-2016 - IEEE Standard for System, Software, and Hardware Verification and Validation is a standard that is to verify and validate system, software, and hardware life cycles. This standard is used to determine whether the design is meeting the requirements to ensure that the user's needs are met. The verification process determines whether the product conforms to the requirements, satisfies the standards, practices, and conventions during the life cycle processes, and that each life cycle activity is being completed. The validation process will tell whether the products satisfy the requirements, solve the right problem, and satisfy the user needs in the operational environment.

The first step of the Validation and Verification (V&V) process is the management process. During this time, the V&V plan is created, reviewed, and revised throughout the life cycle of the design process. This process is also where the results of the V&V tasks are reviewed and compared to the established requirements. All changes that are made to the design during the product lifecycle are analyzed for their effects on the requirements during this process.

There are outlines in this standard related to system, software, and hardware processes. For each one of these product types, the V&V process is there to ensure the requirements and user needs are met during the life cycle of the product.

4.2.2 Design Impact of System, Software, and Hardware Validation Standard

For any product in the design process, it is necessary to continuously review the design to ensure that it is still within the original constraints and meeting the original requirements. Without this oversight it is very easy for a product, especially one with a long design cycle, to stay on track. There are many design requirements for this project and many probable changes that will need to be made. For that reason, implementing the processes defined in this standard is very important.

4.2.3 Solar Charging Standard

IEEE 1562-2007 - IEEE Guide for Array and Battery Sizing in Stand-Alone Photovoltaic (PV) Systems. This standard describes choosing the right size for the solar panel and battery in a PV charging system. The systems that are considered in this standard only contain a solar panel for charging and a battery which is being used to store the energy. This standard also considers the controller which keeps the battery from being overcharged or over charged. Systems which employ hybrid charging are not included in the standard. While our design may be charged from AC power or solar, it will only ever be charged by one or the other, so this still applies for us.

This standard provides procedures for sizing of the solar panel array and battery to increase the performance and life of the solar charging system. The sizing of the battery and panels is based on worst-case solar radiation, load consumption, and system loss. The PV panel array is used to replace the amp-hours in the battery which is providing power to the load as well as providing enough power to charge the battery. The battery size is determined to support the load at times of low solar radiation.

To properly size the solar charging system, according to the standard, the load of the system needs to be calculated. This calculation needs to be accurate to avoid under- or over-designing. To size the battery, the amount of time in which the solar radiation is low will need to be calculated. The solar radiation data can be achieved through experimentation as well as sources relating to certain areas at certain times of the year.

4.2.4 Design Impact of Solar Charging Standard

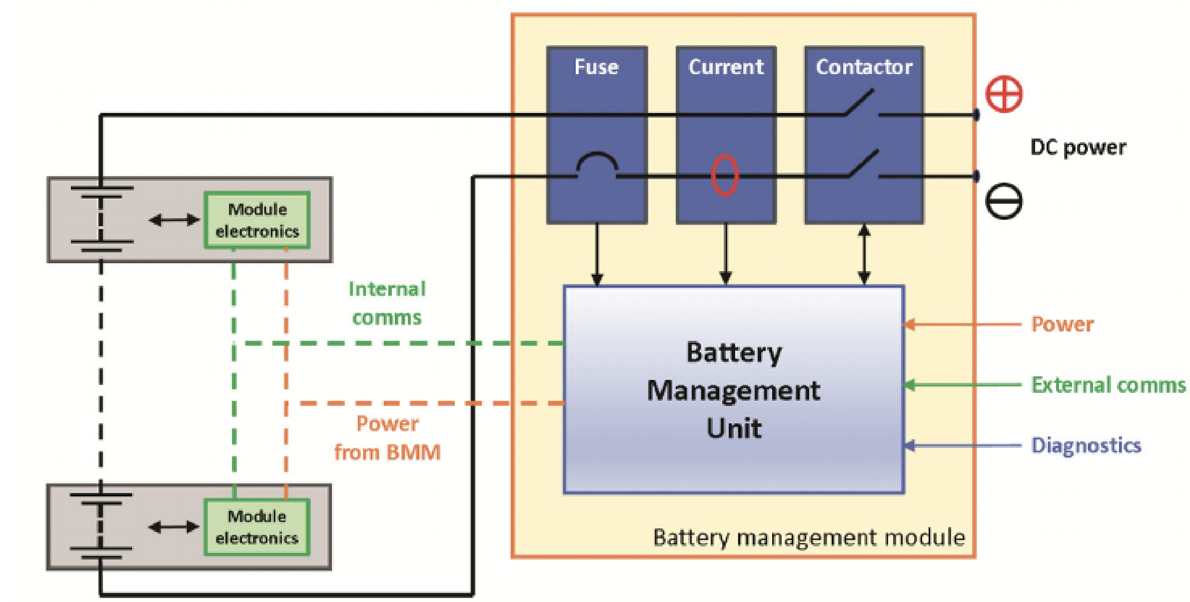
One of the major concerns in the design of this project is the load that will be put on the system. There are two main current draws, the DC motors, and the refrigeration unit. To counteract these high current draws we are implementing a solar charging system. This system is chosen because the main use case of our project is the beach and other sunny outdoor activities. For these reasons it is very important that we choose the correct size of solar panel and battery system to ensure that the requirements are met.

The standard mentioned in the above section will be used to make sure that we have the correct size of panel and battery combination. According to our calculated power consumption of 100W at full performance, the calculated load is 8.3 A. We will use this calculation to choose a battery with at least a 9 Ah capacity to meet the requirement of 1 hour of operation at full consumption. To keep the battery at full charge, the solar panel needs to produce that same amount if not more. At the same time, the maximum size of the panel needs to be around 12” x 24”. For this reason, we have concluded that it will not be possible to keep the battery fully charged. We will conduct tests to determine the maximum range that the battery can provide.

4.2.5 Battery Standard

IEEE Std 1679.1™-2017 which is titled “IEEE Guide for the Characterization and Evaluation of Lithium-Based Batteries in Stationary Applications”, is a standard that provides an objective evaluation of lithium-based energy storage technologies. They discuss several safety features and regulatory issues of the rechargeable lithium battery which are applicable to electric vehicles or some kinds of similar batteries. Lithium-based battery systems are well-known for high-power applications and renewable energy storage. In addition to that, they are suitable for continuous high-rate cycling applications and systems that require thermal controls. However, not all types of lithium-based batteries optimized for an application can be safely reused in different applications.

Charging statistics of the lithium batteries need to be matched for the batteries to operate properly with respect to its cycle life, capacity and safety features. BMS (Battery management system) is used to communicate between the battery system and the charger to ensure the voltage and current match the ones needed for the loads. BMS must be able to monitor and regulate the output values during the entire operational cycle of the batteries. Some common functions of BMS are monitoring voltage/currents of cells and batteries as well as cell temperature and ambient temperature.



(Figure 37)

The guide mentions some typical failures of the batteries that will cause safety risks and system failures as follows:

- Short circuits: could occur due to design failures, assembly error and transportation damage. "Short circuits within a cell can arise due to manufacturing defects or from dendrite formation due to excessive charge rates. Heat from short circuits can lead to thermal runaway" (22). Therefore, most of the batteries need extra protective devices from external shorts.
- Overdischarge: occurs in lithium-based batteries when "a cell voltage falls below a critical minimum, which then allows copper from the negative foil to dissolve into the electrolyte" (22). Extended self-discharge is the main reason that leads to over discharge condition. When overdischarge happens, the battery is quite often unable to

be recharge. Most of the battery management system will have sleep mode as a solution for increasing the storage time.

- Overcharge: Battery cells could be damaged due to exceeding the particular limit of battery charge rate. Rapid aging is a result of charging above the recommended voltages as “more excessive charge rates can cause lithium metal to accumulate in the form of dendrites at the surface of an intercalation negative electrode, potentially causing short circuits” (22).
- Thermal runaway: which is the result of thermal controlled failure, short circuits and electrochemical abuse elevating the internal temperature within the cell. This effect could lead to unstable function of the batteries and even fires occur due to “increasing severity involving breakdown of the electrolyte and then the positive active material” (22).
- Electronics failure: can be expected at cell level and string level of some equipped electronics components. The manufacturer should provide quantity information of failure rates as well as repair time of several potential failure modes.

4.2.6 Design Impact of Battery Standard

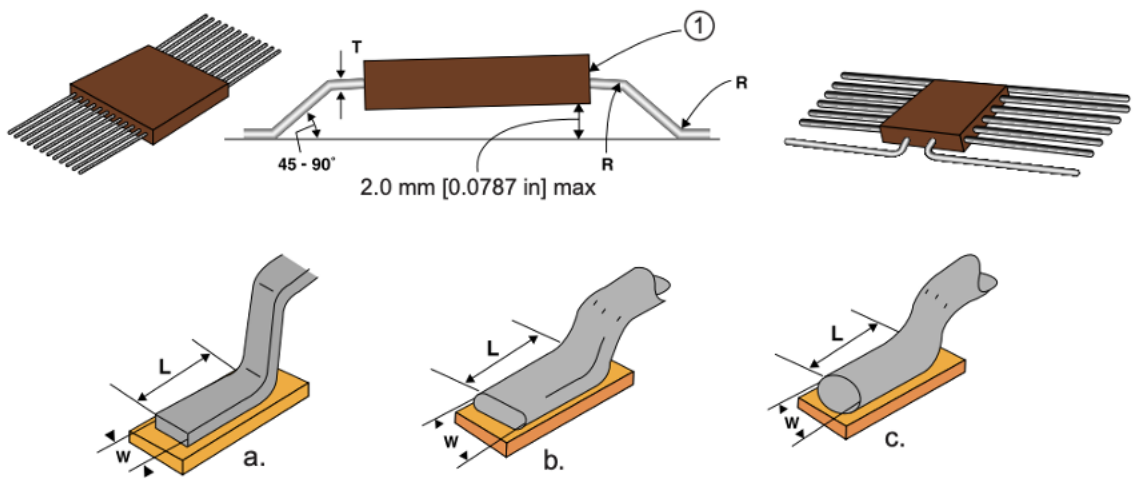
The batteries must strictly follow the specific requirements for safe operation as it is the main power supply for the whole design. We have considered two lithium batteries as the main power source for the whole project including the peltier cooler, temperature monitor, controlling board and motor drivers. The selected batteries have built-in BMS so it can be fully discharged without risk and loss of future capacity as well. On the other hand, we also have two lead acid batteries available for testing purposes and can be used as a supplement to the other lithium ones. The input voltage to the batteries will be monitored by the MPPT charger to ensure over discharge and overcharged effects will not happen. Those batteries will go through a testing process before being connected to power the actual devices. Besides, the batteries would be stored in a dry environment to maintain optimal conditions and prevent fire due to extreme temperature.

4.2.7 Soldering Standard

IPC is a worldwide association that helps publish the source of industry standards involving requirements for electronic equipment and assemblies as well as training intelligence and public policy advocacy. IPC devotes resources to improving technology enhancement programs and is accredited by the American National Standards Institute (ANSI). EIA was formed by individual organizations engaged in the manufacture of electronics-related products, in order to agree on a certain data transmission standard. The association is also accredited by the American National Standards Institute (ANSI).

IPC/EIA J-STD-001C is titled “Requirements for Soldered Electrical and Electronic Assemblies”, is a joint standard developed by a joint standard developed by the Joint National Soldering Standard TaskGroup, the EIA Soldering Technology Committee (STC) and the Soldering Subcommittee (5-22) of IPC. This standard illustrates the materials, methods and acceptance criteria for soldered electrical components.

The standard mentions the assembly processes regarding the requirements for mounted parts. As temperature could have a great effect on some particular mounting components, those parts have to be assembled as a separate operation. If cleaning is required, the parts should have sufficient clearances between the body and the PWB. If there is a mix of through-hole and surface-mount components on the same board, through-hole can stay on one side, but surface-mount can stay on either or both sides of the board. Moreover, if the lead deformation of mounted parts exceeds 10% of the diameter, width or thickness of the lead except as allowed for flattened leads, the parts should not be mounted on the board. For the flat back integrated parts, "leads on opposite sides of surface mounted flatpacks should be formed such that the nonparallelism between the base surface of the component and the surface of the printed board (i.e., component cant) is minimal" (23). As we can see in the figure below, the base cannot go down over the limit of 2.0 mm. Also, the lead bend cannot extend into the seal.



(figure 38)

Electrical soldered parts on the board need to be handled in a manner that the parts do not move within the solder paste. Also, after performing soldering the parts on the board, the assembly has to be cooled and solidified before proceeding to further handling. There is a need to gently hold down the surface mount leads so it will not affect the reliability of the electrical components. Besides, lead trimming needs to be taken care so it will not damage the component or solder connection. Heatsink and thermal shunt are those useful devices to attach on the soldered components so that temperature cannot affect the operation of the main components.

Choosing the right solder paste also plays an important role in minimizing the problems for the PCB assembly process. There are some aspects of selecting solder paste that we need to pay attention to:

- Alloy selection: The selected alloy is identified to meet all the requirements of the products and safe operation. There are lead and lead-free soldering paste. Lead-free is harder to work on since it has a high melting point while the lead one is quite more popular.

- Flux selection: There are various types of fluxes in the industry categorized in four main types and one no-clean type, which was added later by IPC. The Rosin mildly activated type is used widely in most of the solderable surfaces as it is soft and easy to be cleaned by appropriate solvent.

