GROUP 1

Portable Solar Tracker

Senior Design 1

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1 Introduction

The synopsis, goals, specifications, and initial planning will be introduced in this section.

1.1 Executive Summary

Harnessing the energy of the sun has been an ongoing human endeavor from the dawn of agriculture to the modern age of silicon fabrication. In recent years there has been a great deal of interest involving the breakdown and storage of solar energy to provide power and heat to any given structure or device. This interest has manifested itself into new technologies and methods of approach that are constantly being developed to solve the problem of a world dependent on non-renewable energy sources that are gradually being depleted. The problem with photovoltaic solar panels and collectors that have been developed in the past is their efficiency, with ten-percent being generally accepted as a "good" efficiency. Looking at that figure it would seem like there is a lot of room for improvement. This project is an attempt to join the throngs of engineers and scientists in the development and progression of this discipline by constructing a maximally optimized solar energy capture and storage device that can sustain on its own power as well as power an external electronic device.

The principal challenge of this project will be in the optimization of the device. An optical collector, that is yet to be precisely determined due to no tests having been conducted thus far, will be used to concentrate the most area of sunlight onto a smaller solar panel, so save the cost of a wide solar panel array. This optical collector will be mounted on a mechanical device that uses electronic sensors to follow the path of the sun and keep the photovoltaic panel perpendicular to the sun's rays. This orientation of the panel has been shown to provide the highest possible level of output given the conditions of that specific day. Power must also be minimized within the system. All of the voltage requirements must be met for the components that make up the solar tracking device but current needs to be at its lowest possible but still functional level for all of it except the output to the external electronic device to be charged; this will be a challenging undertaking. Another important factor that will need to be examined is value versus cost, for instance if an expensive battery can be purchased to store a lot of energy and make the device a little more useful in that it charges faster, what is its value to the overall design in light of its cost? Questions like this will be closely studied; the more questioning and investigation that arises, the greater the success of the optimization of this device is likely to be.

An optimization project would seem to be a perpetual project, and in a way it is. The project team has a multitude of aspects to work on and analyze, but the principal criteria for this device to be considered successful will be for it to automatically track the path of the sun, store the energy collected through photovoltaic cells to a battery that discharges to an external electronic device, monitor this stored energy and display the analyzed results in a user-friendly format on a digital screen. Other features such as a digital compass and a thermometer may be added to the device and their results will be displayed on this same screen. Overall, the project will be very challenging, but any new breakthroughs or even understanding concerning this discipline will be considered a great achievement.

1.2 Motivation

After hundreds of years of burning fossil fuels, a large “carbon footprint” has been left on the environment, and many government organizations, private organizations, even individuals are beginning to look toward clean, renewable sources of energy to liberate them from the tyranny of those traditional carbonaceous and non-renewable sources that have dominated in the past. With growing concerns for issues such as global warming and ozone layer depletion, there has never been more urgency for the development of these “green” technologies. It is the desire to be a part of this green, earth-shaping revolution that drives this project. The time for change is now; the human race can tarry no longer.

There are several types of renewable energy sources that are currently being vigorously studied and implemented into a multitude of settings, these include wind, hydro-electric, and solar energy, among others. While the two former sources are mostly built on a large scale, while the latter, solar energy, is a source that can be practically built on the top of a building or in someone’s backyard. Solar energy is a field that is on the rise and will likely become integrated into more and more aspects of everyday life as the years progress. It is a safe bet that solar energy will remain a relevant field for at least the next 50 years and for career-seeking college graduates, that is an important detail to consider.

Solar energy is of great interest to many groups and individuals around the globe but it is very important to sun-rich areas like Florida, with its reputation shining through in its nickname, “The Sunshine State”. Several politicians have come to Florida specifically to motivate people to want more solar energy collectors in their state, and the people that listen are generally very receptive. Human beings seem to naturally want to invest in the technology that emerges from this field to achieve energy independence and help save their home planet that has been abused for so long. The thought of creating a device that is not only useful, but one that can enhance the quality of life for many people is very motivating, and to do this would be adhering to the true purpose of science.

1.3 Goals

This project will involve the creation and optimization of a device that absorbs the sun’s energy, stores it, and discharges in the most efficient way possible. The primary goals and objectives for this device include:

- Adhering to modern safety and quality standards
- High efficiency
- Sustenance on its own energy
- Reliable operation

- The best quality for the lowest cost
- Strength and durability, enough to withstand various weather conditions
- A user-friendly interface
- Portability
- The ability to be reproduced and manufactured

In order to satisfy the first goal of high efficiency the device will be tracking path of the sun in the sky to keep the sun's ray's normal to the surface of a photovoltaic panel. An optical collector will be attached in order to assist in the capture of these rays. The energy absorbed will be stored and discharged to a small electronic device when required. The stored energy will also be monitored and displayed in an aesthetically pleasing format on a screen with buttons that navigate the system's information.

1.4 Specifications

The device will have the specifications as listed in Table 1.1.

	S.I. Units	Imperial Units
Dimensions:	0.8 m long x 0.6 m wide x 1.2 m high	2.62 ft long x 1.96 ft wide x 3.93 ft high
Weight:	12 kg	26.45 lbs.
Voltage Output:	10-13 Volts	-
Current Output:	50-100 mA	-
Power Output:	10 Watts	-
Temperature Rating:	-10 °C to 50 °C	14 °F to 122 °F
Efficiency (Output/Input)	20% minimum	-
Life Expectancy	500 uses	-
Accuracy	±3° of the sun's position	-

Table 1.1 Specifications

1.5 Budget Projection

It has been decided that the budget for the project shall not exceed $400. The budget reserved for each element is presented in Chart 1.1.

Solar Panel:	$50
Battery:	$50
Microcontroller:	$50
Motors:	$30
LCD Display:	$30

Optics (Mirrors and Lenses):	$40
Frame Components:	$50
Cooling System:	$40
Miscellaneous Components:	$60
Total:	$400

Chart 1.1 Budget Projection

1.6 Milestone Chart

In order for the project to be completed by the specified deadline, adhering to a schedule of tasks would be ideal to maintain productivity and avoid "falling off track". This section provides Gantt charts for the months that the project will be worked on.

1.6.1 May Milestones

The month of May will be the beginning of the construction of the phase. The research and planning will already be completed and the foundations for the work to come will be laid. The Gantt chart shown in Figure 1.1 displays the periods of time for which the tasks will be conducted beginning with Saturday, May 1st.

The first step will be to order the major parts and components necessary for the device in preparation for the return to school after a brief intermission between semesters. During the break it will be a good idea to begin familiarization with the code native to the microcontroller that was chosen. If all group members dedicate themselves to this task then there should be consistency and cohesion when it comes time to write and debug the source code for the device (a task that is scheduled to be completed three weeks later). A printed circuit board design is scheduled to be completed shortly after microcontroller code familiarization begins; therefore, it is likely that the group will need to multitask in order to achieve these simultaneous goals. The best printed circuit board fabrication company for the specifications required will then be contacted and ordered from. In the process of waiting for the printed circuit board to be delivered, testing can begin on interfacing the microcontroller with the motors after a portion of the code has been written. Hopefully the solar panels have also been delivered at this point and testing can begin to determine their output efficiencies. The purchasing of minor components from local vendors to avoid shipping delay will also be conducted during this time. These minor components will assist in the implementation and interfacing between the other major components.

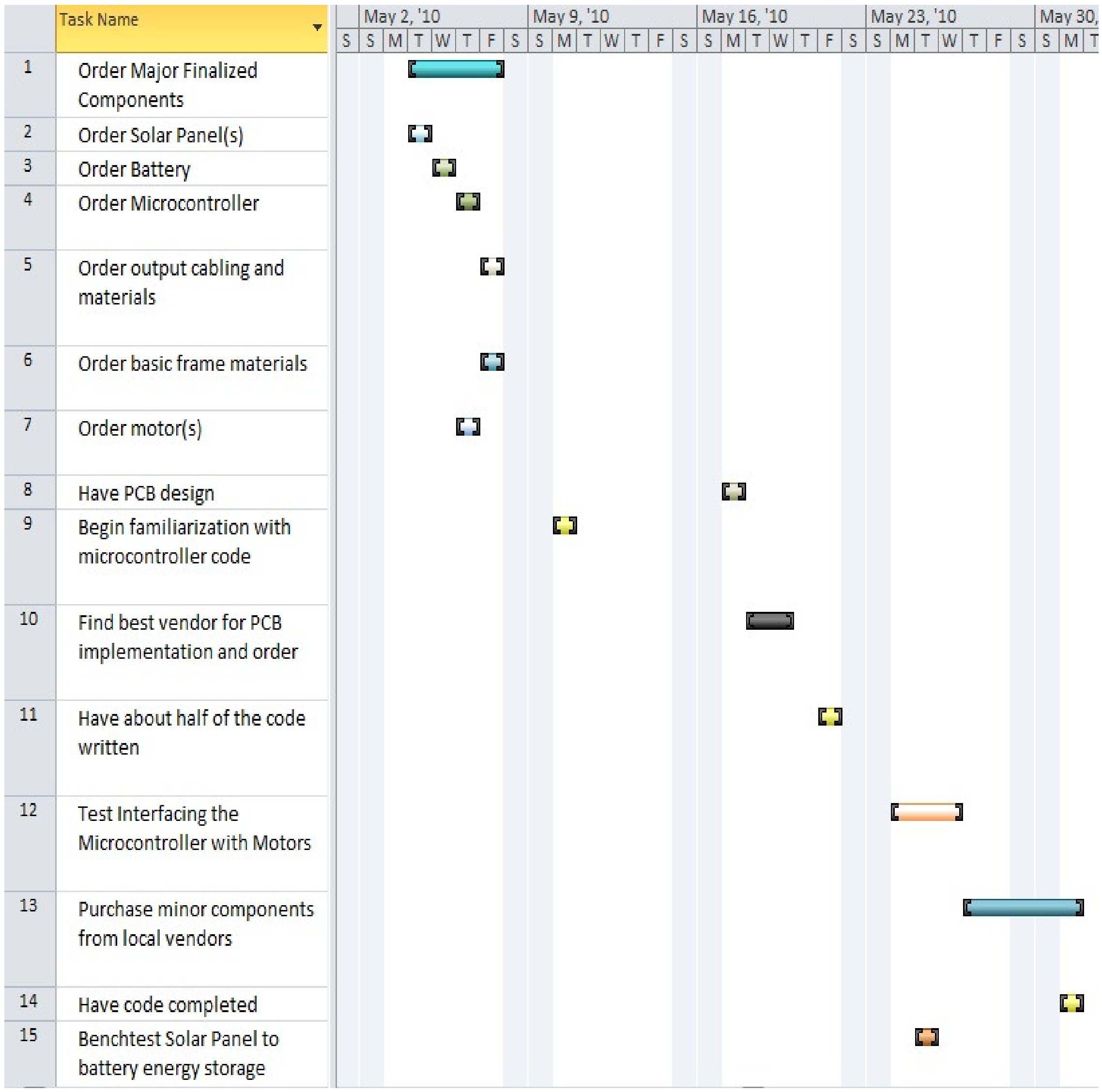

Figure 1.1 May Milestones

1.6.2 June Milestones

The month of June will be a critical month in the construction and implementation of the solar tracking device. This month will likely determine the quality of the finished project in that if it is completed early there will be time to fine-tune it so that it can reach its maximum potential. The Gantt chart in Figure 1.2 displays the periods of time for which the tasks will be conducted beginning with Tuesday, June 1st.

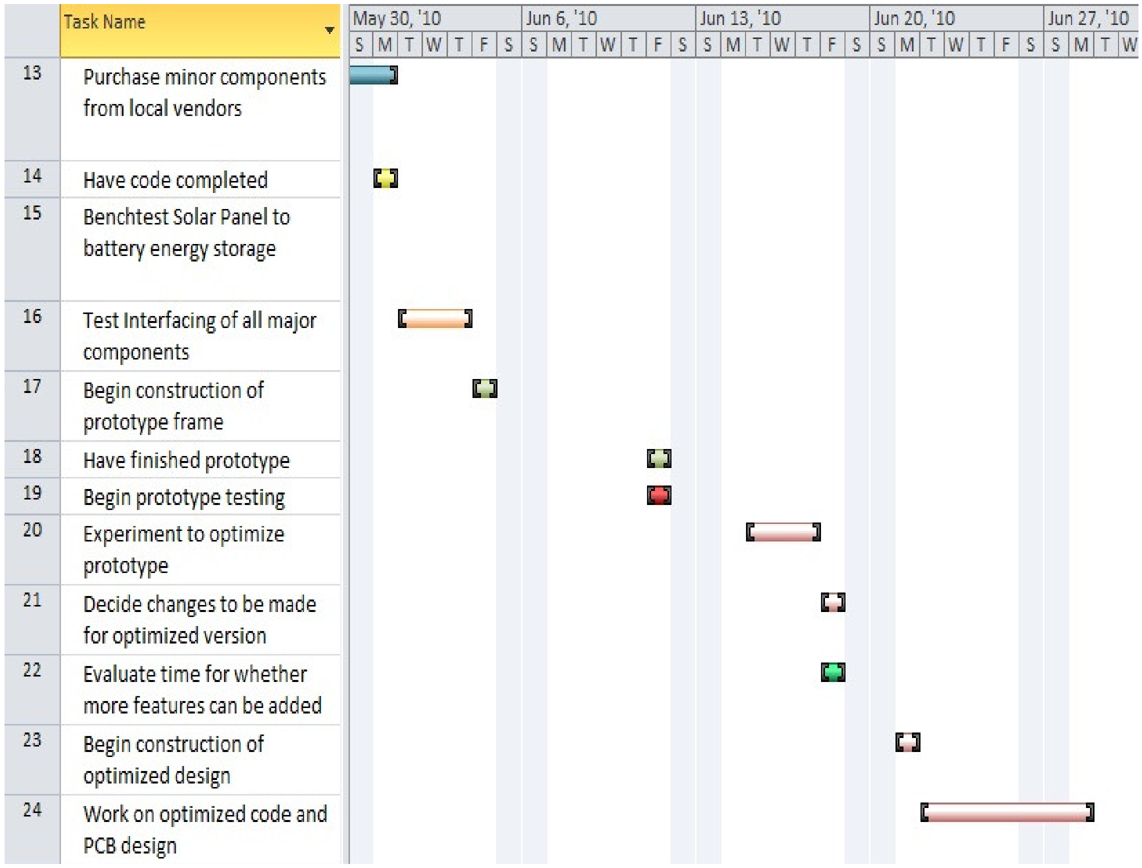

Figure 1.2 June Milestones

The beginning of June will see the final testing of component interfacing and will eventually move on to prototype construction and testing. The components need to work and a design plan will need to be realized and implemented to determine the arrangement of the components in the prototype device. In the construction of the frame for the prototype it is likely that power tools will be needed and a lot of manual labor unrelated to electronics will need to be done. The prototype will have sufficient time to be built and tested. Immediately upon the completion of the prototype, testing of its efficiency will begin. The device will undergo full days of testing and ideas will be considered for its optimization. These ideas will be tested and the information will be gathered and conclusions will be drawn. These optimizations will then be implemented and re-tested. It will also be assessed at this point as to whether any extra features should be added to the device to make it a more impressive overall project. This decision would depend on the challenges that are still present for the group to face and the perceived challenge of the feature that is desired to be added.