4.2.8 Design Impact of Soldering Standard

In our project, we will order parts from different electronics suppliers and have the designed PCBs produced from a fabrication manufacturer. After receiving all of the necessary parts and PCB, we will be assembling and testing the components to ensure there are no issues later when we begin to connect the PCBs to each other and other power supplies. UCF has provided the Senior design laboratory with efficient equipment such as basic electrical testing instruments and soldering stations so that we can perform soldering the components to the boards. Most of the parts will be surface-mount along with a few through-hole components. Therefore, the no-clean solder paste is considered to be used for soldering the SMD/SMT parts along with the heat gun to melt the paste until it secures the parts on the board. On the other hand, the tin lead solder wire will become handy for the through-hole component as we will use the soldering station to melt the wire in order to stick the pins of the parts to the holes.

For cleaning purposes, the wet sponge will be used to clean the tip of the iron soldering station while isopropanol alcohol can get rid of all the excess solder material on the PCBs. There are plenty of tiny components so the soldering procedure must be performed carefully in order to not cause any great damage to the electrical parts.

5. Project Design

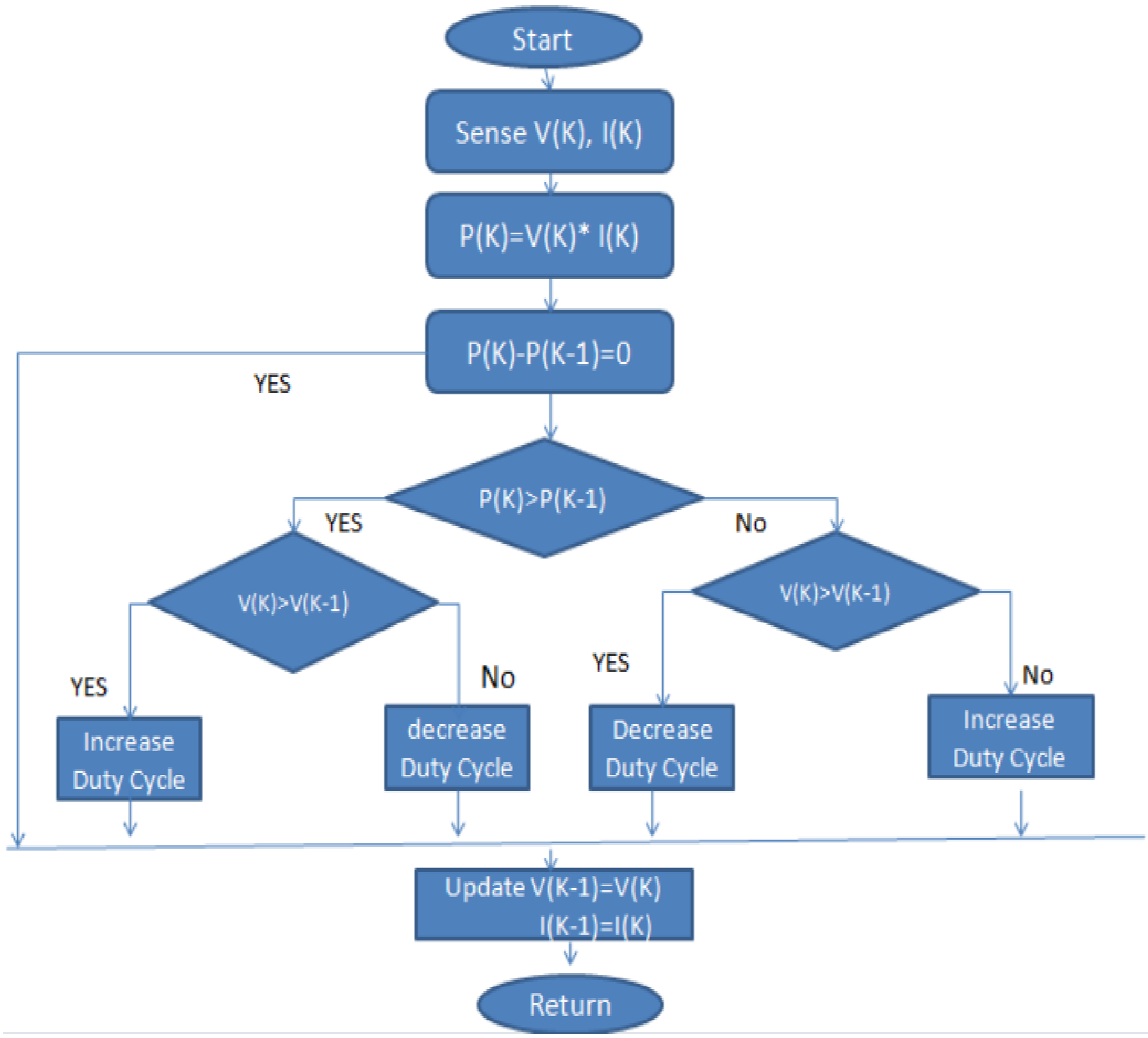
In the following sections we will explain our design. Each section will contain related schematics and diagrams along with a full explanation of the function of the sub system. This section contains two subsections. The first will explain all the software design contained in our project, the second containing the hardware designs.

5.1 Software Design

Software designing is one of the important parts of our project. Since the project is using different microcontrollers, it does need software design for implementation. The following part will discuss the possible flowchart or architecture implemented throughout the design.

5.1.1 Solar charger Flowchart

Since the solar charger is using a maximum power point tracking system. There will be a buck boost converter and it’s switching will be done using a microcontroller for regulating the output voltage for the battery without wasting output power coming from the solar panel. The following algorithm will be implemented in the controller to achieve maximum power point tracking.



(Figure 39)

Perturb and Observe method

This P&O algorithm will periodically check and increment or decrement the output terminal voltage of the PV cell. The power obtained from the current cycle will be compared with the previous one and if the power is increased, then it is supposed that it has moved the operating point closer to the MPP. Thus, further voltage perturbations in the same direction should move the operating point toward the MPP. If the power decreases, the operating point has moved away from the MPP, and the direction of perturbation should be reversed to move back toward the MPP.

5.1.2 PID Motor Control

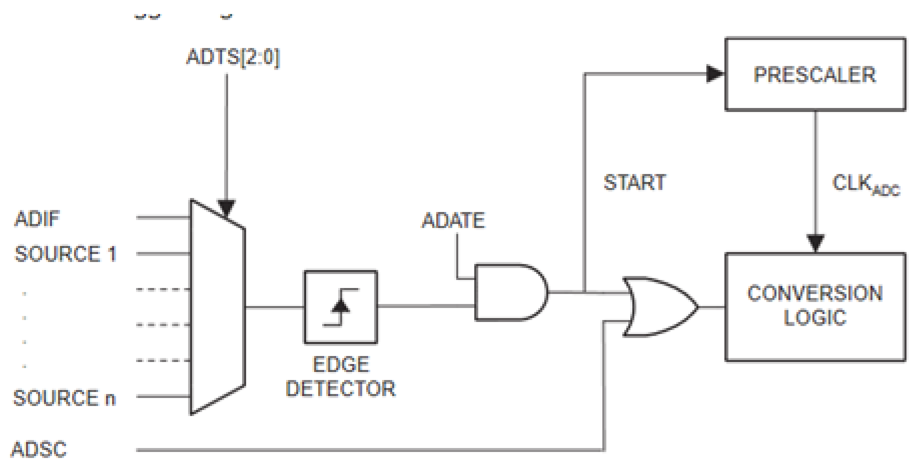
Based on the design of our user input, the best way to properly control the motors is through a PID controller implemented in the ATTINY85 microcontroller. The details of this system are broken down in the following sections

5.1.3 Sensor Input

The user input is sensed through an analog voltage which will be connected to the ADC of the microcontroller. The ADC uses a sample and hold circuit, which ensures that the input is held at a constant voltage while the conversion is taking place. The ADC within the MCU has a 10-bit resolution which is calculated through successive approximation. The input channel for the ADC will be selected by writing to the MX[3:0] bits in the ADMUX register. Based on our design, the ADC1 pin is used. The ATTINY offers differential gain amplifiers to increase the difference between the input and reference inputs. Based on the testing results, this amplifier may or may not be used.

Before being able to read from the ADC pins, they must be enabled. This is done by setting the enable bit ADEN in the register ADCSRA. Once this bit is set, the ADC can then generate results based on the input. The results of the conversion are stored in the ADCH and ADCL registers. Because the result is 10-bit and the MCU uses 8-bit registers the two registers are needed to access the result. To ensure accurate results, the registers are not updated once the ADCL register is read. After the ADCH is read, registers can then be updated for further conversions. The ADC has its own interrupt that can be triggered when a conversion completes.

The conversion process can be started by setting the ADC Start Conversion bit, or ADSC in the ADCSRA register. This bit will stay set as long as the conversion is taking place. Once the conversion is finished and the interrupt is triggered, the ADSC bit is cleared by the hardware. Another possible solution is to have the ADC trigger internally based on the rising edge of one of the internal clocks. This is the strategy that will be attempted first. This is done by setting the proper Trigger Select bits ADTS in the ADCSRB register. We will use the Timer/Counter0 Compare trigger by setting the ADTS[2:0] bits to 3. It can be seen in the figure below, taken from the datasheet, how the auto trigger process works.



(Figure 40) *ADC Auto Trigger Logic*

To get the maximum conversion resolution the clock frequency needs to be between 50 and 200 kHz. The ADC module uses a prescaler to adjust the incoming clock to match the needed frequency. The prescaling can be tuned using the ADPS bits in the ADCSRA register.

5.1.4 Motor Speed Control

Once the analog input is converted, the desired speed of the motors will be calculated. This will require some calculation. In the most basic form, the motor speed needs to increase as the potentiometer moves further away from the center in either direction. Every time the ADC makes a conversion the desired output speed will be recalculated. We want to make input conversions as frequently as possible without losing resolution to provide the quickest response to the user.

Based on the previously defined requirements, the top speed of the cooler should be no more than 5 mph. This gives us a good basis for calculating speed. A simple linear formula can be used in which the coefficients will be adjusted based on testing results. The following formula will be used to calculate the desired speed.

$$RPM = \left[Volt * \left(\frac{MaxRPM}{3.3} \right) \right] - \frac{MaxRPM}{2}$$

Motor Speed Formula

This formula assumes that the maximum voltage will be 3.3 volts and the minimum input will be zero. Because the motors are bi-directional, negative RPM values are acceptable. The voltage reading of 3.3 / 2 corresponds to the potentiometer in the center position and results in a 0 RPM result.

While this will generate a desired motor speed, without the integral and differential aspects of the controller, oscillations and steady state error can occur and are likely. For this reason, feedback from the motor encoders is also necessary. The actual motor speed will be compared with the desired speed calculated in the previous formula in order to calculate an error coefficient. The error is used to adjust the output. This will give a smooth speed transition when accelerating and eliminate any error in the calculated motor speed. This feedback will be read through the ADC of the microcontroller as well as the potentiometer reading. The following formula is a general PID formula and will be implemented in the C language within the ATTINY85.

$$RPM(k) = K_p e(k) + K_i \sum_{i=0} e(i) + K_d [e(k) - e(k-1)]$$

PID Formula

Where Kp, Ki, and Kd are the proportional, integral and differential coefficients respectively and e(k) is the error calculated from the encoder input. These values will be adjusted during testing in order to provide the quickest response with a smooth transition and minimal steady state error.

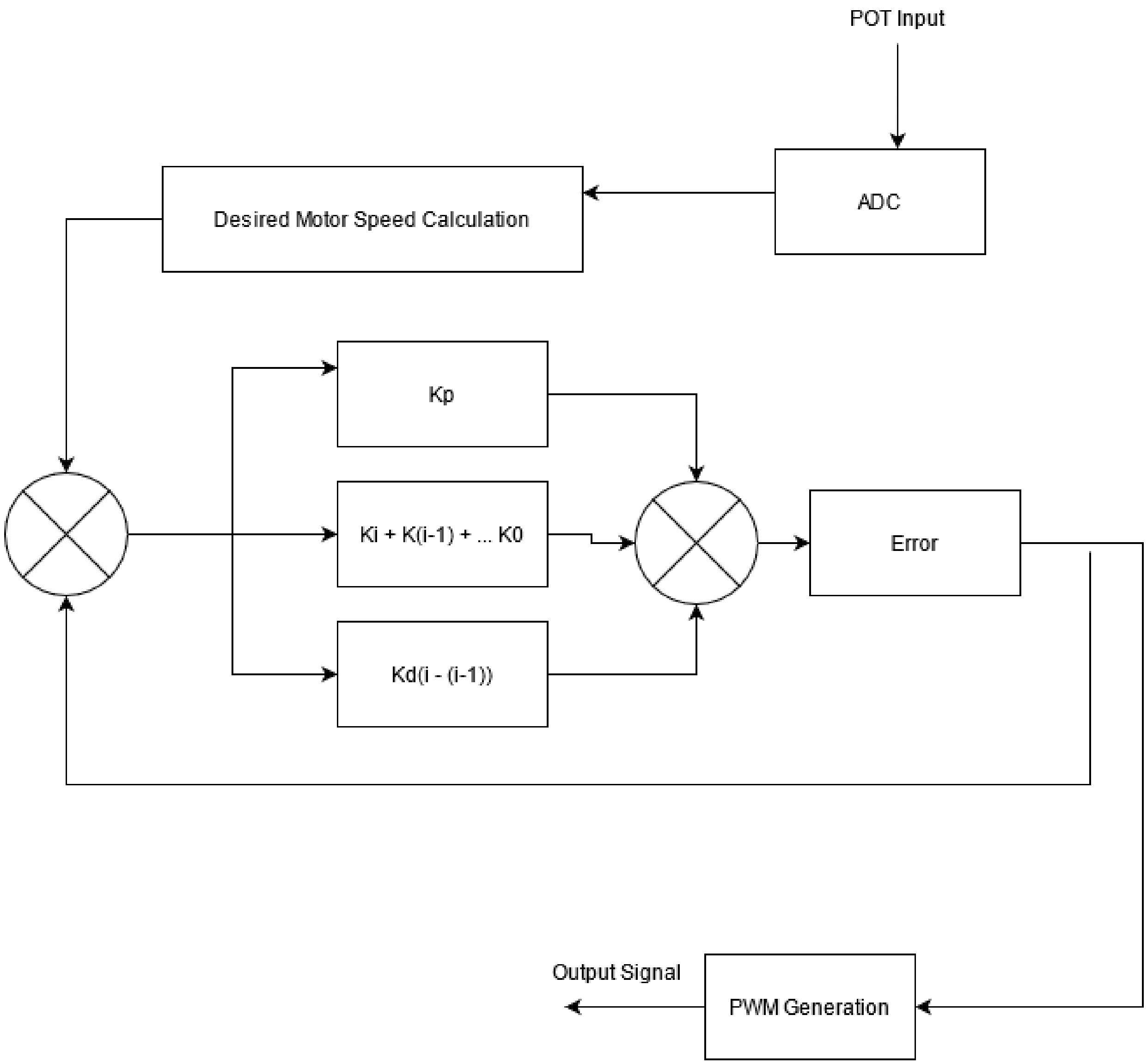
5.1.5 PWM generation

The final output speed generated from the PID controller will have to be converted to its corresponding PWM signal. This signal will be amplified by the MOSFET circuit and used to power the DC motors. We will keep the frequency of the PWM output to between 5 and 20 KHz. This is suggested because anything lower may be noticeable in the form of ripples in the motor output, while higher frequencies may cause overheating in the switching circuit.