1.6.3 July Milestones

The month of July should mark the final stages of the project. The goal is to have a working prototype in early July so that the rest of the month can be spent preparing for the presentation at the end of that month. It is better to allocate extra time that may or may not be used than planning to work until the deadline and needing more time. This month will involve the final testing and optimization stages, perhaps the addition of extra features, and any bugs or issues with the device will be resolved. The tasks for this month are displayed in Figure 1.3 where July 1st is on the first Thursday.

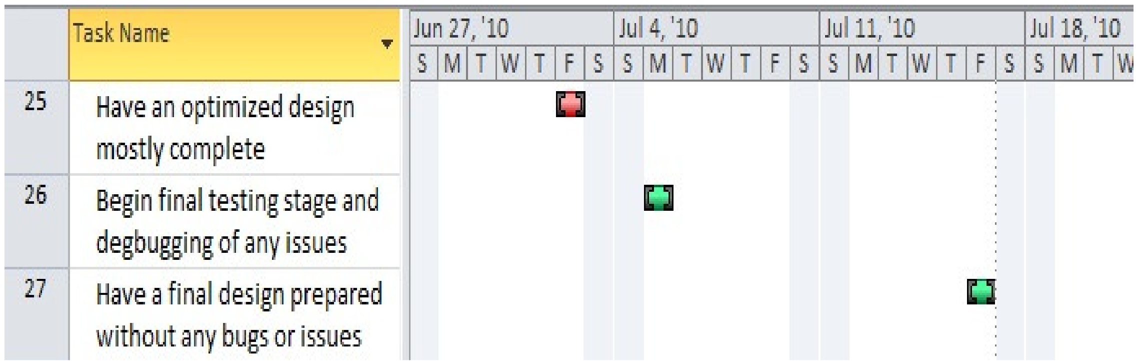

Figure 1.3 July Milestones

Now that the project has been defined the research that will be necessary to create the best design will need to be conducted.

2 Background and Research

As much as the group would like it to be, the solar tracking energy storage device is not an entirely unique idea, nor is any element that makes up its design. The following sections will discuss the processes, results, and conclusions that were discovered through pertinent or similar projects that have already been conducted, as well as vital data and information that will aid in the selection and implementation of the components necessary for the solar tracking device.

2.1 Previous Works

When beginning research for this project, it was decided that the first step was to investigate previous projects and works that had successfully implemented a solar tracker that was portable. Below will be examples of previous projects and works that helped to inspire ways for the solar tracker being designed in this project to be implemented.

Portable Charging Station [1]

Instructables.com is a website that features many how-to examples for various projects. The user DIY Dave posted an extensive how-to on his portable solar battery charging station which will be described below for the purpose of gathering ideas of how to implement a solar tracker that is portable, and yet still as efficient as possible. For the portable solar station, a 12V, 75 amp hour, deep cycle battery was used. To output AC power from the DC battery a 400 watt inverter was used. To make the entire system portable, DIY Dave used a rolling toolbox that could easily hold all the parts that were required. A 5 watt solar panel provided the power to the battery. The total cost of the project was approximately $198, including the battery, solar panel, inverter, toolbox, and miscellaneous wires and electrical connectors. There are a couple of main differences between this project and the project it is being researched for. First the solar panel does not track the sun, but instead just lays dormant wherever it is placed on the toolbox. Second, the solar panel charges the battery and then the battery is connected to the inverter once the battery is charged. In the solar tracker project, the battery and the inverter will be hooked up together and will potentially be turned off and on by a switch on the exterior of the portable unit. DIY Dave's project also used a bridge rectifier in between the solar panel and the batteries to prevent current from flowing back into the solar panels. This was done because the portable tracker on instructables.com can also be used with a wind turbine in addition to solar panels. For the solar tracker project, a simple diode can be used to prevent current from flowing back into the solar panels, although it may be possible that the solar panels have diodes built in for specifically this reason.

Underwater SOLAR PANELS 9% Stronger PV Photovoltaic Sun Power [2]

On youtube.com an experimenter named Dan Rojas conducted an experiment that studied the effect of a solar panel's output voltage in a cooler environment, in this case a fish tank filled with water, compared to that of a solar panel left to heat under the sun. He claimed he was inspired when trying to open a solar panel's casing and determine if he could make it waterproof when he discovered that it was already waterproof! He took a chance and dipped one panel in water and found something interesting, that the voltage output of the panel in tank (23V) was higher than one left outside of it (20V). The conclusion he drew was based on the temperatures of the surface of the panels. For example, the surface temperature of the panel left out in the sun was approximately 135 degrees Fahrenheit, while the temperature of the panel in the fish tank was about 80 degrees Fahrenheit. The viewer can tell that this voltage increase is caused by temperature difference and not a refraction of the light through the tank because the voltage increase is shown to be gradual, in other words if it were caused by the refraction it would have instantly jumped from 20V to 23V. Therefore the cooling of the solar panel can result in a 9% increase of voltage output and could be a useful optimization element if incorporated into the design of the solar tracking device. The 9 % result is a bit of a mystery however, since the change between 23 and 20 is 15%, but regardless this experiment has shown that cooler solar panels exhibit a higher voltage.

Breakthrough Solar Energy Technology from Israel [3]

A news story emerged from Israel in 2009 involving a Professor Fahman whose idea it was to concentrate light from the sun on an inexpensive sheet of inexpensive reflective glass that would focus that light onto a small sheet of the more expensive photovoltaic cells, which is more cost efficient than the other way around. In order to do this he designed parabolic reflective surfaces that would focus the light and result in absorbing and utilizing approximately 70 percent of the sun's energy while a standard panel would only absorb 10 to 15 percent of the energy. This professor and the company he works for plans to be able to sell this energy at $.08 per kilowatt-hour, and by the end of 2010 they plan to have smaller units to be installed on the sides of houses. This design is of interest to the group and could possibly be implemented into the final design due to its potential to enhance the overall efficiency of the finished device's output.

PIC Project- Precise Solar Tracker [4]

This is an example of a similar project that with a goal of precisely tracking the sun using a PIC control and PC monitoring. The experimenter used a PIC 16F877 with 8 analog to digital converters for light sensors and 2 PVMs for control motors. This is a 10 MHz CMOS-Flash based 8-bit microcontroller that is ideal for advanced level Analog/Digital applications. Visual Basic 6 was used to create the PC interface and C++ code along with PIC Basic Pro was sent through serial communication to control the motion of the tracker. The orientation of the sun was then output to an LCD screen through degrees of North/West/South/East. This project proves that it is possible to create a functional solar tracker using relatively basic engineering hobbyist tools.

Solar Concentrator Comparison [5][6]

In the youtube.com video conducted by greenpowerscience.com, they introduce the concept of solar concentration to help improve the efficiency of a solar panel. This video demonstrated the effectiveness of solar panel optimization. The experimenter from the video is Dan Rojas, in the video he used both Fresnel lens and regular mirrors to help test the differences in output between outputs of each compare to the stand-alone solar panel. He showed the amplification of sun light to gain more output power with their photovoltaic panel. In the experiment Rojas uses a 6 watt solar panel to power a 5 watt light bulb. Just hooking up the 5 watt bulb and letting the solar panel run in on a regular day, any nice conditioned weather environment, the voltage across the bulb came out to be 10 V. But when he put the Fresnel lens on top of the panel, the voltage output jumped to 20 V. The output voltage was increase by 100%, resulting in a better efficiency when the panel was attached with Fresnel lens. Of course the panel was position not at the focus point of the lens but under it. Rojas stated that if the panels were to be position at the focus point, this would result in the overheating of the panel and could caused potential damage to the panel. The Fresnel lens he uses was from the greenpowerscience.com website. The capability of this Fresnel lens, conducted by greenpowerscience.com, can potentially heat an object over 2000 degree Fahrenheit and melt zinc and copper metal. He then stated that if the panel were to be properly cooled that would also boost efficiency. Rojas then test the same experiment but instead of using Fresnel lens he used a single mirror. This resulted in an increase in voltage from 10 V to roughly 13 V.

Sun Catcher [7]

Besides using the popular photovoltaic solar panels, there are other high efficient and intriguing methods to absorb the sun's energy. Instead of the conventional method of converting sunlight directly of electricity; Stirling Energy Systems, a company base in Phoenix converts it into thermal energy by concentrating it into a central location. The thermal energy is then use to power an engine that's generate electricity.[7] This system is a gigantic 944 square foot energy concentrator that consists of 82 3x4-ft glass mirrors arranged into a parabolic shape similar to a satellite dish. Lights are focus into a 7 inch area of a power conversion unit called the Stirling engine.[7,8] It's a closed cycle engine that converts heat into kinetic energy by continuously compressing and expanding hydrogen gas. The structure itself, has a dual axis movement for full degrees of freedom to have the reflectors facing directly at the sun. Compare to other solar technologies, this one offer the most efficiency and more scalable at the lowest cost. One generator can produce 25kW at a record peak efficiency of 31%.[7] Since using a concentrator is the most effective way to harness the sun's energy, the parabolic dish shape is one of the designs been considered to be build for this project, although on a much smaller scale. An 18" satellite dish could be use as a concentrator since the shape and structure are identical. The face of the dish can be cover or coated with reflective material as long it still has a smooth parabolic curve. At the focal point of the dish is a low noise block converter that could easily be removed, and replace with a solar panel. Although this is a smaller scale of the Suncatcher, there is no intension of building a small Stirling engine that would be impossible. For the tracking, there are manufactured satellite dishes that have a built-in dual axis motors design for RVs and for tracking non-stationary orbiting satellites. With a simple programming, the motors can be controlled to turn to the direction of the sun.

2.2 Solar Panels

A major component of the solar tracking device will be the photovoltaic solar panel that collects the sunlight and translates that into energy. Finding the most efficient panel for the device will be critical in achieving the goal of having a highly optimized solar tracking device. The following section will discuss the different types of photovoltaic cells and will eventually lead to the selection of the type of panel that will be used for the project.

2.2.1 Solar Radiation

Solar energy depends so much on solar radiation given by the sun. The irradiances, express in watts per square meter (W/m^2) or kilowatt-hours per square meter per day ($kW \cdot h/(m^2 \cdot day)$) (or hours/day), is the solar radiation on a given area. In terms of photovoltaic it is given in terms of $kWh/(kW_p \cdot y)$ (kilowatt hours per year per kilowatt peak rating). The solar radiance given at Earth's distance from the Sun, about 1,368 watts of energy in the form of EM radiation from the Sun fall on an area of one square meter [9]. Shown in the Figure 2.1 are the scatter areas of solar radiation of the United States. By positioning photovoltaic panels across certain areas of the States, where solar radiation radiates the most you can harness or optimize the potential of solar power. Areas in the southeast United States appears to show the most solar radiances, this correlates to the weather in those regions. Other area that is suitable for photovoltaic panels is the whole southern and middle United States.

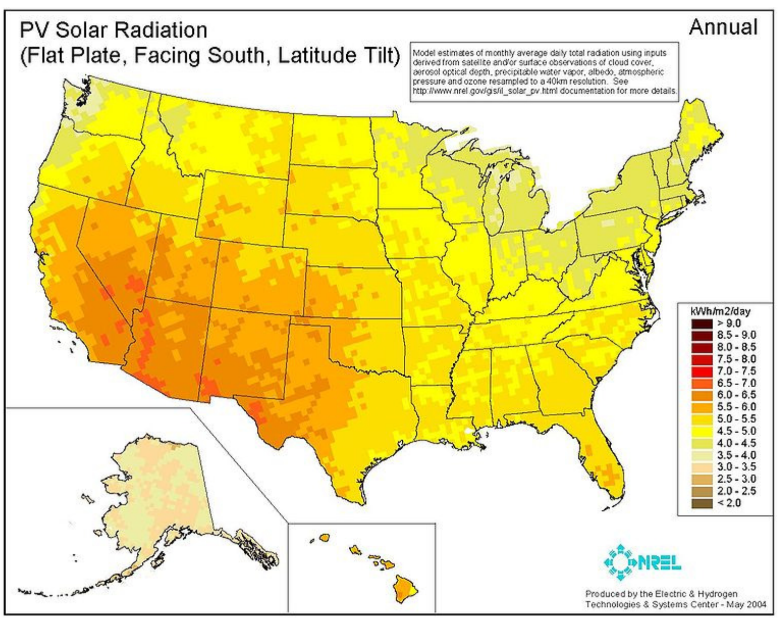

Figure 2.1 Annual solar Radiation in the United States
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2.2.1.a Effects of Sun Light on Exposed Surfaces

The amount of sun light exposure at any location is due to the fact that earth is on a titled axis. This proves to be vital in sun light radiation exposure on a given area. Figure 2.2 shows the effects of direct exposure and exposure at a 30 degree angle. For the direct exposure, the sun's energy is concentrated on a single area; therefore that area will be exposed to a more solar radiation. The effects of this can be experiences in certain areas in the world. This But when sun light hit the earth at a 30 degree angle the exposure is then spread to an area that is twice the size of when the light was hitting from directly above. This resulted in the dispersal of the solar radiation to an area of twice the sizes. In terms of how it affects the photovoltaic panels, with this concept this projects hopes to utilize the solar tracking to allow direct concentration of sunlight to hit the photovoltaic panels at all times in any given day, year long. As you can see the expose of sun light can dramatically affect a solar panel. When sun lights hits the photovoltaic panel at an angle of 30 degree the exposure or focus of the solar radiation on the panels will be less, resulting low efficiency during certain times of the day (mainly in mornings and afternoon with peak efficiency at noon) and year. With the solar tracker the panels can position directly under the sun, perpendicular to the sun's rays at all times.

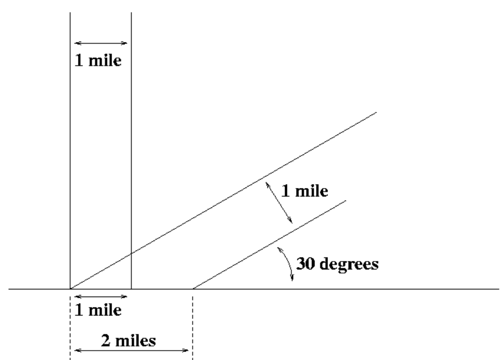

Figure 2.2 Effects of sun light at 90 degree angle and 30 degree angle
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2.2.2 Photovoltaic Cells

As you might know, the dependant for the needs for alternative energy resources is forever wanted. With that said the focus of this project is/are on the usage of solar power energy and how to optimize it so that for a give time, size, or condition it will produce more power than that of conventional solar panel.

Photovoltaic cell uses the photovoltaic effects, using the potential differences between materials when the material is exposed to electromagnetic radiation disperse by the sun. This effect is limited by the band gap of the material. When solar radiation hits the cell, if the energy of the electron is slightly higher than the band gap of the material it will then be converted into electricity. On the other hand if the energy is lower or greatly high than that of the band gap for the material it will then just be converted into thermal energy, heat. The solution for this limitation is to apply layers of photovoltaic cells on top on one another. In do so, this allows each layers to absorbs different energy spectrum. As light hits one layer the light is absorb. Any energy spectrum that is not absorbed initially or is reflected is then pass on to sequential layers and is absorbed. This solution allows for a vast range of absorption in the light spectrum [10]. This method is called multijunction cells.

As of date, there are dozens of solar power plants around the world. Everywhere you go and in some country you can see many people and place that implements solar power. According of pvresources.com, they listed about 600 of the world's largest photovoltaic power plant. The plants vary from 2 MW to 60 MW [11]. Of course there are other plants using other form of solar power to produce electricity. Take the Solar One project. It uses solar thermal to produce power. Solar energy is virtually inexhaustible, except when the sun dies, which isn't going to happen anytime soon.

Using solar power, it can be collected by either photovoltaic, or indirectly by a form of concentration of solar power. With photovoltaic method, material with photovoltaic properties will be arrange in an array to make up a panel and is pointing towards the sun such that the sun's ray are in perpendicular to the panel. From there it will then convert the sun's ray into electricity. With using the concentration approach, that are multiple ways of collecting energy. Take solar thermal for instant. With solar thermal the sun's ray are use to direct (concentrate) heat to a signal point and using some kind of high boiling point liquid, for example some form of water or liquid salt, to conduct the heat and transfer it to a boiler room and using a turbine to produce electricity. Another method of using concentration of solar power is to use photovoltaic in combination of solar concentration. With this method a single high efficient photovoltaic panel is use in parallel with some type of focusing device to focus much of the sun's rays on the photovoltaic panel. By using this method along with a high efficient photovoltaic panel more of the sun's rays will be converted into electricity than just using a normal photovoltaic panel. But concentration of solar energy is mainly use in thermal solar collection. Of course it does have its benefit when combine with photovoltaic panel(s).

Using photovoltaic panel(s), there are a variety of things to be determined over the course of this project. The type of material needs to be taking into consideration. There are a lot of materials that can be manufactured to produce photovoltaic panel. Some of the materials that make up photovoltaic panel(s) are monocrystalline silicon, polycrystalline silicon, microcrystalline silicon, cadmium telluride, and copper indium selenide/sulfide [12]. These are all types of crystalline silicon cells. They are generally made from layers of silicon. There are two type of make up for a solar panel; high-efficiency cell vs. cost efficient cells. As the name indicates high-efficiency cells aim to be high efficient in converting solar energy to electricity. High-efficient cells tend to convert more of the sun's rays than that of normal ones, around 40% conversion. The down side of high-efficient cells is that it is expensive. The popular solar panel that everyone is use to is the cost-efficient one, they have low power conversion, around 20%, but it makes up in being cheaper therefore you can produce the same power with multiple panels for a lower price. They only con to this is the sizes, since it takes more panel and space to have the same power as a high-efficient panel. Most of the records for high-efficient cell are compose of multijunction photovoltaic cells. Multijunction photovoltaic cells base on layers of thin film cells being stack together. Each layer is given their own characteristic band gap so that they can absorb light from different part of the spectrum. This project will most likely use a cost-efficient panel, due to the capability of being able to buy multiple quantity of photovoltaic panel at a cheap price.

The Figure 2.3 shows the improvement of photovoltaic cells over the decades. This figure also shows the different types of photovoltaic cells, its manufacture or place of origin, and its efficiencies. As of 2008, the efficiency of a Boeing-Spectrolab's metamorphic cell has an efficiency of 40.7 %. Although some of those photovoltaic cells are not in production, it just proves the potential of photovoltaic cells as a highly resourceful alternative energy source.

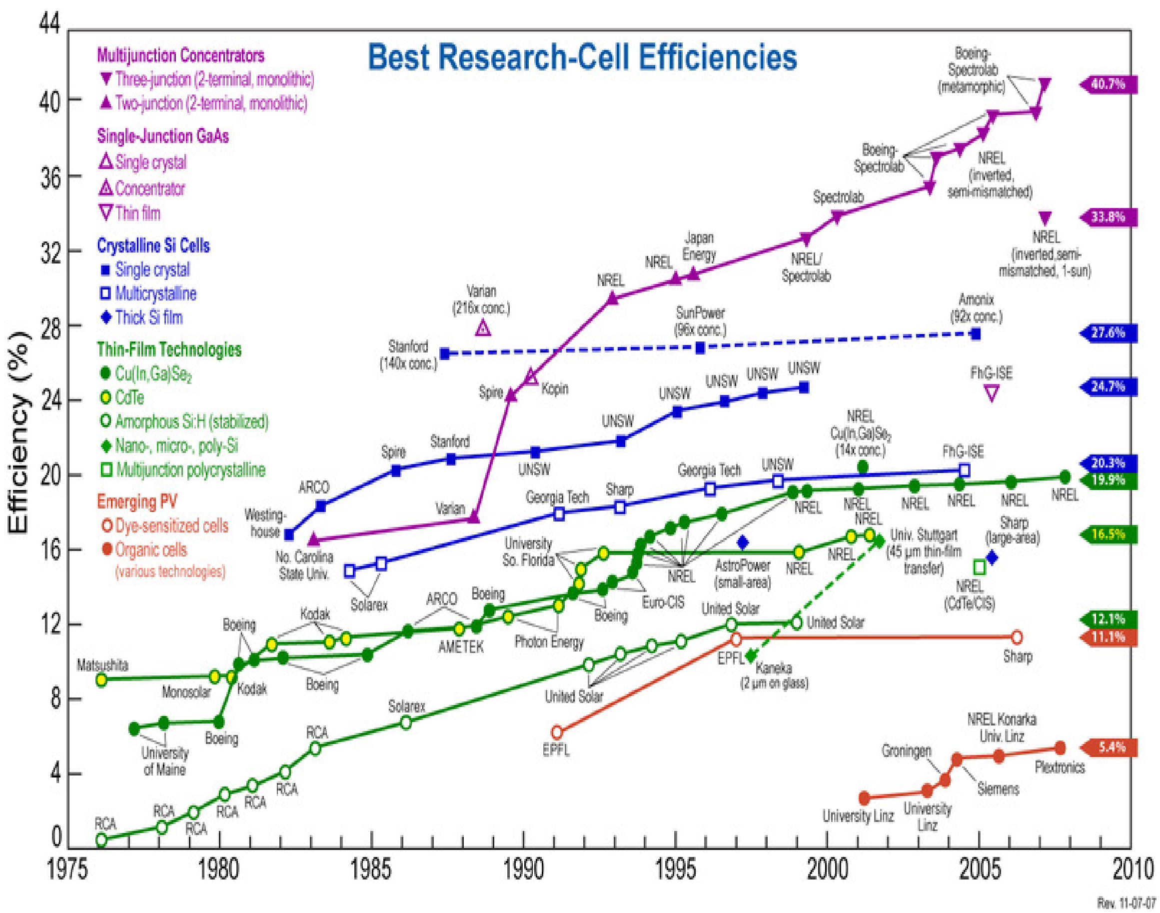

Figure 2.3 Author: east718 [13]
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2.2.2.a Crystalline Silicon

Crystalline silicon is silicon base material. For this project, the choice of using different crystalline silicon based photovoltaic panels will be vital. Each crystalline panel will have their own efficiency; for this projects either a polycrystalline silicon photovoltaic panels or thin film photovoltaic panels will be used, although consideration for monocrystalline will still be available. The only way is if monocrystalline silicon can be available in a cheap or cheaper quantity than that of the other crystalline silicon. The main reason the other crystalline is of choice is that they are the most cost-to-efficient panels. Even though they have low efficiency compare to the monocrystalline silicon cells, this project's intention is to optimize those panels to be comparable or better in efficieny than any standard ones.

2.1.2.b Monocrystalline Silicon

Monocrystalline silicon photovoltaic cells are high-purity silicon wafers. The reason is that they are slices from a single high-purity silicon crystal lattice. Monocrystalline silicon cells are use because they are the most the efficient photovoltaic cell, especially under low light condition [14]. One of the highest commercial available efficient monocrystalline cells is produced by SunPower, having 22% efficiency. Of the silicon base photovoltaic cells, monocrystalline silicon cells have shown to have the highest efficiencies. Although if exceeds the temperature of 50 degree Celsius monocrystalline cells loses its performance (efficiency) [15]. The structured of the monocrystalline cells allows maximum light absorption and current collection, since it's made from a single crystal lattice.

A large 2.5 Watt solar panel from Sparkfun.com has a unit rating for 8 V open voltage and a 310 mA short circuit, but can reach 9.15 V open voltage depending on the condition and exposure to sun light. The solar panel's dimensions are 7 x 4.5". It has a 5.5mm x 2.1 mm barrel plug. It is made from monocrystalline silicon and has an efficiency of 15 – 15.2 %. The weight of this unit is about 100 grams, which is about .220462 lbs or 3.52 oz.

SunWize 5 Watt Solar Panel from altersystems.com is a monocrystalline solar cell. Its uses can include rural electrification, water pumping, telemetry, communications, and battery charging. It can be use independently or in modules. This panel is encapsulated and bonded to a multi-layer of ethylene vinyl acetate and laminated with Tedlar backing, giving durability in severe conditions. It has an open circuit voltage of 20.5 V and a shor circuit current of 380 mA. Its peak voltage and current is 16.4 V and 310 mA respectively. The rated power output is 5 Watt. The dimension for this panel is 11.82 x 9.84" and it weights 3 lbs.

2.1.2.c Polycrystalline Silicon

Polycrystalline solar systems are among the cheapest and most common type of panel(s) out there [16]. Polycrystalline panel(s) are made from multiple crystal, there for is not a pure lattice. Polycrystalline is less efficient than monocrystalline but it is cheaper and easier to produce. Likewise it's the same with monocrystalline, when the temperature on a polycrystalline panel exceeds 50 degree Celsius their performances will then start to decrease.