The timer/counter0 module of the ATTiny85 will be used to generate our desired PWM signals. The clock source will be selected. The ATTiny85 has a built-in phase correct PWM mode that can be set using the TCCR0A register. This mode generates a double sloped PWM signal which is preferred for motor control.

The exact frequency will be determined during the testing phases of the project. The possible frequency choices are also dictated by the available selected clock in the microcontroller. Because we want a clock frequency of between 50kHz and 200 kHz for the ADC, we will start by using the internal 128 kHz oscillator. A prescaler will be used to divide the clock frequency by 8, giving an effective 16 kHz clock for the PWM generation. This can be adjusted if needed, but should work well for this situation.

5.1.6 Motor Control Flow Chart



(Figure 41)

5.2 Hardware Design

The following sections outline the hardware design of our project. Each section contains a description of the designs meant to implement the functionalities of our project as well as meet the necessary requirements. Along with each explanation of the subsystem, any related schematics will also be presented here.

5.2.1 Motor Control Sub-System

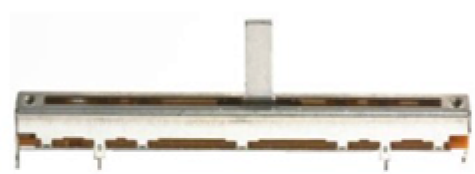
The motor control subsystem is responsible for taking the user's input through the custom handle sensor and generating a signal that will then be amplified and sent to the two DC motors to control the movement of the cooler. For this system to work properly, the user input must be translated into an analog voltage level that will be translated and converted to the output signal for the motors. The first thing that needs to be understood is how this user input will be translated into a usable input control signal. The next step in the motor control process is to take that input signal and convert it into a signal that can be used to control the motors. For this control signal to be accurate, feedback from the motors is necessary. After these two steps, the output signal will be amplified into a high current signal which will power the motors.

This system is a closed-loop system with the intention of keeping the cooler moving with the handle without the user needing to apply the force to move it. When the user pulls the handle, it must feel weightless, and the user input must be intuitive and passive.

5.2.1.1 Handle Sensor Module

In this section, the construction of the handle sensing module and the related circuit design will be introduced. The approach that we have chosen for this requirement is a novel potentiometer-based design. Before the design can be completed, the proper potentiometer must be found. For this design a lateral sliding potentiometer is favorable. We need one that has a significant travel distance and resistance range in order to ensure the precision required for the motor control.

Features:
- Single / dual gang
- 100 mm travel
- 100,000 cycle life
- Metal shaft
- RoHS compliant

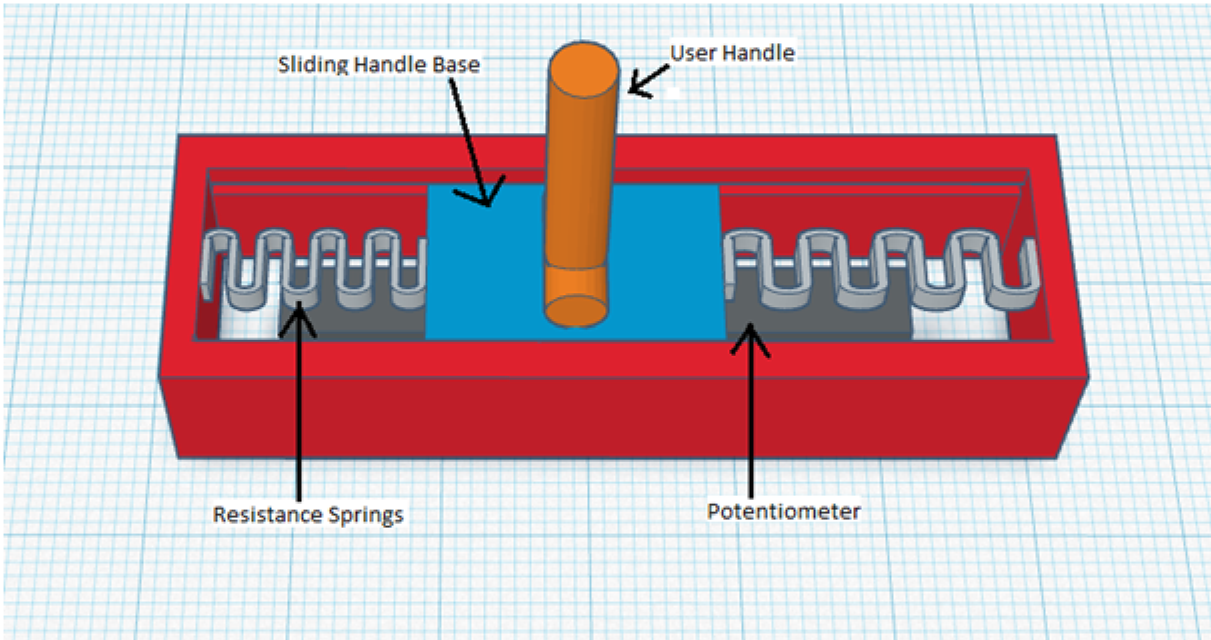


Resistance Range, Ohms 500 -1M

(figure 42)*Potentiometer Selection*

Referring to the above figure, it can be seen that potentiometers having the necessary parameters are readily available. The component above is chosen for the final design.

Because, as per the previously stated requirements, the cooler must be able to support 100 pounds of weight, having this potentiometer connected directly to the handle of the cooler is not an option. Support is needed to ensure that the component doesn't break and also to ensure that the handle doesn't become detached from the rest of the chassis, causing a safety hazard. For these reasons, a structure is designed that will isolate the forces applied to the handle from the delicate electronic component.



(Figure 43)*Simple Handle Sensor Module Design*

The figure above gives a good depiction of the design of the sensor module which will isolate the unwanted forces from the handle from the sliding potentiometer. The handle will be secured to an aluminum base which will have the freedom to slide laterally within the structure. To compensate for the weight of the cooler and the large forces that may be applied by the user, springs will be attached between the module structure and the sliding handle base. These springs will be balanced and will pull the handle base towards the center of the structure. What isn't shown in this diagram is how the sliding handle base will be secured to the overall structure. This will be done using a slide mechanism similar to the one seen below employing ball bearings to reduce friction.

(Figure 44) *Sliding Mechanism*

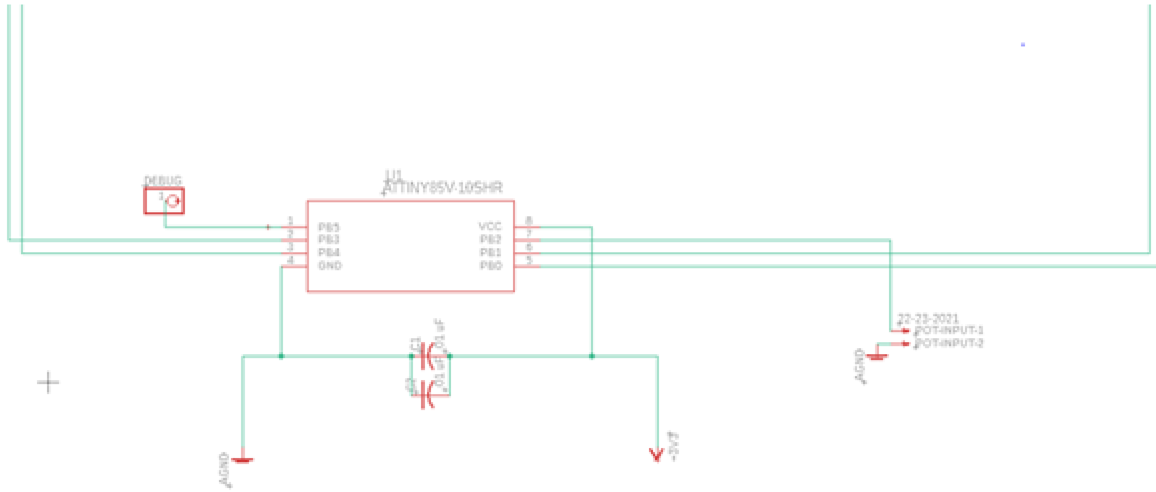
As the user pulls or pushes on the handle, the potentiometer's resistance will change. A 3.3 V power line will be connected to the input of the potentiometer and the output voltage will be connected to the microcontroller through the motor control circuit board. The ground of the potentiometer will also be connected to the ground of the motor control circuit to ensure a clean voltage reading.

5.2.1.2 Microcontroller Circuit

The main functionality of the motor control subsystem will be implemented within the microcontroller circuit. This circuit will take the input analog voltage from the handle sensor module and generate a PWM signal based on the translated position of the potentiometer. A PID controller will be implemented with the goal of keeping the potentiometer in the center position. In this section, the circuit design will be explained. The software which implements the PID control is covered in the software design section of this document.

Because the microcontroller is a self-contained integrated circuit, the design of the circuit containing it is relatively simple. As can be seen in the figure below, the calculations and components that are needed are used to properly decouple the power supply from noise and sharp changes in voltage that could damage the sensitive IC.

As explained in the components research section of this paper, a ATTINY microcontroller from Microchip will be used due to its small size and low energy consumption. A high-powered microcontroller with many features is not necessary for this subsystem. The MCU will be responsible only for converting the input voltage from analog to digital and generating PWM signals based on the output of the PID algorithm. Two PWM signals are generated for the motors, which will be interpreted by the MOSFET driver to control forward and backward movement.



(Figure 45) *MCU circuit*

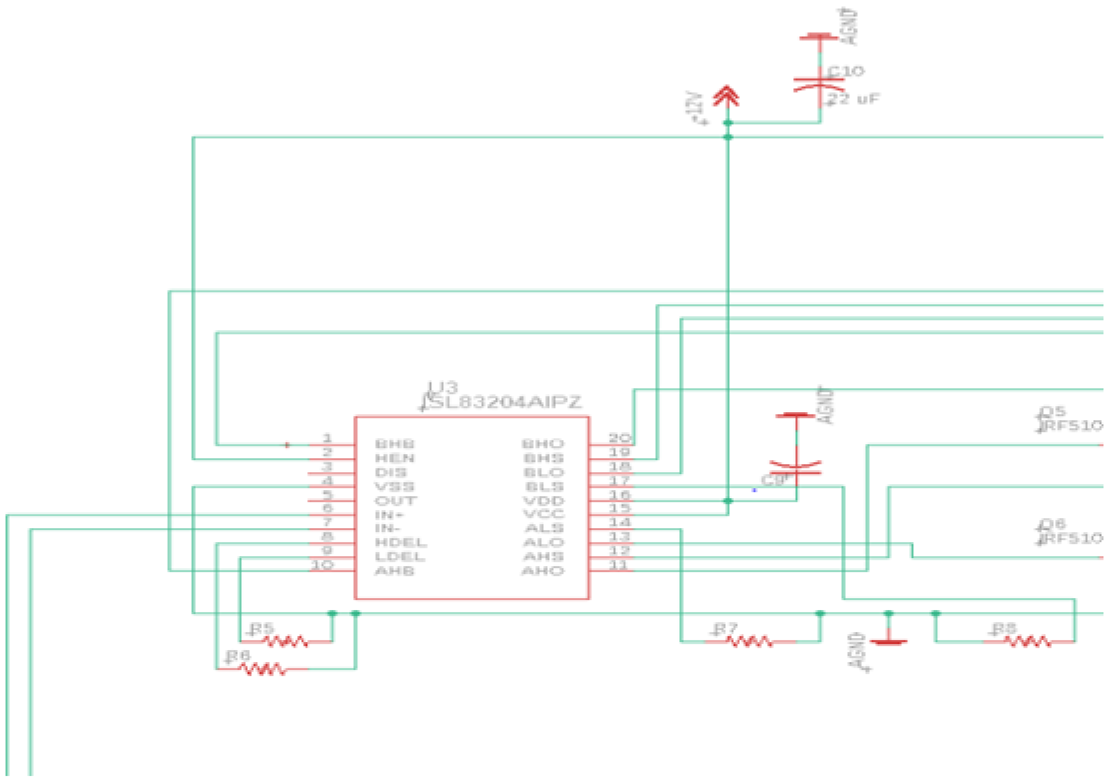
This circuit will require a 3.3 V power rail which will be provided by the power supply circuit explained in its respective section within this document. The output wires which can be seen running off of the picture are going to the MOSFET driver portion of the circuit and will be explained in the next section.