There is a polycrystalline solar cell provided from goldmine=elec-products.com that is a high quality silicon polycrystalline solar cell, it package includes 24 strip of this polycrystalline solar cell. Each can be connected to form and array of cells. The output voltage of each cell is .45 V and the output current for them is 200 mA. The size of each of this strip is .3"W x 4"L. With that, anyone can assemble their own panel array. Put them in series or parallel to get either the voltage or current for any project.

2.1.2.d Thin Film Silicon

Thin film silicon consists of the cost-efficient solar panel(s). Thin film silicon, which can be amorphous silicon the non-crystalline allotropic form of silicon, is inexpensive to make in comparison of the bulk crystalline silicon wafer (cell) and required less materials to form, due to it being made from the same material as the other crystalline silicon cells but in lesser bulk. Amorphous silicon is built using two or three junctions to increase the amount of solar spectrum. Thin films is only micrometers in thickness, although the trade off are that it is low in efficiency, less than 20%. This is due to the high recombination of electron-hole pairs from lower carrier mobility [17]. Other composition of thin films is nanocrystalline silicon. Thin film is deposited at very low temperatures; therefore it can be deposited on glass and plastic. Of course thin film is worth looking into due to the fact that it is cheap and weights less than the other photovoltaic panel(s), which could be useful when designing the frame and structure of the solar tracking device. Unlike of other crystalline silicon cells whose power-generation capability loses when the photovoltaic panel is exposed to the rise in temperatures, thin film generates higher power during summer time [18]. If you implement the thin film with a tracking device along and a structure that allows light to be focus, onto the panel, this will yield a better efficiency for a lower price.

There is a thin film solar cell available from scientificsonline.com. The unit has an operating voltage and current of 7.2 V and 100 mA respectively. It has an open voltage of 10.5 V and a short circuit current of 120 mA. The dimensions are 253 mm X 75 mm and weights 12.9 gram, which is about .028439 lbs or .45 oz.

2.2.2.e CZTS (Copper Zinc Tin Selenium)

Introduced by IBM, researcher there have developed a new solar cells made from abundant material that could be produced at a cost that is on par with conventional energy sources with an efficiency of 9.6%. The material included are copper, zinc, tin, selenium, and sulfur. IBM's aims to use other abundant material in oppose to the cadmium- or indium based devices, which are scarce and costly to produce. With this photovoltaic cell from IBM, it shown to have 9.6% efficiency with is higher than predicted values for these materials. Of course this cell is still in it infancy stage, but according to IBM they indent to improve it so that in the future once in mass production it can meet or exceeds the efficiencies provided by today's standard photovoltaic panels [19].

2.2.2.f Organic Solar Cells

Up and coming organic solar cells just maybe the wave of the future. Researchers look toward organic material to further the speed and response time of technology. Researchers is now aiming at developing organic solar cells, in which the photovoltaic cells are compose of organic, carbon based, semiconductors [20]. Organic solar cells comes in two categories, one is bulk-heterojunction (BHJ) solar cells and the other bilayer heterojunction structures. The make up for bulk-heterojunction cells are conductive organic polymers where as for the bilayer heterojunction cells it is compose of small organic molecules. Similar to how the regular photovoltaic cells works, organic solar cells has to be dope with material so that the recombination of electron-holes pair products current therefore produces electricity. As of now the efficiencies of these cells are low, close to 5% for devices based on P3HT for polymer BHJ solar cells. As for small molecule based cells, they have an efficiencies of up to 6% for devices based on CuPc [21]. More recently, IMEC, a world-leading research firm on nano-electronics, demonstrated the capability of organic solar panel to reach efficiency of more than 3% compare to organic solar cell before by using organic solar cell with a spray-coated active layer and metal top contact spray-coated on top. According to PhotoVoltaics World, Jef Poortmans, program director for photovoltaic, has high hopes for the organic solar cell stating that although as of up to date for organic cells it has an efficiency of 6.7%. He said it's not the limit though. One property that allows for better explorations or usage of organic solar cells is that they have a relatively narrow absorption band. With this property, organic cells can be used in multijunction structure similar to that already implemented polycrystalline cells. Unlike that of the crystalline, the layers of the organic cells can then be allowed to absorb different part of the spectrum [22].

2.2.2.g Solar Panel Summary

Table 2.1 shows the available options for the photovoltaic cells. The table shows the different types of panel and its specifications. Key specifications allow for an easy analysis and comparison of the photovoltaic cells.

Solar panel	Description	Price and Availability
2.5 Watt solar panel	• Output power 5 Watt • Open circuit voltage is 8V with 310mA short circuit current • Weight 100g	$35.00 from Sparkfun.com
SunWize 5 Watt solar panel	• Output Power 5 W • Open circuit voltage is 20.5 V with 380mA short circuit current • Weight 3 lbs	$77 from altersystems.com
Polycrystalline solar cell (box of 24)	• Comes in a box of 24 solar strip • Output voltage of each is .45V with 200mA	$24.95 from goldmine-elec-products.com
Thin Film	• Provides 7.2V and 100mA • Open circuit Voltage is 10.5V with 120mA short circuit current • Weight 12.9g	$29.95 from scientificsonline.com
Polycrystalline solar cell (package of 36)	• Output power 1.75 Watt each • Open circuit voltage .55V with 3.6A short circuit current each	$36.65 from ebay.com

Table 2.1 Solar Panels Opinion

2.2.2.h Temperature

The effects of temperature changes can dramatically change the output power of a photovoltaic panel. Using a 6 V 250 mA solar panel and a 150 Watt halogen office lamp at a distance of 55 mm away and let running for 40 minutes. The result from this experiment shows almost a 40% change if peak output power. While optimum temperature seems to be around 30 – 45 degree Celsius with output power at 750 milli Watt, at 75 degree drop to almost 450 milli Watt [23]. Given if condition was the opposite, having kept the solar panel properly cooled the efficiency or output power could increase farther. Since the panel will be pounded with all sorts of light waves, keeping it cool will be crucial since on a given Floridian summer temperature can soar up over 90 degrees. Companies, like SolarWall have been using technologies to improve photovoltaic efficiencies. SolarWall uses air flow to divert hot air away from the panel(s) and at times can give an efficiency boost of 10% [24]. Integrated panel(s) seen on homes and such, for some of these panel(s) the systems have been rig to a ventilation system where heat from the panel(s) are diverted to supply heat to the homes or offices. This helps in preventing the photovoltaic panel(s) being overheating and losing it performances.

Figure 2.4 is an I-V curve representation as a function of temperature; it shows the effects of increased temperature on both current and voltage.

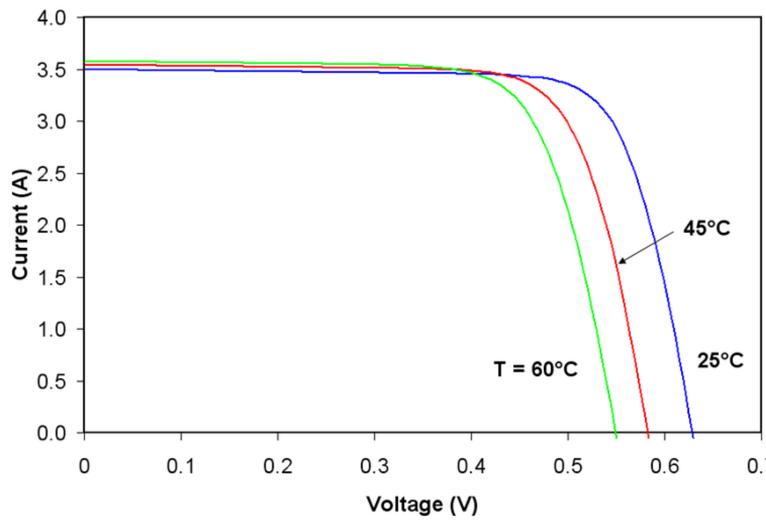

Figure 2.4 I-V curve as a function of temperature by Squirmymcphee [13]
Reprinted Due to Public Domain

The Figure 2.4 shows how voltage and current is affected by the increased in temperature. At lower temperature you produce more voltage, open circuit, with a lower current and vice versa, since temperature can affect the movement of atoms. The way the temperature affects the panel(s) is that as the temperature increases, the band gap of the intrinsic semiconductor shrinks thus decreasing the open circuit voltage [13]. This decrease is tribute to the equation above for the open-circuit voltage of a photovoltaic cell. The T in Equation 2.1 is the temperature impact on the panel.

Equation 2.1 $V_{OC} \approx \frac{kT}{q} \ln \left(\frac{I_L}{I_O} + 1\right)$

As for the current, as stated above for when the temperature increases, more incident energy is being absorbed thus increasing the charge carriers in the valence band to the conduction band [13]. This increase contribute to the increase in current for the given I-V graph.

2.3 Batteries

Cells and batteries come in several different sizes and voltage ratings (e.g. AA 1.5V battery), and are made from various combinations of dissimilar metals, with periodic elements ranging from Lithium to Lead. Batteries can be classified into two types, either primary or secondary. Primary batteries can be used only once and are the most common because they are easy to use and cheap to produce. The market for this type is dominated by Carbon-zinc dry cell and alkaline cell batteries. Secondary batteries can be recharged, and up until the new millennium have primarily been used for industrial and automotive applications. For this project, it is only practical to use the secondary type of battery, one that charges the energy received from the sun's rays and discharges when necessary. The battery chemistries to be discussed will include lead-acid, nickel-cadmium, lithium-ion, and nickel-metal hydride.

2.3.1 Nickel-Cadmium

The nickel-cadmium cell, a rechargeable energy source, is common in consumer electronics and many other applications; it has a set of desirable physical and electrochemical characteristics that attribute to its success. The nickel-cadmium cell is an "electrochemical system in which the active materials contained in the electrodes change in oxidation state without any deterioration in physical state… the nickel-cadmium cell charge/discharge reaction does not require the transfer of material from one electrode to the other." [25]. According to one source, a nickel-cadmium battery can withstand over 800 charge/discharge cycles. [26] Nickel-cadmium cells are also capable of withstanding a broad temperature difference from approximately -20 degrees Celsius to 55 degrees Celsius; however 23 degrees ambient temperature is usually the ideal operating condition. [27]

The sealed nickel-cadmium cell, a refined type, operates as a closed system that recycles the resultant gases, eliminating electrolyte loss. This type has several advantages over vented cell designs including lower operating costs, improved reliability, greater freedom in battery location, and the elimination of corrosion from vented electrolytes. It is clean, rugged, and lightweight. Most of these cells when commercially produced have a re-sealable vent mechanism as a safety feature but are still referred to as sealed cells. The safety vent opens under excessive pressure and safely release gas into the atmosphere then re-seals automatically. "Sealed nickel-cadmium cells normally operate at internal pressures well below the vent pressure because gas evolved during charging is readily recombined." [25] Even when the battery is overcharged the current will generate oxygen that will subsequently and conveniently be recombined, therefore the sealed cell can be continuously overcharged at constant rates without developing excessive internal pressure. This type of battery can be left on "trickle charge", keeping the cell in a fully charged condition for long periods of time. "It is important to remember that during charge the conversion of active material is an exothermic reaction. When the cell is in overcharge, essentially all of the energy in the current coming in is converted heat. With proper matching of the charger to the battery and attention to battery location and heat dissipation, the battery system can be designed to reach a thermal steady-state that will permit the batter to remain in overcharge indefinitely." [25] Table 2.2 displays the cyclic methods and applications of nickel-cadmium batteries and cells.

Charge Method	Quasi-current charge cycle	Timer-controlled charge cycle	-ΔV cut off charge cycle	Temperature cutoff charge cycle	Trickle charge cycle
Features	Simple and economical charge method. Low charge current but long charge time	More reliable. Simple and economical.	Very safe method that protects the battery	Economical and safe. Reliable, good with overcharge in low temp's	Simple and economical method used for long charges
Charge Time	15 hours	6 to 8 hours	1 to 2 hours	1 to 2 hours	30+ hours
Charge Current	0.1 C	0.2 C	.5 to 1 C	.1 to 1 C	.03 to .05 C (constant)
Application Examples	Cordless Phone, Shaver	Wireless equipment, RC toys	Cell Phones, iPods™	Portable power, Racing toys	Emergency lighting

Table 2.2 Nickel-Cadmium Cyclic Processes [26]

In this table, quasi-current charge cycle refers to a cycle process where the current remains the same throughout the charge however the voltage steadily increases. The timer-controlled charge cycle has a constant current and a rising voltage but as soon as a certain amount of time has passed it will lower the amount of current being stored, or control it. For the -ΔV cut off charge, when a drop in voltage is detected the battery stops charging, 100% charge capacity will be maintained if this method is used however an extra circuit will need to be implemented. [27] Temperature cut off will stop charging after a spike in temperature is detected, and trickle charge will charge at a very low current and take the longest. Care should be taken so that the battery does not experience a high ambient temperature while on overcharge, continued charging once the battery has reached its maximum storage capacity, so as not to reduce the battery life. [25] It would also be ideal to design the system in the proposed "thermal steady-state" so that the battery can be kept at its maximum performance condition for a long time. Of these listed cycles, a -ΔV cut off charge would be ideal to implement and store the energy transferred from the photovoltaic cells. One of the goals of the project is to be able to charge a small electronic device such as a cell phone and this method would seem to be the be the best for achieving that goal.

An important aspect of the batteries the group will consider will be the battery's capacity. The standard measure for a cell's capacity is in ampere-hours and can be calculated using the Equation 2.2.