5.2.1.3 MOSFET Driver Circuit

Because the output of the microcontroller can be no more than 3.3 V and in the milliamp range, a separate circuit must be used to convert that low power signal into a high powered one. This task will be completed by the MOSFET H-bridge circuit. However, this circuit can be dangerous if used improperly. That is where the driver circuit comes in. The MOSFET drivers are used to ensure that only certain switches are open at time to combat short circuiting and what's called shoot through, where both terminals of the motor receive positive voltage at the same time.

The driver is an integrated circuit that essentially applies a voltage to the gates of the right transistors at the right time based on the input signal that is received by it. Because the H-bridge circuit allows for forward and reverse control of the motor, there is a high-side and low-side that needs to be controlled for each motor. For this reason, two PWM signals will be sent to each of the drivers, one for the low-side and another for the high-side.

A 12-volt power rail will also be needed by the driver to power it and decoupling capacitors are used to make sure the power supply is clean. Some of the pins of the driver need to be grounded and are done so using pull down resistors. All these design factors can be seen in the following schematic.



(Figure 46*) MOSFET Driver Circuit*

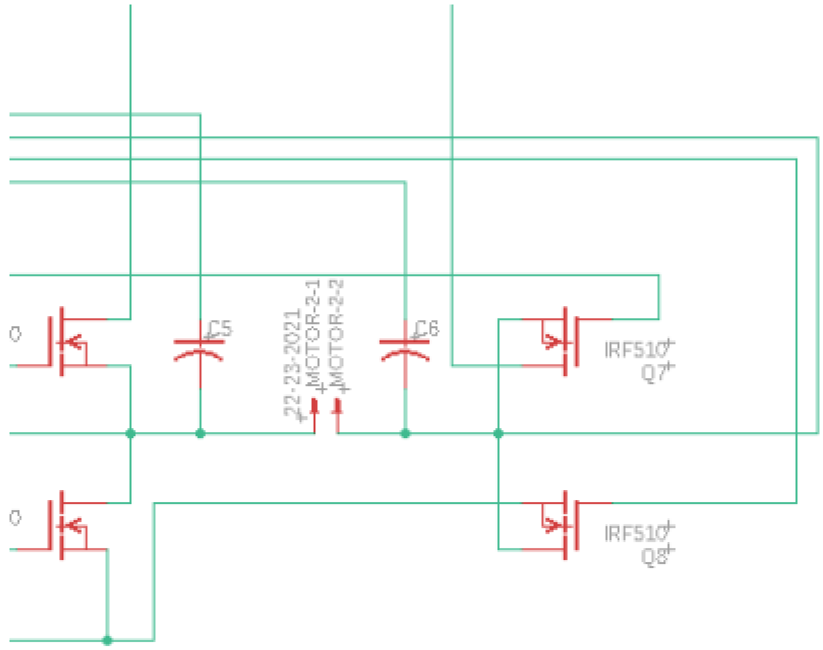
The outputs that can be seen going off the picture are going to the H-bridge MOSFET circuit. There will be two of these identical circuits, one for each motor.

5.2.1.4 MOSFET H-Bridge Circuit

The H-bridge circuit is used to control high powered signals using low powered signals. The low powered signals activate and deactivate the transistors which either allow or stop the current from flowing to the load, DC motors in this case, from the power source. We have decided to go with an H-bridge design because we need the ability to rotate the motors in either direction based on the user input. The H-bridge design allows for this.

Because this circuit does not contain any integrated circuits the design of the circuit itself becomes much more complicated. In the schematic, the transistors are shown in the H configuration. The transistors chosen, as mentioned in the components research section, allow for very high voltage and current throughput while still having a low resistance and gate voltage.

The transistors are essentially connecting each of the motor terminals to either the ground rail or the power rail based on which transistor has a gate voltage applied, which can be seen in the following figure.

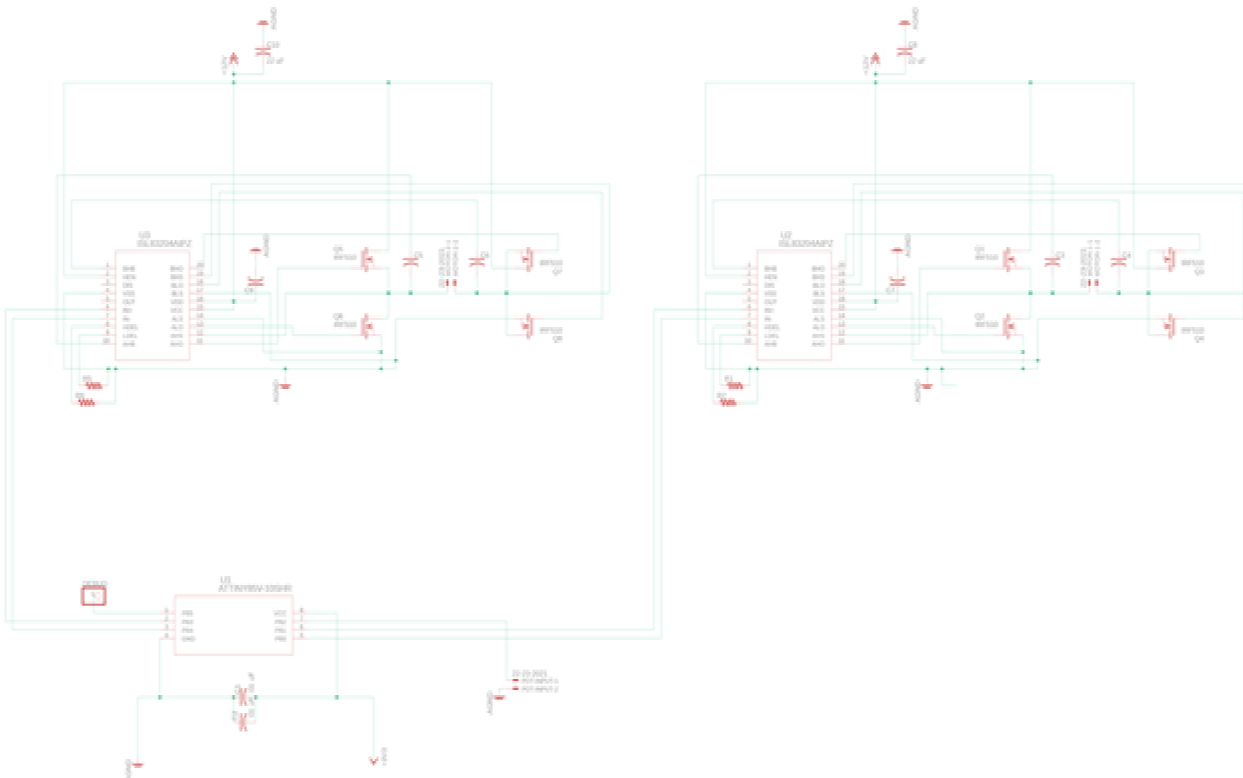


(Figure 47) *MOSFET Circuit*

The two incoming lines from the top come from the 12-volt power supply rail and the lines coming from the left are from the driver circuit. Due to the complexity of this circuit, some changes may be made in the way of decoupling capacitors or resistance between certain nodes after testing to ensure the safety of the components and the users alike.

5.2.1.5 Complete Motor Control Circuit Schematic

This section provides an overview of the entire motor control sub system schematic. This system will be implemented on a single PCB board.



(Figure 48) Complete Motor Control Circuit

5.2.2 Display and Protection Circuit

A display and protection circuit will be added in design to protect the design in the worst case scenario.The block diagram shown in this section will be implemented into the actual circuit to achieve the final outcome.

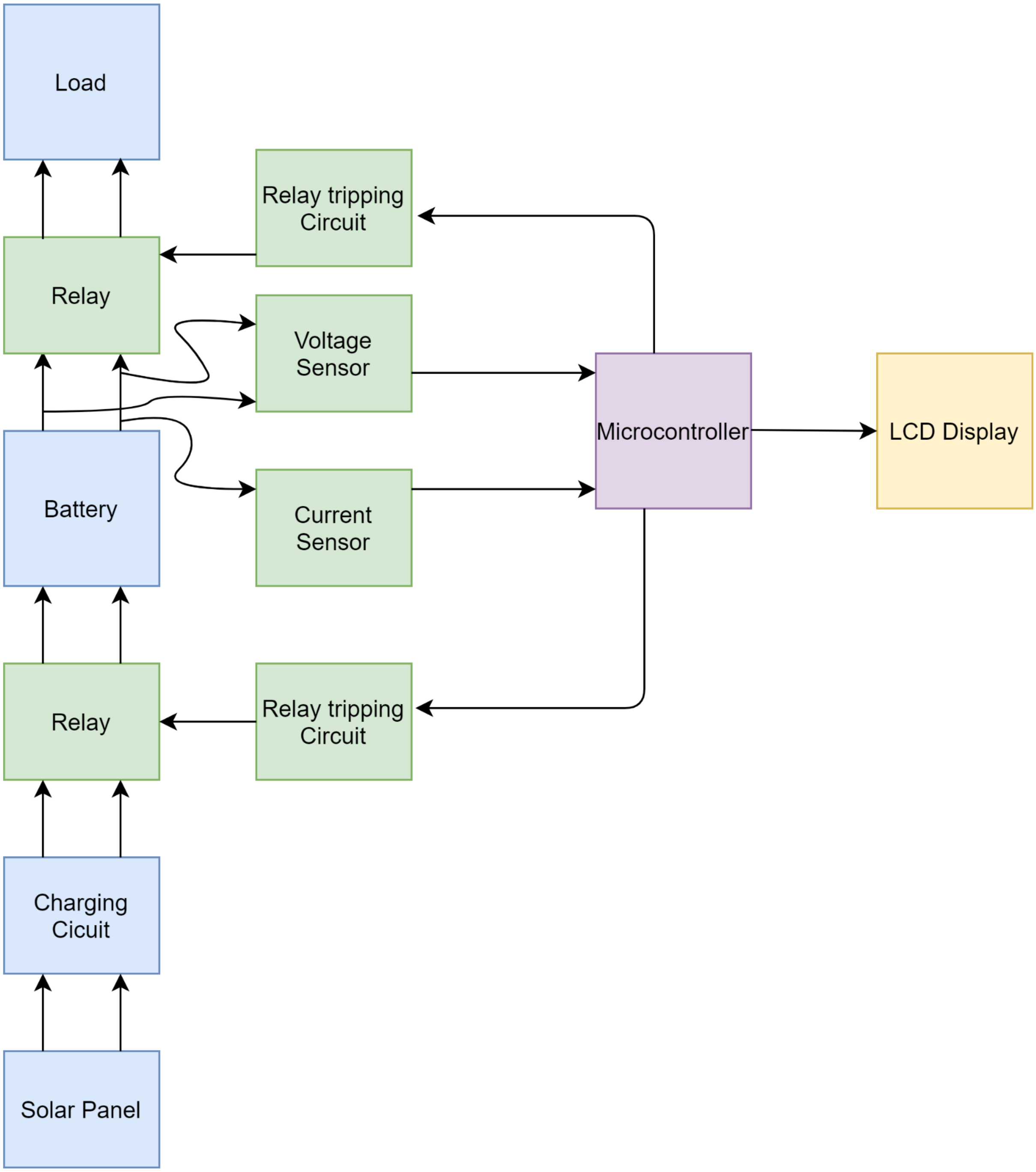
It can be seen that the most integral part is to display the important values on display so the user can see the information about the state of the battery. The user will be able to see the battery state of charge before leaving home. Display will show how much the battery is charged and the voltage of the battery. It will also display the current drawn out of the battery when either the cart or refrigerator is working or both loads are taking out current.

Current and voltage sensors will be used to measure the output voltage and current drawn by the battery. The microcontroller will read the sensor's reading and display corresponding values on display. Based on internal programming and sensor reading it will determine whether the battery is fully charged or not. For better performance it will make sure user do not run the load when the battery state is less than 20 percent.

When the display shows the battery is fully charged a control signal will be sent to relay operating circuit on the charging side to disconnect the charging circuit from battery to avoid over charging and when battery drop enough charge the rely will be closed again based on control circuit and battery will start charging.

For the better performance of the battery we won't let the battery draw more current than its capacity and also do not run load when battery voltages are low. A load current will be measured through current sensors and when sensors read more than required current, a disconnect signal will be sent to disconnect load from the battery. In that case users need to reduce the weight on the cart which will reduce the taroque and amount of required current to drive the cart.

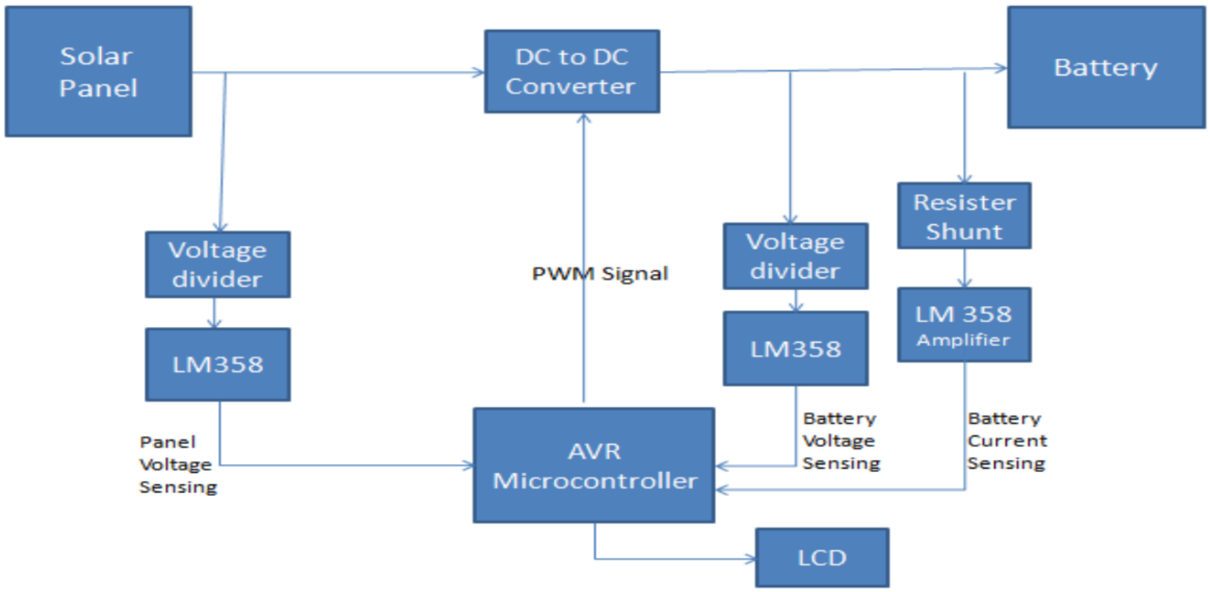
This whole designed circuit will give a visual representation to the user and protect the battery from overcharging as well as avoid the user to put more weight on the cart than it required and also provide safety incase of fault, and won’t drive the load.



(Figure 49) *Display and Protection Control Circuit*

5.2.3 Solar Charging Circuit

The solar charger will be implemented using the ADC and PWM channels of the microcontroller. The PWM signal will turn on and off the buck converter to achieve the maximum tracking point and avoid losing much power. The purpose of the microcontroller will be to read output voltage and current and calculate the power. Same data will be read on the other hand from the battery side. Based on the reading on both sides a microcontroller will control the buck converter by increasing or decreasing the duty cycle of PWM or even turn off if needed. Below is the block diagram of the solar charger.



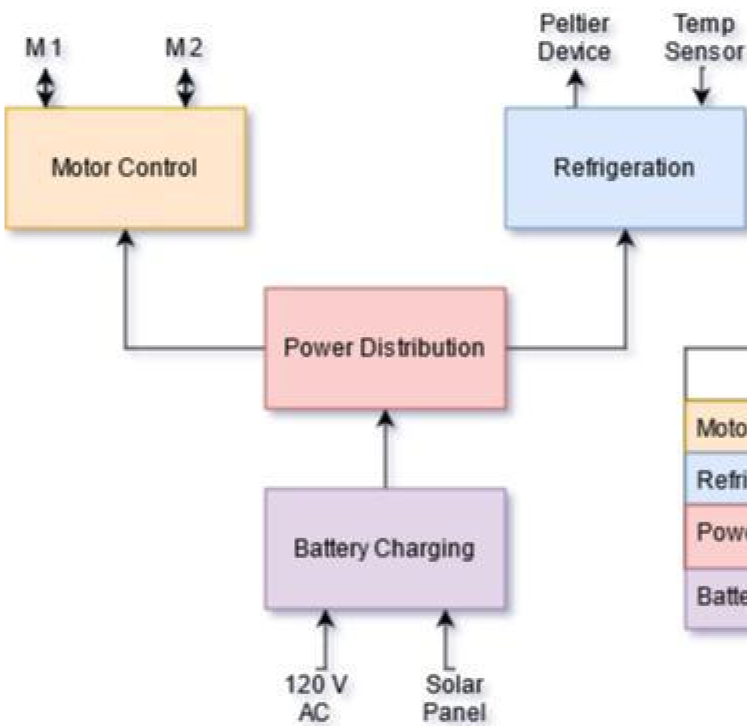
(Figure 50) Solar Charger Block Diagram

Different approaches are used DC to DC converter, but most common is to use either buck boost or buck converters. Our requirement can be met with only a buck converter so it is decided to implement a charging circuit using buck converter but if the solar charger is used for a big scale like in utility then it is recommended to use buck boost converter.

A normal charging circuit only converts 30 to 40 percent energy into electrical and this efficiency can be increased by using mppt and in our case since the cart may be left outside for a longer period of time so we need a fast charging system with higher efficiency. Perturb and observe methods will be used to implement the design. According to Maximum Power Transfer technique, the output power of a circuit is maximum when the source impedance matches with the load impedance. In the source side a buck converter is connected to a solar panel in order to enhance the output voltage. By changing the duty cycle of the buck converter appropriately by PWM signal the source impedance is matched with that of the load impedance. P & O method does have some drawbacks like oscillations and confusion with rapidly changing environment conditions. But it is widely used due to its simplicity and cost effectiveness and our project will use the same technique.

5.3 Project Block Diagrams

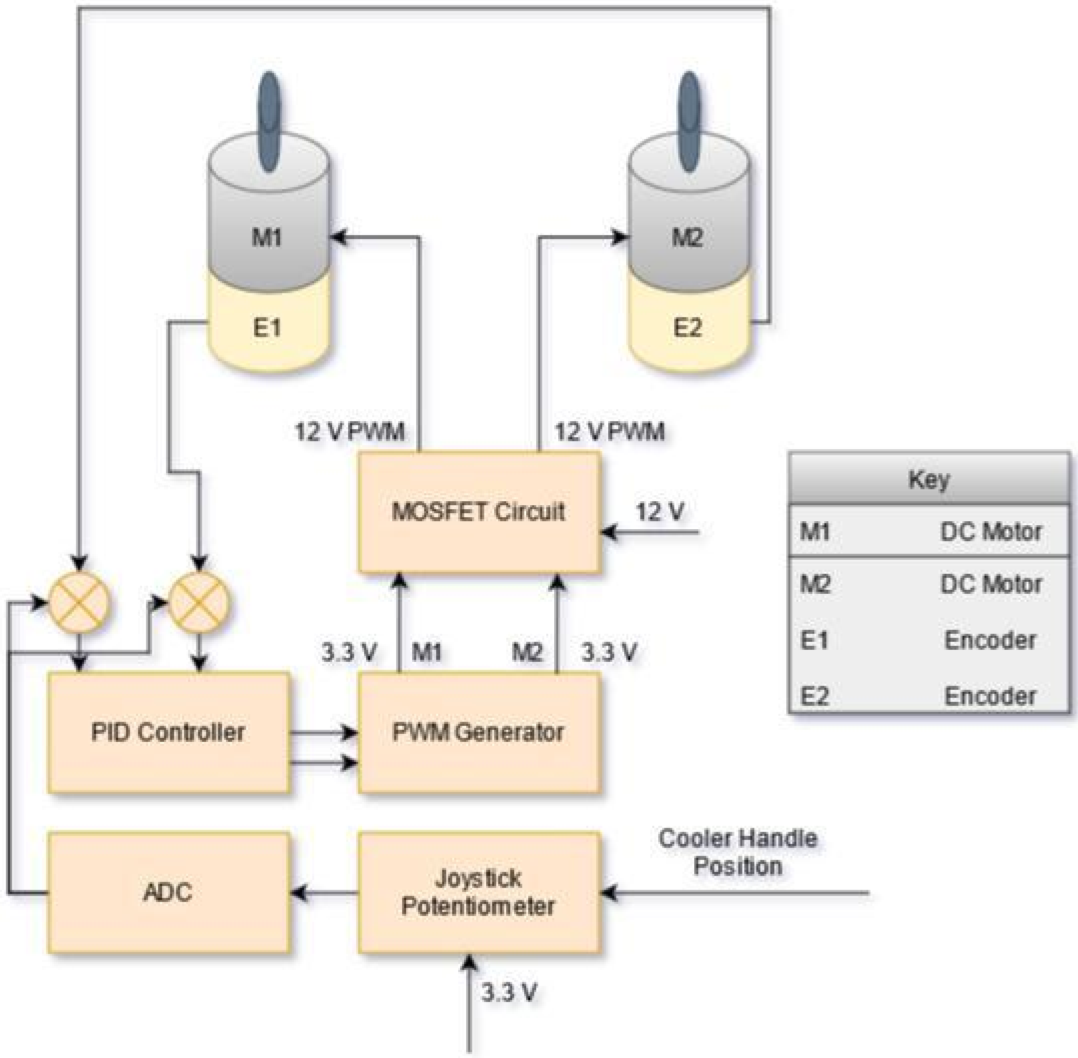
5.3.1 Task Allocation



Task Allocation	
Motor Control	David Crumley
Refrigeration	Min Park
Power Distribution	Aqeel Ahmed
Battery Charging	Phuong Thi Y Duong

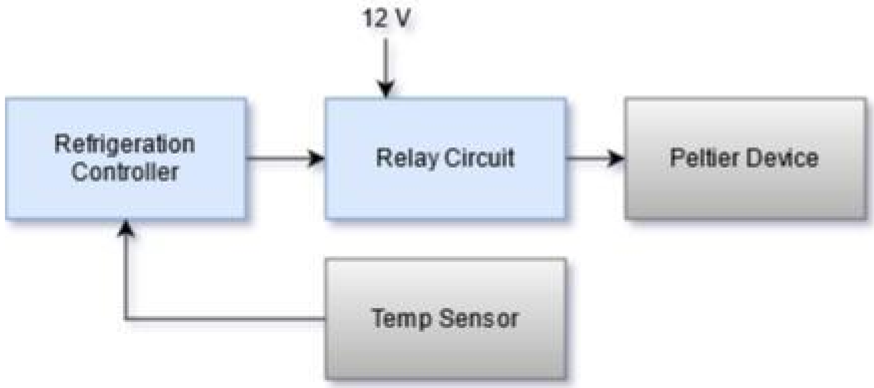
(Figure 51)

5.3.2 Motor Control



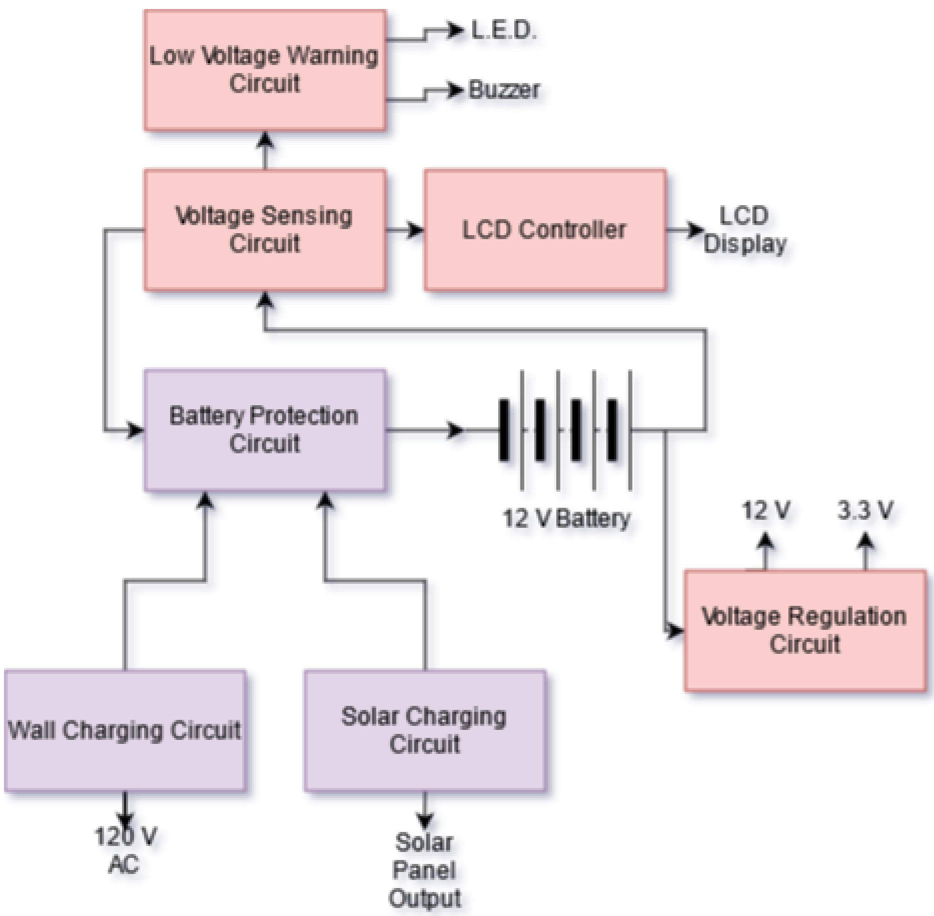
(Figure 52)

5.3.3 Refrigeration



(Figure 53)

5.3.4 Power Distribution / Charging



(Figure 54)

5.3.5 Voltage Regulator Design

To power the control board of the cooler which needs the input voltage of 3.3V, we choose the buck switching regulator TPS562208 to step down the 12V input from the battery to 3.3V. This regulator is optimized with minimum external component counts and has a low standby current. Its input voltage ranges from 4.5V to 17V and output voltage ranges from 0.76V to 7V. The regulator can provide fast transient response and support the low equivalent series resistance and output capacitors. We have used Webench TI design tool to obtain a complete schematic for the regulator.