Equation 2.2 $$Capacity = \int_{t1}^{t2} i\, dt$$

Where *t2* is the final time, *t1* is the initial, and *i* is the current. This measurement is determined by the quantity of active materials included in it and is directly related to the cell's volume, to put it simply the bigger the cell the higher the capacities. A common term used to represent the current flow rate of a cell is called the **C** Rate, which is the equal to the aforementioned ampere-hours. [25] The **C** denotation used in the table and henceforth represents this value.

Sealed cells have many advantages and benefits. They are fitted for applications that need high versatility or reliability. Next to lithium-ion batteries, a type discussed later, this type has the most energy per unit of weight. Nickel-cadmium batteries can also deliver energy at rapid rates, and these high discharge rates can even be sustained over many repeated cycles. Special sealed nickel-cadmium cells are capable of recharging in one hour or less, where the average nickel-cadmium cell would take 16 to 20 hours. They can tolerate overcharge of up to 0.3**C** and require less complicated charging circuits than fast-charge batteries. They generally have a long life and can provide hundreds of charge/discharge cycles and operate for many years in a standby condition. As mentioned previously, nickel-cadmium batteries perform well over a broad range of operating temperatures, but there are some specially designed cells that are able to operate higher temperatures of up to 70 degrees Celsius. Sealed-nickel cadmium cells can function in anything from a vacuum to a positive pressure environment and are mildly impacted by changes in humidity. The cells are also known for their versatility in that they can be mounted or oriented in any position at any altitude. An added bonus is that they are a very low maintenance battery, referred to by one source as an "install-and-forget" power source. [25]

A negative aspect of the nickel-cadmium battery that is worth noting is that it exhibits what is called a memory effect, also known as lazy battery effect or battery memory. This process occurs when certain nickel-cadmium batteries gradually lose their maximum capacity after being repeatedly recharged after only being partially discharged, thus it is said that the battery "remembers" the smaller capacity. [28] It is important to remember that batteries do still age and diminish in capacity with time, in conjunction with internal shorts and other issues, so just because the capacity is less does not mean that a memory effect has occurred. It may also be important to know that monitoring the state of charge through electrolyte concentration changes is not possible for nickel batteries, therefore leads and measurement devices will need to be gauging charge in another manner.

Within the nickel-cadmium family there are many other forms that are designed for specific purposes. For instance, the aerospace industry has put a lot of work into developing their own cell to meet the strict specifications required for it to function for a space vehicle. They are lightweight, capable of many charge/discharge cycles, and are highly reliable and free from defects. All of the aforementioned characteristics would be great for an optimized solar energy collector but when cost is considered, for a more terrestrial device that does not demand one-hundred percent reliability due to its ease of access, it may not be the most practical nor easiest to obtain in terms of availability for purchase. Another member of the family would be vented nickel-cadmium batteries. The application for these is in larger battery sizes. Battery sizes of this type actually have some of the highest energy densities of any commercially available rechargeable batteries. They can deliver very high currents for their capacity. There are two types of vented nickel-cadmium batteries: sintered-plate design and pocket-plate design. Sintered-plate construction gives a very rugged battery with low electrical resistance; it is great for the high vibration environments such as those created by aircraft. A pocket-plate design skips many complex manufacturing steps giving lower cost per amp-hour, but energy density can be sacrificed. This type is generally used for large stationary applications such as uninterruptible power supplies. Nickel-cadmium cells generally have long lives, between 20 and 25 years, and operate at extreme temperatures, The vibrations experienced by the solar collector should be negligible, hence the use of a sintered-plate design for this project is unlikely, but a pocket-plate design could prove useful for this project as long as the size and weight of the battery is not an issue in the design specifications. [25]

Photovoltaic cells are often used to charge nickel-cadmium batteries for devices in remote locations. When the photovoltaic cells are arranged in series it is good to place a reverse blocking diode at the end of the series so the battery does not discharge through the cells at low light-intensity. There must be enough solar cells however, to supply a minimum array voltage of 1.45V per nickel-cadmium cell, and when each cell is capable of delivering a maximum of 0.45V at midday it is a specification that needs to be taken into consideration. [25]

Batterydepot.com is selling AA size 1.2 V nickel-cadmium batteries with 1000 mAh capacity for $1.39 each. Onlybatteries.com is selling a 9V nickel-cadmium cell at 120 mAh for $4.65. The same vendor is also selling D capacity (5000 mAh) batteries individually for $7.59.

2.3.2 Sealed Lead

Sealed lead batteries have allowed designers to have a rechargeable battery that is clean, economical, high-performance alternative to implement into their system. In a conventional flooded lead-acid system, electrolyte is lost on overcharge resulting in a need for replenishment, but the sealed lead cell uses recombination to reduce, even eliminate, electrolyte loss. In sealed cells the positive electrode is limiting. The negative electrode will be discharged slightly after recombination to accommodate for overcharge. [25] Overcharge is not a problematic issue for this robust type of battery, along with the multitude of perks involved with a sealed-lead cell battery.

The sealed lead cell has many benefits that make it useful and shine through in its great performance. The low-impedance of the design gives it much higher discharge currents, sometimes up to 12**C** can be taken. It can perform better than most batteries at low temperatures, which could be useful if the solar tracker is sent to operate in a cold region of the planet or even to continue working through a harsh winter. The voltage in the battery is also maintained throughout the discharge and is resilient to temperature extremes, where classic lead batteries would often decline. Resistance to high temperatures could be useful for this project since the device will be resting under the hot sun, and maximum power output will be desired for the devices that will be draw energy from the collector. The sealed lead cell battery also exhibits a long life span whether employed into a floating or cyclic duty. On average, these batteries have a 10 year life expectancy at room temperature before their maximum capacity drops to 80 percent of its rated value. Very little maintenance is required for this battery; it is also very durable and rugged. Unlike conventional lead-batteries spillage and corrosion are not a concern and can be used for more sensitive applications such as computers and aircraft. The product also works well for some applications “out of the box”, without it being charged, due to its low self-discharge rate, however if a deep discharge is planned then it should be charged prior. These starved-electrolyte sealed-lead batteries are great for many different applications, handling more sensitive and patient tasks like standby power for security alarm systems, computers, and medical equipment to more demanding applications such as the electric-start lawnmower. [25]

The starved-electrolyte sealed-lead battery has its versatility in discharge performance as an advantage. Some designers choose to use this battery in high-rate applications such as engine starting and uninterruptible power supplies (UPS). While this type of battery can be used to deliver a high rate of current for a short period of time, the current must be reduced if the discharge continues for a more extended period in order to avoid damaging the battery. A common property of lead-acid batteries is referred to as “*coup de fouet* (whipcrack)” when there is “a momentary depression of the voltage below the plateau immediately after the load is imposed.” Apparently this has no effect of the battery system’s performance; it is only of concern for systems with low-voltage cutouts, often digital electronic systems, so when charging an electronic component such as a cell phone this effect will need to be considered. A sealed-lead cell should also be disconnected from the load once it has discharged its full capacity. It needs to be disconnected to eliminate the possibility of overdischarge, which would cause the sulfuric acid electrolyte to become essentially water and significantly reduce current flow, perhaps even to the point of battery failure. Cells need to be matched by discharge capacity because combined cells are only as “strong as their weakest link.” The discharged performance of starved-electrolyte sealed-lead cells are a strength for this type of battery and if these precautions against overdischarge and mismatching are taken the battery should operate excellently. [25]

Sealed-lead cells are very durable and more problems would likely arise from the undercharging than the overcharging of this type of battery, there is however a proper way for charging them. To put it simply, “charging a sealed-lead battery is analogous to pumping water back into a water reservoir from which it has been removed. But unlike a water reservoir, the battery is not fully charged when the amount of charge returned is equal to that previously removed.” There will be some gas to escape that will diminish the efficiency but this is very minimal. At full charge the current will be applied to the generation and recombination of oxygen inside the cell since all the usable active materials on the plates have been converted to the charged state, there will also be a secondary tendency to oxidize the current-carrying lead gird onto the positive-plate active material. Excessive overcharge current and high temperatures speed up oxidation that will continue to diminish the conducting cross section resulting in a loss of electrical continuity. High-purity lead grids will minimize this rate of oxidation. At low rates of charge the recombination process approaches ideal efficiency with recombination near to one-hundred percent. It is also not sufficient to leave the battery on an open-circuit for extended periods of time for it will self-discharge. "At 25 degrees Celsius a fully charged battery will self-discharge to approximately 50 percent of its rated capacity after one year. Therefore, it is necessary, in these applications, to provide some manner of sustaining charge, normally through a continuous float or trickle charge." Ultimately it is best to leave this type of battery in a state of overcharge to prevent loss of capacity as a result of self-discharge. [25]

It is also recommended by the Gates Rechargeable Batteries book that when a sealed-lead battery is being charged by photovoltaic cells a constant-voltage output is preferred in order to minimize the effects of light intensity and temperature variations. [25] Constant voltage charging, also known as constant-potential or float charging has been used for over 50 years in a variety of lead battery types with great success. Constant-voltage chargers are used in one of two different modes, either to charge quickly or as a float charger to minimize effects of overcharge. These types of batteries can handle charge currents as high as 4**C**. If a photovoltaic cell is implemented then is will essentially serve as a constant-voltage source with varying currents that depend on the time of day (that is, if the cell is stationary, but the tracker should help keep the current constant throughout the day). The Gates organization advocated that "a blocking diode should be used between the battery and cell array to prevent the battery and the [photovoltaic] cell array to prevent the battery from discharging through the cells when the light intensity is low." Sealed-lead batteries are also good for all humidity ranges, which is important for an experiment conducted in Florida, a state with generally high humidity, during the summer. Tests have been conducted on this type of battery in 95 percent humidity conditions and the only element that were affected included the terminals, straps, and steel cases that showed minor signs of rust after an extended period. [25]

A negative aspect of the lead-acid battery type could turn out to be its weight. For example an automotive type lead-acid battery rated at 60**C** would be about 14.5 kilograms or approximately 32 pounds. [28] Another possible hazard to be alerted to is that lead-acid batteries can explode on occasion, not enough to create mass destruction however it can burst the plastic casing or blow off the top of the battery, flinging casing shrapnel at anyone nearby and possibly spraying them with the internal acid, a very toxic and skin-penetrating substance.

It has been proposed for the project that the battery for the collector be capable of handling 12 volts. Here are some specifications of a six-cell lead acid battery that should produce these 12 volts according to the British Cave Research Association: [29]

- Open-circuit voltage at full charge: 12.6 V to 12.8 V (2.10-2.13V per cell)
- Open-circuit voltage at full discharge: 11.8 V to 12.0 V
- Loaded at full discharge: 10.5 V.
- Continuous-preservation (float) charging: 13.4 V for gelled electrolyte; 13.5 V for AGM (absorbed glass mat) and 13.8 V for flooded cells

- All voltages are at 20 °C, and must be adjusted -0.022V/°C for temperature changes.
- Float voltage recommendations vary, according to the manufacturer's recommendation.
- Precise (±0.05 V) float voltage is critical to longevity; too low (sulfation) is almost as bad as too high (corrosion and electrolyte loss)
- Typical daily charging: 14.2 V to 14.5 V (depending on manufacturer's recommendation)

Lead acid batteries vary widely in prices. This pricing seems to depend on the ruggedness and performance attributes of the battery. For instance, Batteries Plus Technologies are selling a 12 V 7 Amp-hour sealed lead-acid battery for $39.90 but are conversely selling 12 V at 253 Amp-hour rating. Batterydepot.com is selling 12 V lead-acid batteries with 2.3 Amp-hours for $36.94 and they only weigh 2 lbs.

2.3.3 Lithium-ion

Lithium-ion batteries are a newer type of battery compared to that of the lead-acid and nickel-cadmium batteries, and they came in response to the need for better batteries in portable electronics. Recently, they have been applied to power tools and are in development to replace the Nickel-Metal Hydride batteries that power hybrid electric vehicles. Early rechargeable lithium-ion batteries were afflicted by safety issues because highly reactive powder would deposit on the lithium-metal anodes. As a result of this safety issue attention was shifted to the development of lithium-intercalation material as an anode. Today there is no lithium metal in the cell it is merely the lithium ions interacting with mostly carbon, oxygen, and graphite, but the name “lithium-ion” is the accepted term worldwide. [30]

There are several advantages and disadvantages to using lithium-ion batteries. Some advantages include it being the chemistry with the highest energy and the lightest weight, there is no memory effect (gradual loss of energy capacity if they are repeatedly recharged after being only partially discharged), it has good cycle life, has a high energy efficiency, and a good high-rate capability. Lithium batteries have the highest energy density, which is a result of lithium being the most electropositive element. One must be wary however, of dendrite growth, a branching crystalline form, after repeatedly charging and discharging the battery. This dendrite growth will eventually short-circuit the cells and create an explosion hazard, a distinct disadvantage of this battery type. [2, 49] Some other disadvantages are that lithium-ion batteries can be relatively expensive compared to other chemistries, it requires protection circuitry for safety and to prevent overcharge and overdischarge which adds to the cost. In other words, lithium-ion batteries are not tolerant of overcharge and overdischarge, and there are also thermal runaway concerns. There are also further advantages and disadvantages if Li-Ion polymer/laminate cells are implemented , advantages being a flexible footprint, plasticized electrolytes, internal bonding of the anode, cathode and separator. Disadvantages if this were added would include a limited high rate capability further increasing the cost, and it would have a poor low-temperature performance. Prices have dropped significantly in recent years however, for example in 1995 a 1.8**C** cell sold for $8 whereas a 2.6**C** cell sold for $4 in 2006. [30]

Commercial lithium-ion cells typically operate at temperatures as high as 60 degrees Celsius. Protective devices are used to control the cell's operating voltage. These devices consist of a positive temperature coefficient (PTC) material and it will include protective circuits that block overcharging, generally about 4.35V, along with overdischarging, generally below 3V, and any overcurrent in excess of 1**C**. In spite of these protective features, many fire and explosion related accidents have been reported and are a result of thermal runway, a negative aspect that was discussed earlier. Thermal runaway occurs when heat generation exceeds heat dissipation because the rate of heat generation has increased exponentially with the increased cell temperature, while the heat transfer to a cool environment increases only linearly.[30] For instance, if all the energy in a 2.4**C** cell is released internally by an internal short circuit, it can reach a temperature of over 700 degrees Celsius in a few minutes. [30]

The shelf life of the Lithium-ion is significantly better than Nickel-Cadmium and Nickel-Metal Hydride cells. [30] A manganese-based lithium-ion cell has a 3.5 times higher accuracy than a Ni-MH cell with the same voltage detection method of identical precision. [30] Lithium-ion batteries also keep their capacity even after several charge/discharge cycles, and are known for supplying higher voltage and enduring for a longer life in lighter packages. Once again, a principal drawback is the safety concern, since lithium ion has a tendency to reach a very high temperature and perhaps explode under abusive conditions including overcharge, external impact, heat shock, etc. [30] There are however flame-retardant additives such as fluorinated cyclophosphazene that can be implemented to eliminate fire danger, increase performance and suppress dendrites. An early blend of the lithium battery known as Li-Al-PAS can be used in conjunction with a small solar cell to provide a convenient and compact power source like what is used in road sign lighting. [30]

Onlybatteries.com is advertising a low-end lithium-ion 7.4V rechargeable battery pack with protective integrated circuitry and 600 mAh capacity at $16.95. The same voltage battery at a 5200 mAh capacity is being sold by the same vendor with similar features and is priced at $54.95. If a 14.8V battery is desired then one can be purchased for the same price of $54.95 with a 2600 mAh capacity rating and protection IC. And to compare with the other listed 9V batteries a 9V 600 mAh lithium-ion battery can be purchased for $17.95.

2.3.4 Nickel-Metal Hydride

Nickel-Metal Hydride batteries were initially very popular in the use for backup power on space vehicles but in the early 2000s it became the leading battery chemistry used to assist in the powering of hybrid electric vehicles. This chemistry is ideal for those applications due to its high energy density (generally has a higher capacity than Nickel-Cadmium), long cycle life (even in deep cycling applications), high tolerance for electrical abuse (overcharging and reversing), and the state of the charge is indicated through the H_2 pressure. This type has a very efficient recombination process that makes it so tolerant of overcharge, and does not require special circuitry like that of the Lithium-ion battery. The disadvantages include the cost and complexity of this cell, for instance it needs to maintain an internal hydrogen pressure that approaches 1000 psi in order to be effective, therefore careful design needs to be made in its development, hence an increase in the product's cost.[25] It has been said that Nickel-Metal Hydride has a lower discharge rate than Nickel-Cadmium but this would not matter when charging electronic devices since it wouldn't need bursts of high energy, just a constant low source of energy. [31]

This type of battery is known for its high capacity. It is truly ideal for electronics and devices that have long lives. It has a strong power output per charge. Its lack of a memory effect is another ideal feature that sets it apart from another type of battery in its family, Nickel-cadmium. [32] The pricing of these batteries matters in their consideration for the project. A nickel-metal hydride 9V battery with a 150 capacity is currently being sold by batterydepot.com for $10.95. Greenbatteries.com is selling 9 Amp-hour D-size batteries for $11.79 each. Batteriesplus.com is selling AA-size batteries in a four-pack for $18.50, it advertises a 2 Amp-hour capacity and that it retains 90% charge capacity after 6 months. However, greenbatteries.com are selling the same AA size cells individually at $2.79 and advertise a 2.5 Amp-hour capacity.

2.3.5 Battery Monitoring and Management

As with any device that has its own dedicated power source, monitoring and managing that source are crucial to its sustainability and efficiency. One of the plans for this project is to have a battery monitoring system to over watch the capacity, and the amount of power coming in and out of the battery. With these values, they can be analyzed to see if the amount energy absorbed from the collector is efficient enough to power all the components in the solar tracker. Today, many portable electronics such as cell phones and laptops have a graphical bar at the corner of the screen showing the percentage of the remaining battery. This allows users to be aware of the battery's condition, and alerts them when it's depleting and needs to be recharged. Also, when the device's battery is low, it enters a sleep mode to save power for essential functions only. It is desired to have these types of features incorporate into the solar tracker's design to be able know to the current capacity of battery, when it is charging and discharging, how much power it received from energy collector, and amount that it's producing. Also, another function needed the design is the capability to detect when the battery is in a critical condition such as overcharge or about to be completely empty. If these conditions occur, then appropriate steps must be taken to ensure that the solar tracker can still maintain its functionality. When the battery monitoring system collected all the necessary data, it will be sent to the MCU to be processed and displayed. In the MCU, the value that's received will be used to calculate the percentage of voltage available, and the amount of power the battery received and delivered. Once these values are known, they will be sent to the LCD to be displayed. Additional procedures can take place if the percentage reaches a certain crucial point, such as when the battery only has 15% left. At this situation the MCU will display a message alerting the user, notifying he/her stop charging and disconnect his/her device from the solar tracker output socket. If the battery continue to reduce and no action has taken by the user, then the MCU will disable any nonessential components such the LCD and the accelerometer to converse power. There many ways to implement a batter monitor and management system. Some are simple yet ineffective; some are complex and difficult to construct but once it's completed the information its gives can be so much of value. Below is a couple design of the monitoring systems, they are order from least complexity to most. A basic configuration of a battery monitoring circuit would be a voltage divider or op-amps. In these circuits there are no computations, it's just a straight analog approach until it send to A/D port of the microcontroller. Since the MCU's A/D port accept a max value of 5V as a highest level of quantization, the 12V needs to be attenuated to 5V. Figure 2.5 below shows how a voltage divider can represent an output 5V from an input 12V. All that is needed to do is to find the resistors values. The first to do is to choose a resistor, and then use the voltage divider equation to solve for the other resistor. In this case, with a value of 100kΩ and 140KΩ, an output/input ratio of .41 is produced. If the battery is at 6V, then the MCU will receive 2.5V. One problem will arise is when the battery is under a heavy current load (such as motors running) the voltage will tend to drop.[33] Monitoring the battery should not occurs when it is under heavy load. This may cause a false reading from the MCU. A 10mF capacitor connecting from power to ground can be use to counter the short term voltage drop.[33]

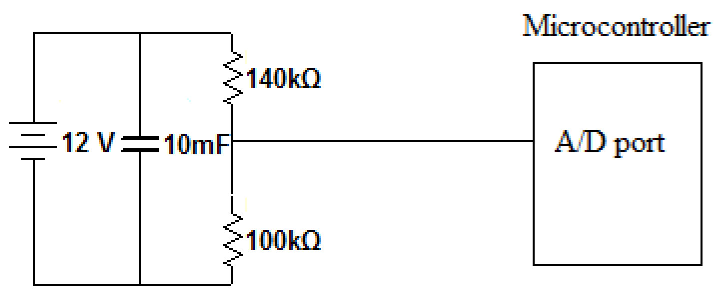

Figure 2.5 Simple battery monitor circuit

Although these direct analog-to-digital methods works, they only provide a voltage measurement of battery, it doesn't gives an accurate indication of the remaining run-time.[34] Figure 2.6 below shows the voltage characteristic with respect to usage time. The voltage remains constant majority of time and then a sharp drop when the battery is about to be depleted. The voltage also changes with discharge rate, temperature and as the cell ages. Direct voltage output is not a good indicator of the battery remaining capacity.[33]

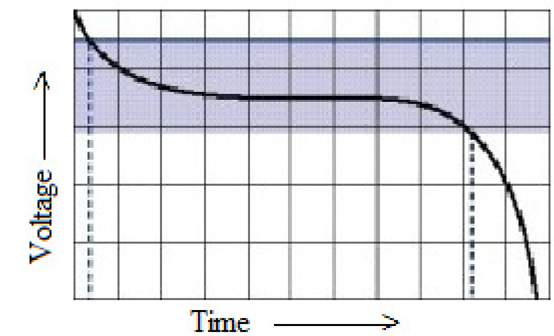

Figure 2.6 Voltage profile of the battery cycle life.
Reprinted with the permission of John Palmisano (www.SocietytofRobots.com).

There are still other methods using analog circuitry to determine the battery's voltage level. For instance, a circuit can be designed involving the use of op-amps to compare the voltage levels and indicate, after pre-calculating the voltage necessary to know the percentage, what the percentage of the remaining energy is left in the battery. A similar approach was conducted on robots.freehostia.com under "Battery Monitoring" and the schematic is listed in Figure 2.7. [35]

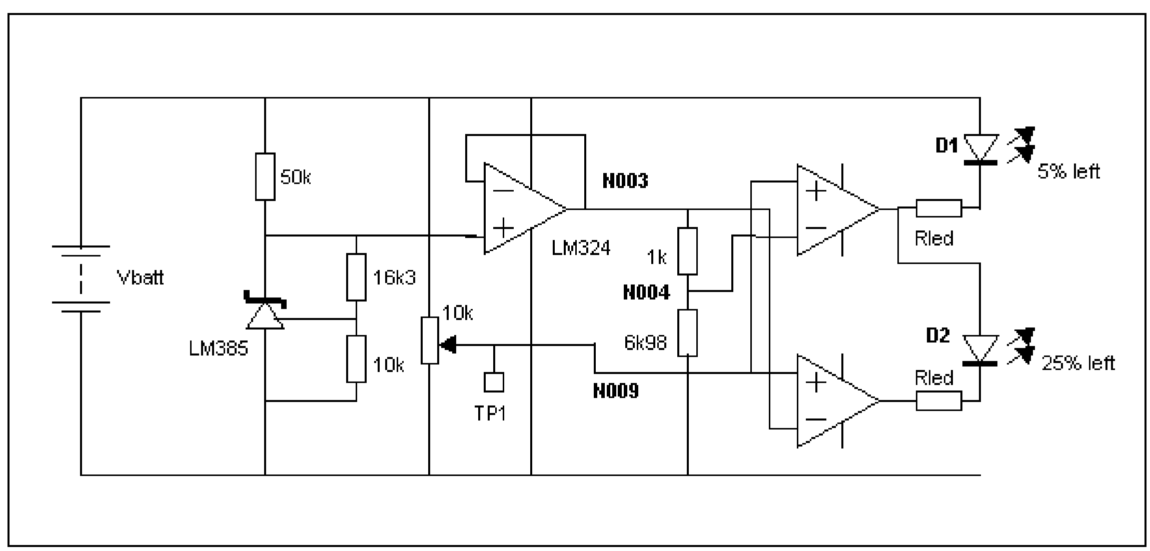

Figure 2.7 Battery Monitoring Schematic
Reprinted with Permission of Paul Hills from Landys+Gyr UK Ltd.

The schematic shows the battery cells in parallel with two voltage dividers that establish reference voltages to compare and determine whether these voltages are at a 25% ratio or 5% ratio with the maximum power. If there is 25% of the battery's capacity remaining, then an LED representing that 25% remaining will be lit. If the battery's capacity falls to under 5% of its capacity then a second LED is lit to indicate to the user that charging will shortly be necessary. Apparently, this circuit design works best for lead-acid batteries since this circuit measures the battery's terminal voltage. Since the other types of batteries have less distinct terminal voltages it would be difficult to evaluate the battery capacity in this fashion.

The LED indication of the battery capacity would be possible to implement and the custom circuitry would make the design of the project seem more intricate and impressive, however a goal of this project is to achieve cost effectiveness. With three op-amps, multiple resistors, and diodes there must be a more cost effective way. There are indeed battery monitoring IC's that exist and can do all of the work necessary without the extraneous wiring that could cause complications.

The "Fuel Gauging" method is another indirect way of monitoring the remaining power in a battery. This is a concept that involves a fixed amount of energy that is put into the battery, and can only lose that same initial quantity.[33] There are smart battery monitoring IC's that can measure the energy going in and out of the battery. The MCU can read from the IC's register to know when the battery is running low. With this monitoring system, it gives additional information that could be use the improve efficiency. The IC that has been looking at is the DS2438 from Dallas Semiconductor (now Maxim Integrated Products). The chip is design monitor in real-time the condition of the battery of devices such as portable computers and handheld instrumentations. This little IC has a width if 3.9mm, cost about $2.50 at Digikey.com and contains a lot rich features. Some of these features are: [36]

- The unique one-wire interface allows it to connect with the MCU using the just only one port.
- An on-board A/D converter that can monitor end-of-charge and end-of-discharge voltage.
- An on-board integrated current accumulator that's keep the total of all current going into and out of the battery.
- A 40 byte nonvolatile memory for battery data.