- Cost: $ 0.88 (each)

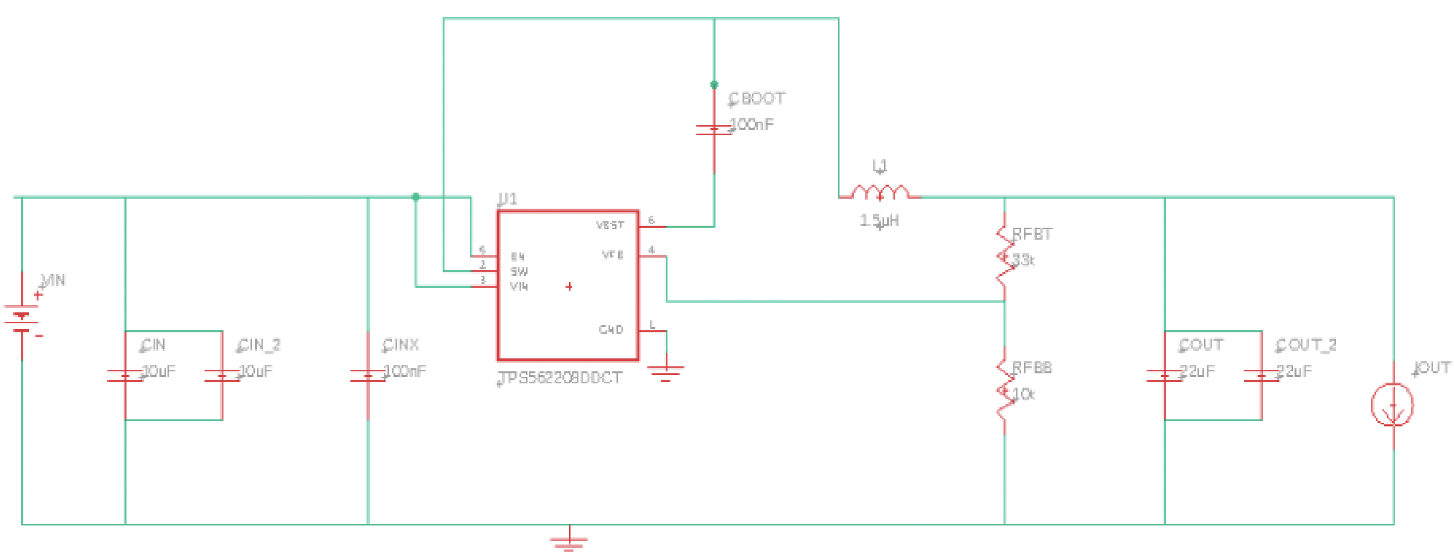
To increase the efficiency for the light load, we are recommended to use large resistor values. We used the formula below to select the value for the resistors:

$$V_{OUT} = 0.768 \times \left(1 + \frac{R1}{R2}\right)$$

The LC output filter has double pole at:

$$F_P = \frac{1}{2\pi\sqrt{L_{OUT} \times C_{OUT}}}$$

The schematic of the selected voltage regulator is shown in figure below:



(Figure 55)

Bill of material (BOM) for the switching voltage regulator is show in the table below:

(table 31)

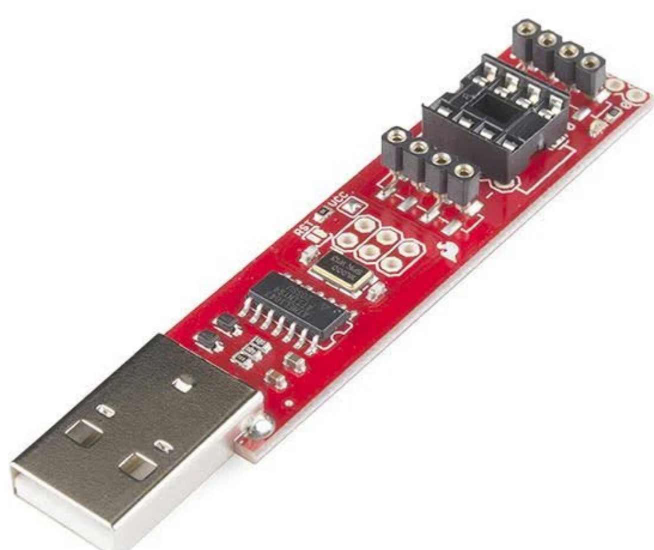
Part	Manufacturer	Part Number	Quantity	Description
U1	Texas Instruments	TPS562208DDCT	1	TEXAS INSTRUMENTS-TPS562208DDCT - DC/DC CONV, SYNC BUCK, 580KHZ, SOT23-6
L1	TDK	VLP8040T-1R5N	1	L: 1.5 µH DCR: 13 mΩ IDC: 7.8 A
Cin	MuRata	GRM21BR61E106MA73L	2	Cap: 10 µF Total Derated Cap: 3 µF VDC: 25 V ESR: 4 mΩ Package: 0805
Cboot	Taiyo Yuden	EMK107B7104KA-T	1	Cap: 100 nF Total Derated Cap: 100 nF VDC: 16 V ESR: 1 mΩ Package: 0603
Cout	TDK	C1608X5R1A226M080AC	2	Cap: 22 µF Total Derated Cap: 9.1 µF VDC: 10 V ESR: 3.71 mΩ Package: 0603
Cinx	Yageo	CC0805KRX7R9BB104	1	Cap: 100 nF Total Derated Cap: 99 nF VDC: 50 V ESR: 1 mΩ Package: 0805
Rfbt	Vishay-Dale	CRCW040273K2FKED	1	Resistance: 33 kΩ Tolerance: 1.0% Power: 63 mW
Rfbb	Yageo	RC0201FR-0710KL	1	Resistance: 10 kΩ Tolerance: 1.0% Power: 50 mW

6. Project Prototype Construction

This section will comprise of details related to the construction of our prototype. This includes the technique used to install our software onto our microcontrollers, the layout of our PCB boards which will contain all circuitry, and finally the overall configuration of the cooler. In each of these sections, schematics will be used when necessary to give a visual aid of our design construction.

6.1 Programming the Microcontrollers

Because we have chosen the Microchip AVR based microcontrollers, the Arduino IDE can be used to generate the code which will be installed on our microcontroller chips. However, unlike the Arduino UNO or other development kits, an external programming device is needed. For this we have chosen the AVR Tiny Programmer developed by David Mellis at MIT Media labs, which can be seen in the following figure. This device connects to a PC via USB port and contains headers that allow the MCU to be inserted and removed with ease. The USBTinyISP drivers are all that needs to be installed on the PC besides the Arduino IDE itself. Once these drivers are installed, the IDE can be used to move the programs directly over to the chip. This programmer also contains female headers that can be used for prototyping without having to remove the chip from the programmer.



(Figure 56) Tiny AVR Microcontroller

6.2 PCB Vendor and Assembly

Once the circuit designs for the project are finalized, the PCB layouts are designed and need to be printed and further tested. It is important to choose the best possible vendor for PCB board printing to ensure all connections are solid and that the general construction is solid. Because these circuits will essentially be the heart of the product, if they fail so do we.

We have chosen a company called OSHPARK as our PCB vendor. This choice was made based on previous experience with the company. The quality of their product is outstanding, as well as the prices, not to mention they come with a cool purple finish.

Once the boards are designed and shipped to us, the construction begins. We plan on using equipment at UCF, namely the soldering ovens, to attach all components to the PCB boards. This process is tedious, and mistakes can be made very easily. For these reasons we will be sure to order extra boards. This will not be an issue in terms of cost because it is necessary to buy in multiples from the PCB vendor anyway.

6.3 PCB Layout

Before the PCBs can be bought and assembled, they must be designed. For this task, we have chosen the EAGLE software provided by Autodesk. This same software was used to design the schematics seen in the hardware design sections of this document. To create the PCB layout, the software replaces the schematic parts with their PCB footprints, and the circuit connections are replaced with “airwires”, which represent the connections between components. The components are placed on a shape which will represent the final shape of the PCB. Once all components are placed, the airwires are then used to outline the actual copper traces which will be printed on the board.

The following sections will illustrate our proposed PCB design for the circuitry of our project. These designs are subject to change based on results of testing procedures.

6.4 Cooler Configuration

One of the last things that will be done during the construction of our project, is the assembly of all the subsystems into the chassis. The chassis consists of two main components; the cooler and the cart which the cooler sits on. These two parts will be constructed separately and then assembled afterwards.

Inside of the cooler will be housed the battery, electronics, and of course the peltier refrigeration device. This configuration is chosen because the cooler will be sealed from dirt and water which can damage the sensitive electronics. Housing the electronics components in the cooler will also help keep the electronics from overheating in the hot temperatures which it will be used in.

Attached to the cart will be the dc motors and handle sensor module. These will need to be held in sealed containers to avoid damage. The cart will need 12-volt and 3.3-volt power from the cooler. This will be provided by sealed connectors.

The following sections will illustrate the final look and construction of all of the subsystems of our design

6.5 Overall Construction

(Figure 57) Chassis configuration

It can be seen from the figure that the solar panel will be located on top of the lid of the cooler. This will give the best position for the panel to absorb the most sunlight while still keeping the profile similar to the original cooler profile. Located on the side of the cooler will be an LCD display showing the battery life, current temperature and charging status of the solar panel charging module.

6.6 Cart Construction

(Figure 58) Cart Layout

The cart will be configured as shown in the above figure. A motor will be attached to each front wheel using a belt drive system. The motors will be attached to the from steering mechanism using brackets which will be welded to the frame. The handle is removed from the steering mechanism so that the sensor box module can be placed in between the handle and steering mechanism. The handle will then be attached to the sensor box which will be attached, possible welded, to the frame of the steering mechanism. The sensor box will be securely insulated from the outside environment. This includes water proofing, rubber insulation for electrical isolation as well as shock absorption, and a secure locking mechanism to ensure that the box does not open during testing.

The motors and belt drive will also need to be properly insulated from the outside environment. A housing will be constructed for the motors as well as for the belt drive. This will be most likely 3d printed or constructed from available materials. Sealed bearings will be used for the belt drive and motor modules.

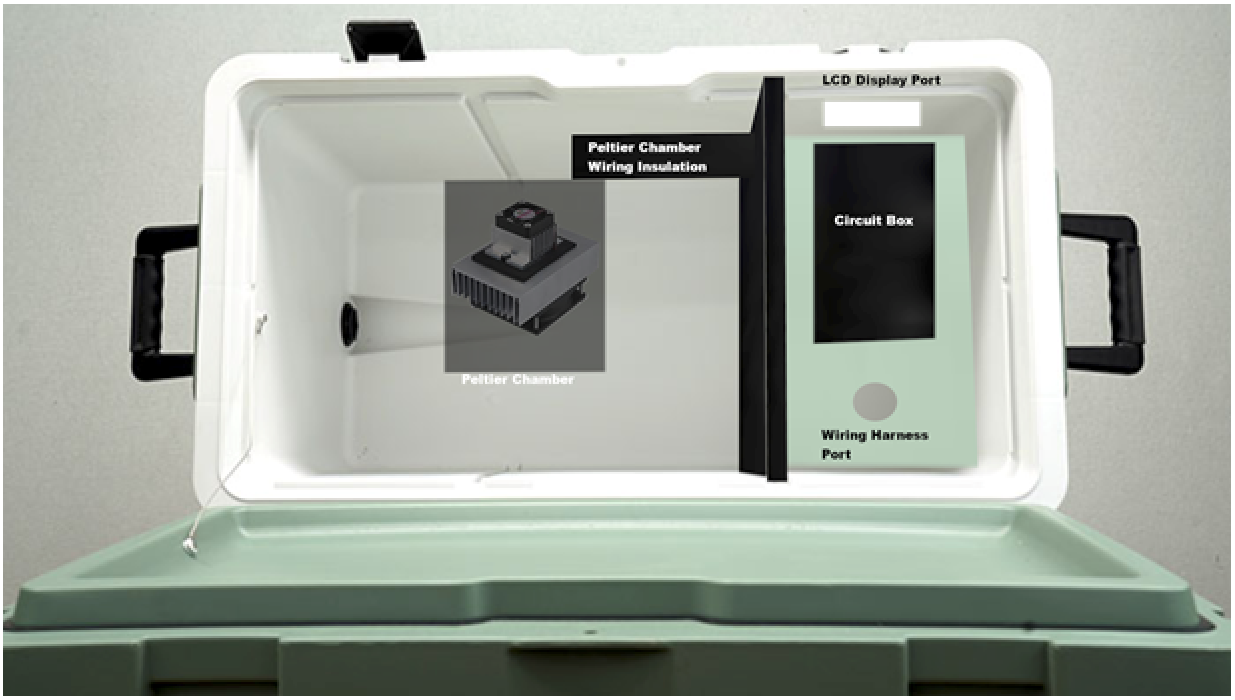
A safety switch is attached to the handle of the cart which will connect the 12-volt power supply to the MOSFET circuit when the handle is pulled. This is a safety measure to ensure that the handle is being pulled by the user and not some other outside force.

6.7 Cooler Internal Layout

(Figure 59) Cooler Internal Layout

Because we have chosen to keep the battery and circuitry within the body of the cooler, it is necessary for some of the cooler volume to be partitioned and sealed off from the rest. The figure above shows the partition that will hold the battery and circuitry. As can be seen from the figure, the battery will be held above the floor of the cooler. This is to keep the battery safe in case the sidewall of the partition leaks. For this same reason, the circuit box will be placed on the top shelf separated also from the battery. The battery wiring will run through the top shelf, enclosed within a sealed wiring harness. Wiring will also be run from the exterior solar panel to the circuit box using a sealed wiring harness. The same strategy will again be used for the wiring that will run to the cart and the refrigeration module.

This internal partition will be at most 8 inches deep and will span across the whole width of the cooler. All electronics components shall fit in this sealed compartment. It will be accessible via a locking, sealed door at the top and the shelves will be removable to facilitate easy troubleshooting and repair.