With a data storing capability, it's helpful to know when to know when the battery is receiving its maximum recharging rate from the collector. The IC also has some other nonessential features but might be useful for battery management. These functionalities are: battery temperature sensor, and elapsed time meter. Figure 2.8 below shows a diagram of the DS2438 and the pin assignment. Pin 2 and 3 are for battery current sensing, monitoring how much going in and out, pin 4 is for the A/D port voltage monitoring, and pin 8 is the interface connection to the MCU. The one complication with the DS2438 is that its voltage rating may not be suitable for the solar tracker if the battery is 12V battery.[36] Although the DS2438's spreadsheet indicates that a supply voltage is 12V can be use, it's only at an absolute maximum rating. The recommended normal DC operation condition is only 10V. Using a battery over 10V may cause unreliability readings. Figure 2.9 is the circuit representation of DS2438Z IC shown in Figure 2.8.

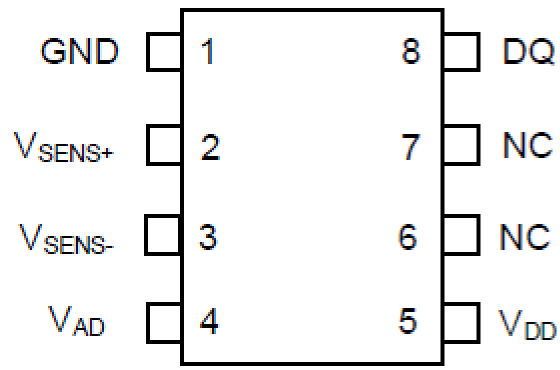

Figure 2.8 DS2438 pin configuration, reprinted with permission of Maxim Integrated Products http://www.maxim-ic.com

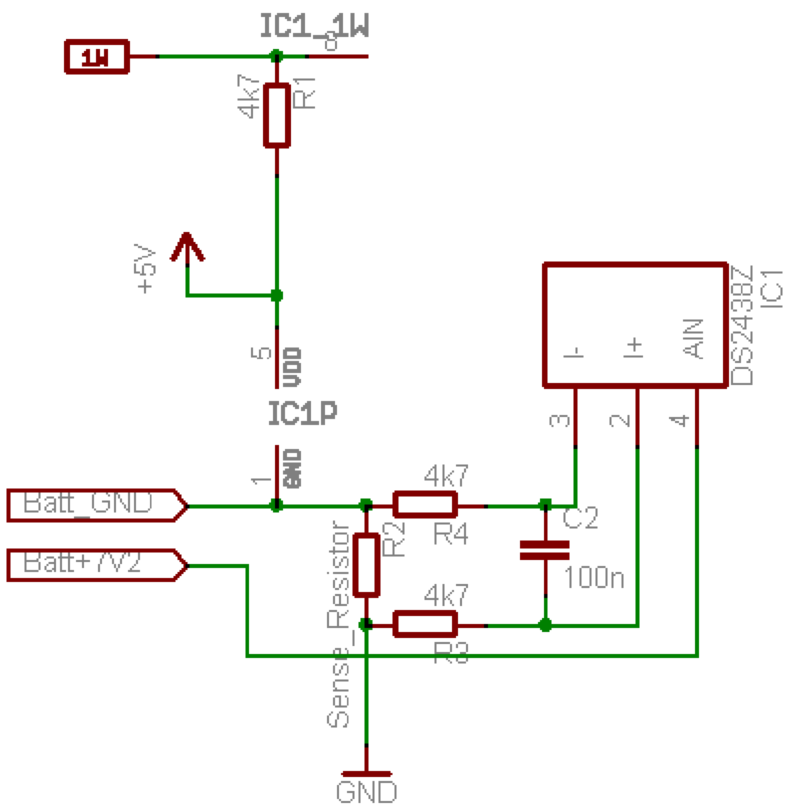

Figure 2.9 The circuit diagram of the DS2438Z IC Reprinted with permission of www.societyofrobots.com

Another IC that has also been looking at is the MAX1660. Unlike the other fuel-gauge chips that have been researched that only operate with 5V or 10V, this one operates with battery voltage from +4V to +28V, and with any type if battery chemistry. Some of its features are:

- 2-wire serial bus interface.
- Two Micropower shutdown modes.
- Independent 32-bit charge and discharge Coulomb counters.
- Overcharge/discharge protection.
- Short-circuit/Overcurrent protection.
- 3.3V linear regulator output for external use

The MAX1660 can accurately monitor battery charge and discharge current flow, and record them into an on-board Coulomb counters. Each counter can be externally accessible by a two-wire interface called System Management Bus. An optional third wire can be connect to the MCU for interrupt when the charge or discharge counters reach a preset value, or overcurrent conditions occurs. When an overcurrent does occur, the IC disconnects the load and send an alert to the MCU. Figure 2.10 is a typical mode of operation for the MAX1660 that can be implemented to the solar tracker design. Starting from the top, BATT is the supply voltage from the battery, and OCO and ODO is use to control the charging and discharging path respectively. SHDN is an active-low shutdown input that can put the Max1660 into power-on reset state. To keep it inactive, it can safely be connected to BATT. VL is a 3.3V linear regulator use to power an external load such as MCU and other circuitry. It can bypass to ground with a 0.33uF capacitor. SDA and SCL are serial data input/output and clock input that interface with the MCU. They also connect to VL with a 10kΩ. The MAX1660 act as a slave, only response when it receives commands sent from the MCU through the SDA. INT and RST are interrupt and rest output, and their connections are optional. OCI and ODI are charge and discharge overcurrent-dectection input. An overcurrent occurs, when the voltage of the current-sensing resistor input (CS) exceeds the voltage on OCI or when ODI drop to ground.

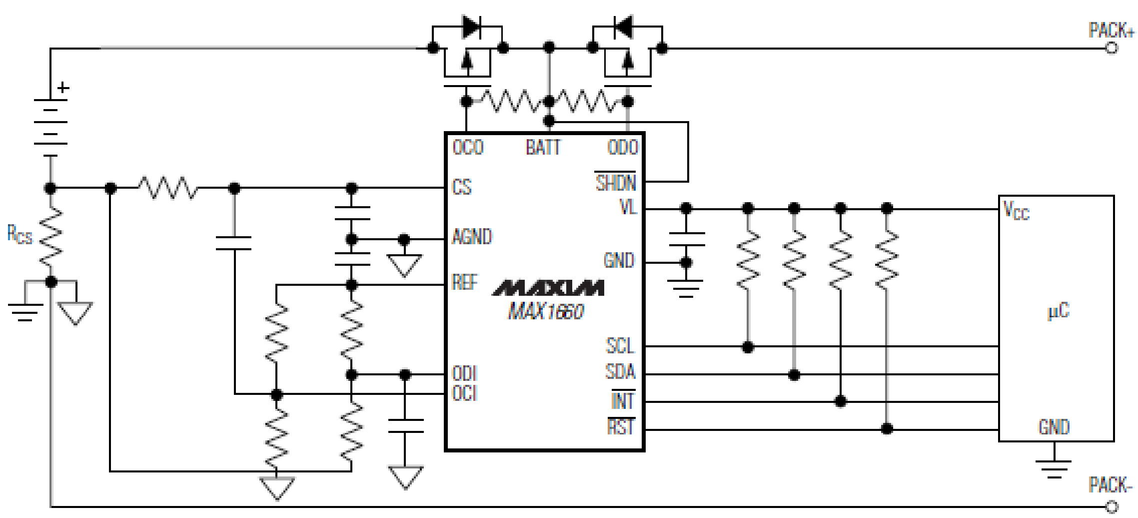

Figure 2.10 Typical operating circuit, reprinted with permission of Maxim Integrated Products www.maxim-ic.com

2.4 Outputs

The sole purpose of building this apparatus is use the sun as an alternative source of energy. And to know whether this goal has been achieved in the producing such energy, it must be tested with actual applications, such as powering an electronic device. This process helps the creators to evaluate the input and output efficiency, as to how the battery performs when a load is place on it. Also, it defeats the purpose of having the solar tracker if the absorbed energy cannot be utilized. There are several design proposals for power outlets, some of them are either DC or AC output use for low power devices. The goal is to have at least two powering methods, capable of charging portable devices like cell phones, mp3 players, laptops, and other AC gadgets. To decide which designs will be implemented in to the final project, it's depends on the follow specification that they must meet:

- It must be able to charge the device that it was intended for. Maintaining a stable voltage and amperage to prevent causing any damages to the device or the solar tracker.
- There must no power lost due to heat dissipations.
- It has to be compatible with the battery. The amount of power the outlet drawn must not exceed the amount of power the battery produce.

2.4.1 DC/AC Inverter

To be able to use the solar power for wide range of electronic devices, it must be able to convert DC power from the battery into AC power. And to do so, the design calls for a power inverter. Non-portable devices such as TV and stereo require an AC power source that is much higher than the 12V battery from the solar tracker. The U.S standard for household power outlet is 110-120V at a frequency of 60Hz. The goal to build or buy a power inverter that complies with this standard. It also must not draw a lot current so rapidly that the battery wouldn't have time to recharge. The minimum usage time when a device is connected must be at least an hour. There are three types of DC to AC converter that can be choose to implement, a square wave, modified sinewave, and a pure sinewave.[37] Selecting the proper one can benefit from the output performance. A square wave is the simplest and cheap type but it has low quality of power and high total harmonic distortion. The modified sine wave is low cost and popular for commercial use with a distortion of 25%. The sine wave inverter has the best performance with a total distortion of 3% but very expensive.[37] Out of the three types, the modified sine wave power inverter seems to the most suitable. If it's decided that an inverter must be made from parts in order to for it to be compatible with the 12V battery, then Figure 2.11 below shows how it's going to be built. And Table 2.3 below is a list the required components and their labels corresponded to the schematic. This inverter takes 12VDC and step it up to 120VAC. This method allows more flexibility in adjusting for the desired outputs. The inverter can be constructed to supply anywhere from 1W to 1kW.[37] The amount wattage produces depends on the type of transistors (Q1 and Q2) and the amp rating of the transformer that were used. Larger transformer and more powerful transistor means more power can be produce.[37] If a 300W output is desired, then the transistors need to be a 2N3055 NPN and the transformer needs to be a rating of 15 Amp.

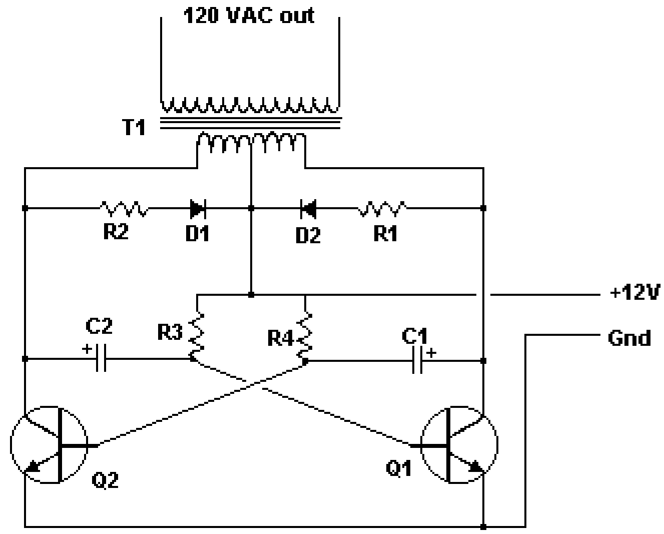

Figure 2.11 A 12VDC to 120VAC inverter, reprinted with permission of Albert Bates at http://www.i4at.org/

T1	24V Center Tapped Transformer
R1, R2	10Ω, 5 watt resistor
R3, R4	180Ω, 1 watt resistor
D1, D2	HEP 154 silicon Diode
C1, C2	68uf, 25V Tantalum capacitor
Q1, Q2	2N3055 NPN Transistor

Table 2.3 DC to AC Components

Another feasible way to have AC output is to buy a car power inverter. This type of inverter has a car charger plug that uses the cigarette lighter as its DC source. The size of typical ones is about 7x3x12 inches with one or two outlets and cost from $12 to $250. The cheapest would be fine for this project as long as it can produces 110V. Implement the inverter to the solar tracker would be fairly simple. All it is needed to do is cut the wires that connect the charger plug to the converter and reroute them to the 12V battery. There two power inverters that are currently being look into, the XR100-12 100W and the Philips Gemini 150W. The XR100-12 100W Slim Power Inverter is from Voltageconverter.com. This carbon fiber design inverter weights 1lb, has a dimension of 3.75 x 0.9 x 2.8in., and costs about $30. It has two outputs; one USB port and one AC outlet. It produces modified sinewave with 90% efficiency. It can convert 10-15.5VDC into a continuous 0.9 amps AC power at 100W and 200W when it's at peak power. It has a protection system to prevent damage from critical conditions. It will automatically shut down when the DC input is over or under voltage. It also shutdown when an overload or overheat condition occurs.[38] For the Philips Gemini, it's cheaper since it's an old power inverter and the form factor is bigger. Biblio.com sells it for $15. It has a dimension of 6 x 1.75 x 3in. and weight 1.2 pounds with two power sockets. This inverter takes 12VDC produces a modified sine wave AC output of 120V. The maximum continuous watts it can delivers 150W with peak output power if 300W.

2.4.2 12V Car Charger Outlet

Cars' cigarette lighter socket was not originally design to provide power for electronics devices, but as the usage of portable devices increases, it's now mainly being use for charging the devices. The socket has a diameter of 0.824 inch and one inch in depth. With special adapters, 12V from the socket can be drawn to power portable DVD players, laptops or GPS. It has been considered to use the car charger outlet as one of the output components of the solar tracker. The benefit to this approach is that there's no need for power conversion from the battery to the socket. Since the battery is a 12V and the output is 12V, their terminals can be connected directly. The cheapest one could be found on spheralsolar.com for $4.40.