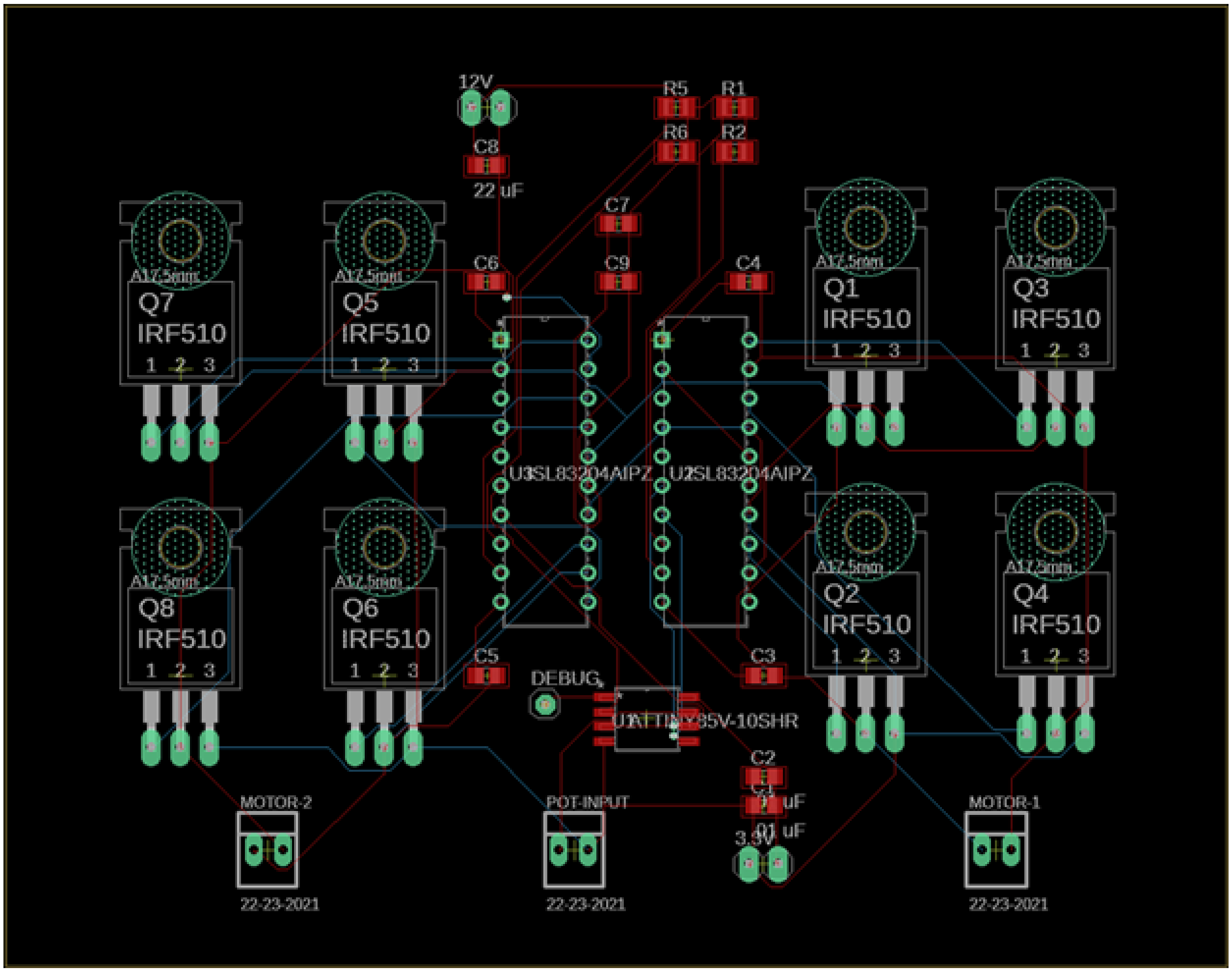


(Figure 60) Cooler Internal Top-Down View

Not only will there be a sealed partition for the circuitry and battery, there also needs to be a sealed chamber which the Peltier device electronics can reside. As can be seen from the above image, the Peltier chamber will be in the center of the remaining volume of the cooler. There will also need to be insulated wiring conduit that will provide the power needed by the unit. This wiring will be running along a channel made in the side of the cooler to take up the least possible amount of internal volume. Inside the chamber, the Peltier devices heatsink will be against the wall of the chamber, creating an ice-cold surface in the center of the cooler. This is the optimal location and setup to provide the highest level of refrigeration while still providing enough volume for the user’s refreshments.

It can also be seen in the above image, the wiring harness port for battery wiring and cart connection wiring. Sealed conduit will also be used for this wiring harness and a rubber gromet will be used to provide the best possible insulation for this port. The LCD port, which can be seen will be used to control the external LCD screen and user input buttons. This port, too, will be sealed.

6.8 Motor Control Circuit PCB Layout



(Figure 61)

It can be seen from the figure that all airwires have equal width. These dimensions will be adjusted based on the measured current through key parts of the circuit during testing of the systems. The Eagle software from Autodesk was used to generate this PCB layout from the schematic design seen in the hardware design section of this document. Bypass capacitors are carefully placed to be located as close to the power inputs and certain MOSFET driver inputs as possible, giving the best noise filtering capabilities.

7. Project Prototype Testing

Before a project can be considered complete, it must be tested thoroughly. We plan to test each component separately before starting construction of the project both in the hardware and software aspects. While we wanted to test our components during this design document creation phase, we were not able to acquire the necessary materials for our testing within the time frame. This is due to a constraint which is felt by all engineers at this time, which is the shortage of components available. This constraint has caused us to choose different components than what was originally planned and the ordering and shipping of these components has been stalled.

Although we were not able to complete the testing, we have outlined the procedures which will be used to test our sub systems when the necessary components arrive. The following sections describe these procedures. We start by describing the environment in which the testing will be conducted along with the equipment that will be used, followed by the individual procedures which will be used to test each subsystem. First, the hardware testing, lastly the software testing.

7.1 Hardware Testing Environment

As college students at the University of Central Florida, we are fortunate enough to have access to the Senior Design Lab environment. Within this lab, we have access to all the equipment we will need. This includes analog power supply, oscilloscope, and multimeters. We also have access to basic components such as resistors, capacitors, and transistors.

Along with the Senior Design Lab, we also plan on using simulation software to test our circuit design. Testing in a simulation environment is much faster and cheaper than testing the physical circuit on a breadboard. Also, simulation testing can be done anywhere on a computer, adding to its efficiency. For the simulation software, we have access to LTSpice and Multisim through the university license.

7.2 Hardware Specific Testing Procedures

The following sections outline the individual procedures that will be used to test each subsystem. Within each section, the motivation for testing, the values which are important, the equipment used and finally the procedure will be explained.

7.2.1 Potentiometer Range Testing

The first step of the motor control system is the voltage reading at the output of the potentiometer connected to the handle of the cooler. Before we can create the exact algorithm for control, we must know the actual values that will be read from the potentiometer. The important values that will be recorded in this test is the voltage reading at the output and the position of the sliding potentiometer for each of these output values. The input voltage will be held at a constant 3.3 V.

For this test we will use the analog DC power supply located in the Senior Design Lab as well as a multimeter to read the output voltage of the potentiometer. A high precision ruler will be used to measure the position of the potentiometer. We will start the test by connecting the potentiometer to the DC power supply set at 3.3 V. Next, we will connect the multimeter to the signal pin of the potentiometer and connect the ground to the ground of the pot which is also the ground of the DC power supply. In this test, there is no need for an added resistance to avoid damage due to high current when the potentiometer is at its minimal resistance value of 500 Ohms because the input voltage is low, at 3.3 V. The maximum current that will theoretically flow through the system will be 3.3 V / 500 Ohms = 6.6 mA.

The next step is to record voltage values at the multimeter with different positions of the potentiometer. We will start at the lowest resistance value, then move to the highest resistance value, after, moving to the middle. Next, we will move 10 millimeters at a time in either direction from the center to get a diagram of resistance at each of these positions. Because the slide range of our chosen potentiometer is 100 millimeters, we should have 10 readings.

7.2.2 DC Motor Speed Vs. Voltage Testing

Before knowing the proper PWM signal that we want to output to the motor, we need to know the analog voltage level that we want to achieve to get a desired speed. The PWM simulates this analog voltage level, so it is very important to understand the motor speed that is achieved at different voltage levels. The RPMs of the motor can be read using the encoder built into it, after some simple calculations.

For this test, we will be using the analog DC power supply, and the oscilloscope, both found within the Senior Design lab. We want to connect the power supply directly to the positive and negative terminals of the motor. The motor will draw a maximum of 0.52 Amps when there is no load, and this will be safe for the DC power supply module. The oscilloscope will be connected to the channel A and the ground pin of the encoder. A 12-volt supply will also need to be connected to the Input of the encoder.

To begin the test the motor will be supplied its minimum voltage of 6 volts. The pulses generated by the magnetic encoder will be seen on the oscilloscope. According to the data sheet of the encoder, there will be 324 full pulse cycles meaning a voltage rise and drop, for each full rotation of the output shaft. This is due to the internal gearing within the motor and the fact that the encoder is using a 24-pole magnet. We will use the oscilloscope to get an RPM value of the output shaft by multiplying the frequency of the encoder pulses by 60.
Once these calculations are complete and recorded, the voltage will be increased by one volt. The process will be repeated 6 times in total with the final reading being at the 12-volt rating of the motor. This will, after all, be the highest voltage that will be supplied within our project.

Once these RPM values are found, we will then need to calculate the MPH, given the wheel size of our cooler. We want to ensure that the cooler will never exceed 5 Mph, which would be a safety hazard.

7.2.3 PWM Output of Microcontroller Testing

The PWM signal output of the microcontroller is integral to the functionality of the motor control subsystem. These signals will be used to simulate the desired analog voltages acquired in the DC motor vs. Voltage testing procedure. We need to test the PWM with different duty cycles and frequencies to calibrate the needed duty cycles that will produce the desired analog signals. This can be calculated theoretically, but as we all know, the components will not act exactly the way they should, and it will be necessary to get these physical values to ensure our project functions properly.

The values that we are interested in finding during this testing are the waveforms generated by the microcontroller, and the apparent analog voltage seen at the output. To measure these values, we will be using an oscilloscope and a DC multimeter connected in parallel with the PWM output pin of the microcontroller and ground.

This test will involve some software, though the software will not be tested. A code will be installed on the ATTiny85 which will generate PWM signals which increase in duty cycle in a periodic pattern. The test code will take a button push as an input that will trigger an interrupt, increasing the duty cycle by 10% each time. Once the duty cycle reaches 100%, the next button push drops it back to 0%. For each of these duty cycles, the oscilloscope readings and multimeter readings will be recorded. We want to ensure that when the duty cycle is at 50%, the apparent output voltage is one half of it's max and that the output changes linearly with the duty cycle.

We will use these values to calibrate the PWM signal we will use with the motors based on the actual values we found.

7.2.4 MOSFET Circuit Output Testing

The final testing procedure used to prove the functionality of the individual components of the motor control subsystem is the MOSFET circuit output testing. This test will reveal the effect of the circuit on the PWM signal. The final signal generation algorithm may have to be adjusted based on this testing. It is expected that the MOSFETs will incur some delay on the waveform and possibly some loss in resolution and shape. It will not be known for sure until this test is completed. It is also necessary to ensure that the polarity switching functionality of the MOSFET drivers is working properly. This will be necessary for the functionality of our project

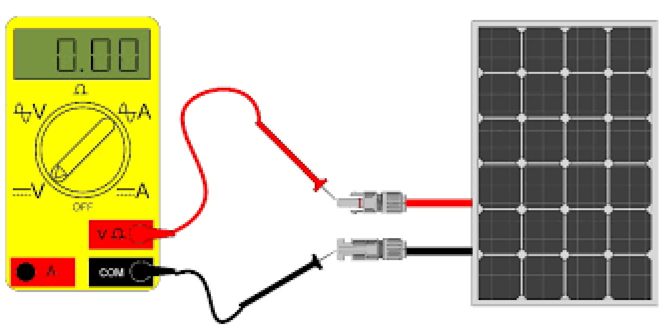
The values that we will be looking for are the output waveform of the MOSFET circuit and the output waveform of the microcontroller. We will use an oscilloscope to measure and compare both. We will also use a multimeter to measure the apparent analog voltage at the output of the MOSFET circuit. The Oscilloscope will have one channel connected in parallel with the MCU output and ground, while the other channel will be connected in parallel with the output nodes of the MOSFET circuit. The multimeter will be connected to the output of the MOSFET circuit as well.

This test will require some software although the software will not be tested. The code which will be created for this test will have to interact with the MOSFET drivers by not only providing a PWM output from the microcontroller but also outputting control logic to dictate the polarity of the output. This test code will also take a single button as input, but it will add a second routine after cycling through the duty cycle which will switch the polarity. During this process, we will be recording the oscilloscope readings as well as the multimeter to ensure proper functionality of all components. The goal of this test is to ensure that the MOSFET circuit does not distort the PWM signal in a damaging way and to ensure that the MOSFET driver is able to properly invert the voltage. This test will also be used to ensure that the output voltage of the MOSFET circuit is able to reach the maximum of 12 volts.

Many functions of this project will be proven to work or will fail during this testing procedure, making this the most important testing procedure for the motor control subsystem. After our design is able to pass this test, we will attach the motors to the output and retest our circuits under load.

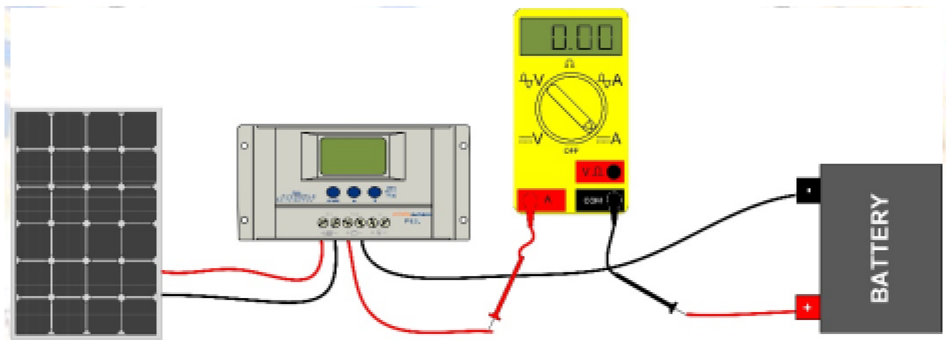
7.2.5 Solar system testing procedure

Disconnect the solar panel completely from the battery and regulator. While the solar panel is directly in the sunlight, measure the voltage by connecting the negative (COM) test lead from the multimeter to the negative MC4 connector and the positive test lead on the multimeter to the positive MC4 connector. If the measurement is zero, then the junction box on the back of the solar panel should be opened with a flat-head screwdriver. Then the measurement can be taken directly from the positive and negative terminals inside the junction box.

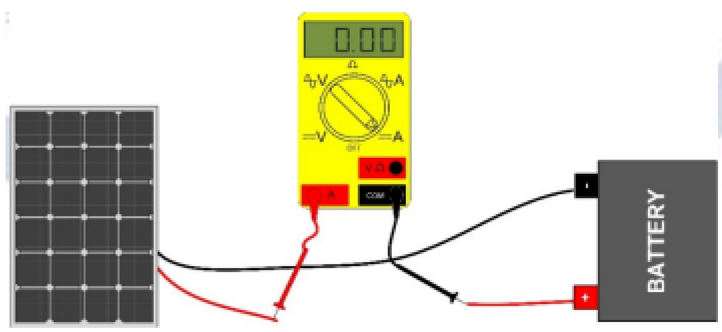


Disconnect the solar panel completely from the battery and regulator. While the solar panel is directly in the sunlight, measure the amps directly at the positive and negative MC4 connectors by connecting the negative (COM) test lead from the multimeter to the negative MC4 connector and the positive test lead on the multimeter to the positive MC4 connector.

Connect the panel to the charge controller and the charge controller to the battery. Disconnect the positive cable between the battery and the charge controller. Measure the current by connecting the positive test lead from the multimeter to the positive cable from the controller and the negative test lead from the multimeter to the positive battery terminal. This measures the current that the panel and charge controller are passing to the battery.



Now connect the solar panel directly to the battery without the controller. Disconnect the positive cable between the battery and the panel. Measure the current by connecting the positive test lead from the multimeter to the positive cable from the controller and the negative test lead from the multimeter to the positive battery terminal.



If there was no current when the regulator was in place, but there is now current present without the controller, then the two main possibilities are (1) Loose cable connection at the charge controller terminals. Disconnect and re-attach the battery and solar cables from the charge controller, making sure that there is solid electrical contact to the charge controller terminals. This is the most common problem. (2) There is a possibility that the charge controller could be faulty.

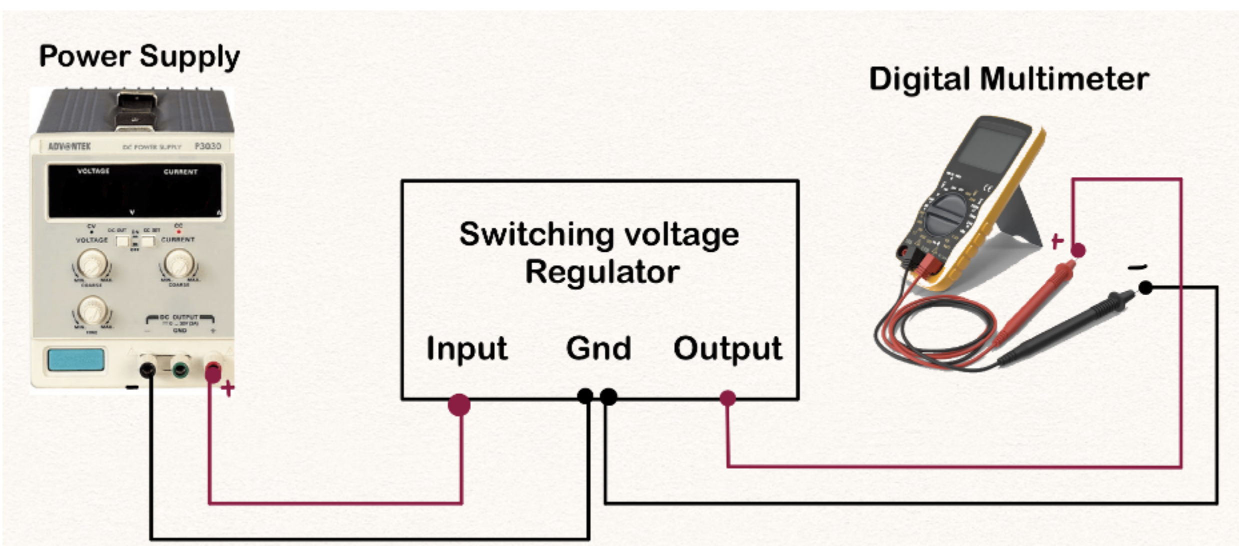
7.2.6 Voltage Regulator Testing Procedure

We have used the schematic/PCB design software tool – Eagle to simulate and design the physical board for the switching regulators in the previous section. In this part, we will discuss the design implementation and how the regulator will be tested to confirm the system functionality.

In the next semester, we will have to order the PCB design fabricated. We also will be able to access the senior design lab to perform testing and have all the circuit testing equipment provided. We will have to ensure the values of the purchased voltage regulator IC, resistors, capacitors, and inductors fall into the acceptable range according to the datasheets.

As the selected battery will provide at most a 12.8V input to supply the circuit board, for testing purposes we will use a DC power supply to input a 12V to the regulator circuit. The goal of this testing is to ensure that the output side will always receive roughly 3.3V to supply the main board. Furthermore, when the battery is discharged the resulting voltage of the battery is around 10V. Hence, we will also need to set the power supply voltage to 10V to check if the output is capable of remaining unchanged output as expected. The measured range of the output falls inside the input range from 10V to 12.8V. The DC power supply should not provide over 17V to prevent damage to the circuit.

The diagram below illustrates the way of connecting the testing mechanism and the regulator. There could be some minor discrepancies due to instrument error but the measured results should stay in an acceptable range.



7.2.7 Peltier Cooling Testing Procedure

To begin our initial testing for our Peltier cooling system, we need to know some baseline information, such as how cold can our device get down to and how long it took to achieve it within a smaller refrigeration space than our cooler.

For the testing phase, we will be using a DC power supply provided for us at the University to power on our Peltier device. With the DC power supply set to 12V, we will place our device inside a relatively smaller cooler and see how cold our unit can get while constantly checking the temperature with an instant read thermometer every 10 minutes. We will do this first with an empty cooler and once again with some items inside. With the information gathered here, we will be able to calculate the necessary time allotted to reach the temperature we need.

With that being said, the standard for refrigeration temperature in the United States is 40 degrees Fahrenheit and 0 degrees Fahrenheit or below for a freezer. So our goal is to get our cooler to at least 40 degrees to keep within safe guidelines from the FDA (Food and Drug Administration) to stop possible bacteria from multiplying, with the ideal temperature being between 38 and 35 degrees.

Due to the nature of our design, the Peltier device does not need to be constantly running because in theory, the cooler itself should be able to retain a good amount of the cold inside. To circumvent this we will be testing our Inkbird ITC-1000 in conjunction with testing our cooling device.

We will be able to set the temperature on the Inkbird ITC-1000 to automatically shut up the power to the Peltier device. Initially testing will be to check the temperature of the ambient air alongside an instant read thermometer to check for accuracy, followed by hooking it up to our device and setting the temperature to at least 40 degrees and see if it shuts off our Peltier device. We will run both of these tests at least 10 times to get a good sample size and average of our desired cooling output.

7.3 Software Testing Environment

While, for the most part, software testing can be done on any computer that can run the software, our project will require some physical measurements to properly test some of our software. For this reason, the software testing environments will include software IDEs as well as some hardware measuring devices. We have chosen to use the Arduino IDE for programming our microcontrollers as it provides a high level of support for C/C++, as well as many debugging tools necessary to test our scripts before ever loading them onto the microcontrollers. After the scripts are loaded, the outputs will have to be tested using hardware measuring equipment provided to us by the Senior Design lab located on campus here at UCF.

7.3.1 Software Specific Testing Procedures

The following sections will outline the individual procedures that will be used to test the important software aspects of our project. In each section, the source code under test will be explained, the important values and necessary equipment listed, and finally, the test procedure will be outlined.

7.3.2 PWM Output Based on Potentiometer Input

The source code that will be tested during the following procedure is responsible for translating the analog voltage from the potentiometer into PWM signals with the proper duty cycle at the output. We will also be checking that the correct PWM output pins are active which correspond to the forward and reverse polarity control needed for the MOSFET driver. This polarity control is done by outputting the PWM channel to different pins, which are connected to the IN+ and IN- pins of the MOSFET driver based on the current voltage value read at the input of the microcontroller. The details of this source code are explained further in the Software Design section of this document.

The values which will be looked at in detail are the PWM output signals generated by the microcontroller and the voltage that is being read by the microcontroller, corresponding to the user's input. For the first part of this test, an analog DC power supply will be used to simulate the potentiometer output. Once the system passes the test using the controlled power supply, it will be replaced by the potentiometer module. An oscilloscope will be used in parallel with the outputs of the MCU and ground pin to measure the PWM waveforms generated by the microcontroller and a multimeter will be used in parallel with the ADC input pin of the microcontroller and ground pin to measure the input voltage.

The first part of this test procedure is writing the script. As the code is being written it will be tested by the debugging applications within the Arduino IDE. When the code is complete and can be compiled, it will be loaded onto the chip using the programmer device. The programming device that we have chosen, explained in the Project Prototype Construction section of this document, contains female pin headers which can be used to connect the microcontroller to a breadboard while still being in the programmer. In the first phase, using the analog DC power supply, the input voltage will be connected from the supply directly to the breadboard where the multimeter will be connected in parallel, then routed to the chip through the programming device. In the second phase, the power supply will be connected to the potentiometer at 3.3 V, and the output voltage of the potentiometer will be connected to the breadboard. The PWM outputs of the microcontroller chip will also be routed to the breadboard and the oscilloscope will be connected in parallel there. The ground pin of the chip will be connected to the ground rail of the breadboard and will be used as a common ground for all devices in the test.

Once setup is complete, the testing can begin. The input voltage, whether from power supply or potentiometer, will be adjusted to simulate user input. This value will be changed incrementally by 0.5 V at a time and recorded. As the input changes, the output signal being measured by the oscilloscope will be recorded. During the test, we want to ensure that the PWM duty cycle adjusts linearly with the change in input voltage. We also want to ensure the correct output PWM pins are active based on the position of the potentiometer or the simulated input from the power supply.

This will be the final test of the individual modules of the motor control subsystem. Once these systems all pass their corresponding tests, a test of the entire system will be conducted.Voltage Regulator Testing Procedure

8. Project Budget and Financing

(table 32)

Component	Price (Estimated)

DC Battery	100$
Peltier Device	50$
Cart	100$
Thermostat	15$
Cooler	50$
Current and Voltage Sensor	30$
Solar Panel	80$
LCD	10$
Electronics Parts	40$
MCU (Controller)	10$
DC Motor	2 x 25$
PID Controller	70$
Wagon	150$
Total	755$

9. Initial Project Milestone

All projects have a deadline and ours is no different. Many projects fail due to poor planning and execution of necessary milestones to complete on time and hopefully under budget, which is our goal. Below we outline what our team needed to achieve by the given deadlines to ensure a complete product by the end of our college careers and into our future ones.

9.1 Senior Design I

(table 33)

Due Date	Deliverable	Steps to complete
5/21/2021	Senior Design Project Ideas	1) Individual's idea submissions for the potential projects 2) Team agrees on one idea
6/11/2021	Divide & Conquer 1.0	1) Independent research 2) Team meetings to collaborate
6/25/2021	Divide & Conquer 2.0	1) Meeting with Dr. Richie to go over v1.0 2) Team meeting to formulate plan 3) Independent Research 4) Team meetings to collaborate
7/9/2021	60-Page Draft Senior Design Document	1) Team meeting to formulate plan 2) Independent Research 3) Team meetings to collaborate 4) Team meeting to proof-read before submission
7/23/2021	100-Page Report Submission	1) Independent research to elaborate on initial document parts 2) Team meetings to collaborate 3) Team meeting to proof-read before submission
8/3/2021	Final sd1 Document	1) Team meetings to review the 100-page report 2) Independent work to make changes/corrections.

		3) Team meeting to proof-read before submission

9.2 Senior design II

(table 34)

Due date	Deliverable	Steps to complete
September/2021	Initial PCB design	1) Order parts required 2) Team continues to update documents
October/ 2021	Finalize design for PCB and project prototype	1) Test to ensure all the parts function properly 2) Fabricate, assemble and debug 3) Have the final physical design 4) revised 5) Complete the final physical design
November/ 2021	Final document	1) Work on conference paper and SD2 final document
December/ 2021	Final presentation	1) Team prepares for final presentation 2) Present and conclude project

10. Appendix

This section is all the references used throughout the paper and resources gathered.

10.1 References

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