2.4.3 USB Charger

USB (Universal Serial Bus) has become the standard form of connection between computers and electronic devices. As technology becomes an integral part of the living stands, the demand for fast and portable transfer of information has also increases, and USB connection was developed to meet such demand. This type of interface is popular for its high data transfer rate, large bandwidth so more than one device can connect to a single port, and also supports plug and play capability.[39] This function allows the computer to automatically detects and powers the peripherals that being connected. It also runs the appropriate program to communicate with that device. In this project what will be focused on is the USB chargeable ability. As more gadgets become computer dependent, they begin to adopt the method of using USB connections for recharging. This creates more portability to the devices since it's not restricted to just using a wall charger. The goal in this design is to convert a female USB port to a power outlet that has the same specification as the typical computer USB port. The port will not be difficult to acquire because it can be taken out of a discarded PC, all it is needed to do is de-solder the pins from the PCB board.

To find the power rating of the USB port, a multimeter was used. Measuring between the power and the ground pin showed that the port produces 5V and 500mA. As long as the USB port maintains these specifications, it can charge any devices. The main challenge in this design is to be able to deliver the correct voltage and current efficiently. Too much power can result in a loss of energy due to heat dissipations and possibly damage the components. There are numerous and feasible ways to implement the USB as a charge for electronics devices. The connections itself, is very straightforward. There are four pins, two for power and ground, and the other for data transfer. Since no information needs to be transferred, the two data pins can be disregarded and only the two power pins will be use. One simple design of a USB charger is to use a linear voltage regulator and what it does is converting high input voltage to a lower output voltage. It's inexpensive and suitable for low power performance. With the LM 7805 and two capacitors each has a value of 100uf and 0.1uf can be use to produce a constant 5V to the USB.[40] Figure 2.12 below shows these components can be connected. Although this method will charge devices, there is one major setback. Any unused voltage will dissipate has heat. If a 9V at 100mA power source applies to the LM 7805, it's only 55% efficiency since 0.4W will be lost.

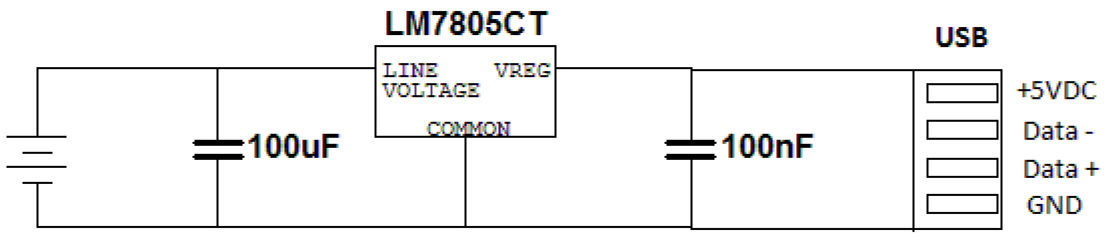

Figure 2.12 USB output circuit [4]

To reduce this lost, a boots regulator (also unknown as DC/DC switching/step-up regulator) can be use to converts power from a smaller DC input to a larger DC output. The input energy is stored in an inductor and when the energy is releases, it produces a different voltage.[41,42] This type regulator is more favorable than the linear regulator because it's more efficient at 75% to 98%, waste little power to heat, and with these advantages it can extend the battery life longer. The IC that is interest in using for this purpose is the MAX757 from Maxim Integrated Products. This IC is an adjustable output CMOS step-up DC converter for low input voltage. It accepts voltage as low as 0.7V and converts it to a higher output of 3.3V to 5V. At full load its efficiencies can be greater than 87%.[42] The figure 2.13 shows the circuit of The MAX757 has 8 pins and each one has different function pertaining regulation and monitoring the input. Pin 1(SHDN) is use to disable to the switched-mode power supply. Pin 2 (FB) is a feedback use for correcting the output voltage. The circuit of R1 and R2 acts a voltage divider, by adjusting the resistances, the voltage between the two resistors can use as reference for the desire output. Pin 5 (LBI) is use to detect when the battery drops below 1.25V. If it does drops below the specified voltage, the output of pin 4 (LBO) will indicate so.[42]

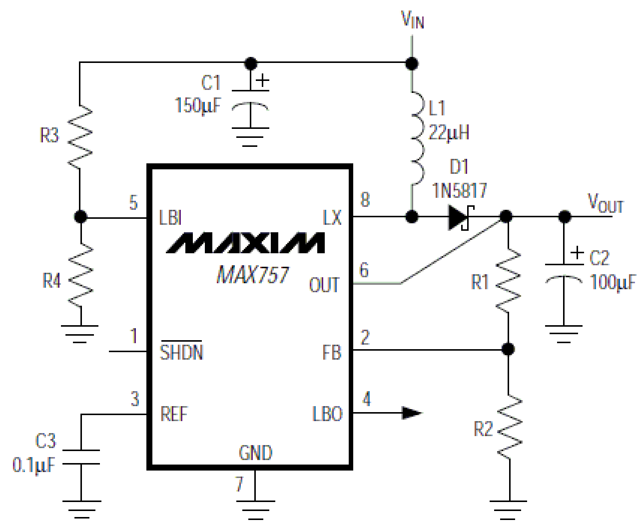

Figure 2.13, DC/DC switching regulator. Copyright Maxim Integrated Products http://www.maxim-ic.com, used by permission

2.5 Microcontrollers

PIC12 F510 and PIC16 F506 are microcontroller develop from Microchip Technology. They use the RISC architecture with 33 single-words per single-cycle instructions. These microcontrollers are cost effective and can be bought through various places, which will be useful if this product were to be chosen. Integrated into it are Power-On Reset and Device Reset Timer. There are also a Power-Saving LP Oscillator mode and a Power-Saving Sleep mode. Those modes can be helpful in trying to preserve power for other usage or just to save power in general. They have an operation speed of 8 MHz for the PIC 12 and 20 MHz for the PIC 16. They both have 1024 word flash program memory. The PIC 12 has a 38 byte Data Memory, while the PIC 16 has 67 byte data memory. The PIC 12 only has 5 I/O pins in oppose to the PIC 16 which has 11 I/O pins. The Architecture they use is the Harvard architecture, where fetching instruction and program are on separate address bus, allowing for faster operation. They have an 8 bit wide ALU and can perform all the basic function, addition, subtraction, shift and logical operations [43]. They both have a 3 channels 8-bit Analog to Digital Converter (ADC). It has a 25 mA source and sick current on the I/O pins. Its low power sleep current is 100 nA. Operating temperature for the both of them is -40 to 125 degree Celsius for industrial use and -40 to 125 degree Celsius for extended use. The operating voltage for them ranges from 2 to 5.5 V, while the operating current is 170 µA at 2 V, 4 MHz [44]. Having low voltage and current, the PIC12 and PIC16, preferably the PIC16 can be operational at low power input. This allows the power supply to either provide power for other components or to fully charge while powering components. The limitation to this microcontroller is that the operations and registers are not orthogonal. This result in some instruction can access RAM or immediate constants while other have to access the accumulator [45]. Add to that it only has one accumulator.

The BasicATOM pro 24-M is a microcontroller base around the 3664 Hitachi micro and is designed for a wide array of applications. The 3664 Hitachi micro is a CMOS 4-bit single-chip microcomputer. It has 32K internal FLASH memory for storing programs and 2K of RAM for variables. It has up to 8 A/D pins. It also have a remarkable speed, can run instruction up to 100,000 instructions per second. Operating (input) voltage for this microcontroller is regulated input voltage of 5V. It contains a built in PWM (Pulse Width Modulation).[46] The programming language this microcontroller uses a version of BASIC. The down side to this microcontroller is that it only contains the chip and an addition BasicATOM development board will have to be bought. The price of the chip is $49.95 and the development board is $49.99, the total price for this microcontroller board is $99.94.

Based on the Atmel mega168 AVR microcontroller, the Pololu Orangutan Robot controller, Orangutan LV-168 (product code RB-Pol-31), is a microcontroller development board with a removable 8-character x 2-line LCD screen. Design to operate off three AA batteries, the module includes two bi-directional motor ports. Each of the ports is capable of drawing 2A to the motors. It contains eight general-purpose I/O digital lines, with 6 lines that can also be use as analog input channels with 2 extra analog input lines accessible on the board. The Orangutan LV-168 can be supply with a lower than 5V input voltage since it has a step-up voltage regulator that generates 5V. This allows the board to run on lower voltage will supplying other components or sensors that require 5V. The two bi-directional motor ports are H-bridges that use low-voltage MOSFETs and draw 2A each and can deliver up to 5 A. The motor is protected by a resettable fuse trigger by temperature readings, an optional temperature sensor can be attached to pin ADC6 to read the temperature. The sensors are there to detect if the motors are drawing more than 2A for long duration. If detected it would reduced the voltage supplied until the temperature cools. A potentiometer can also be optionally attached to ACD 7. The onboard Atmel mega 168 AVR is a low-power CMOS 8-bit microcontroller based on the AVR enhanced RISC architecture.[47] It features 16 kbytes flash program memory, 1024 bytes of SRAM, and 512 bytes of EEPROM. Its full running speed is at 20 MHz. The microcontroller can be program with C/C++ compiler. The operating voltage range from 2.4 to 4.5 V, although it can go up to 5.5V some sensors will be limited to 5.25V. With the low voltage, the components will operate but its performances will decrease. As for an input over 5V, the regulator will cease operation and the input voltage to go to Vcc. [48]

The Arduino Duemilanove USB Microcontroller Module is a development board module containing the ATMega128 microcontroller, the same microcontroller that is in the Orangutan mention previously. It comes with ATMega128 pre-loaded with bootloader. This board contains 14 digital pins, of which 6 provide PWN (Pulse Width Modulation) output, and 6 analog input pins. It has two output pins, one at 5V and the other at 3.3V with a current of 50 mA. The current per I/O pins is 40 mA. This module can be supply with either a USB or external power supply. Its operation voltage is 5V. The recommended input voltage for this board is 7-12V. If provided under 7V, the 5V may not supply adequate voltage to the board and thus rendering it unstable. The opposite if, supply over 12 V it may overheat and damage the module. The minimum and maximum input voltage is 6-20V. The ATMega168 has a 16 KB flash memory, in which 2 KB is used by the bootloader, 1 KB SRAM, 512 bytes of EEPROM, and a clock speed of 16 MHz.[49] The Arduino comes with its own programming software that resembles C that can be downloaded of their website. Figure 2.14 is a photograph of the Arduino, which is similar to the one that may be used for the solar tracker.

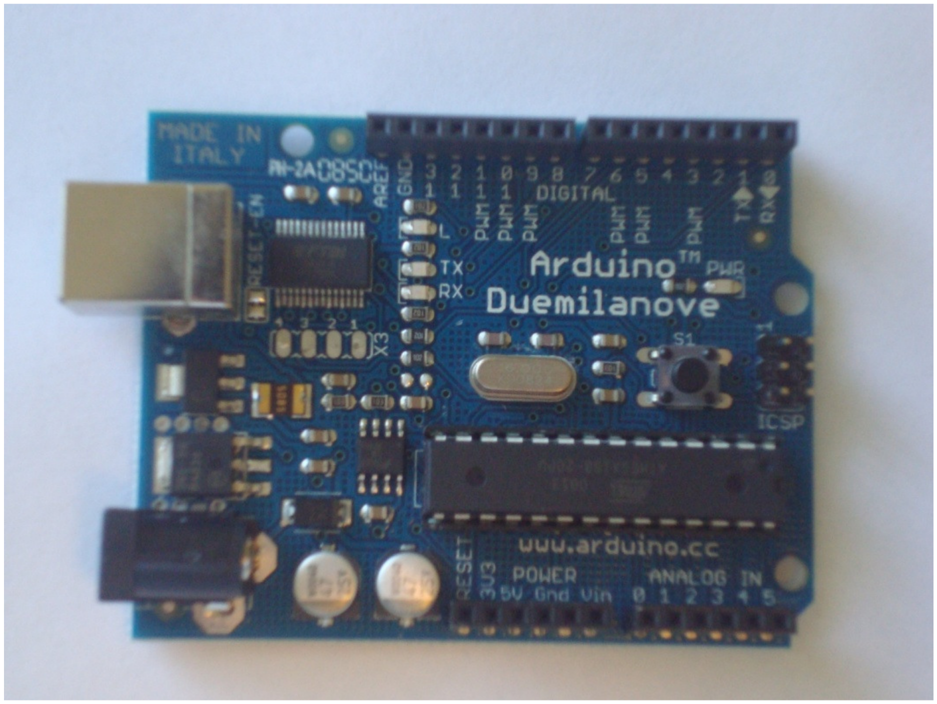

Figure 2.14 Arduino Duemilanove Atmega168

Parallax BS2sx, BASIC Stamp IIsx microcontroller board and is base on the BASIC Stamp models developed by Parallax, Inc. This development board contains the SX28AC microchip from Scenix. It has the RISC-like architecture and an operation speed of 75 MHz. The EE/FLASH program memory and SRAM data memory for this chip are 2048 words and 136X8 bits respectively. Using the modified Harvard architecture, where there are two separate memories one for fetching instruction and one for memory transfers, this allows for it to be fast, deterministic, and jitter free. Its operation temperature at 3 to 5.5 V with 50 MHz speed is from -40 degree Celsius to 85 degree Celsius, while at 4.5 – 5.5 V with 75 MHz speed its temperature range is from 0 degree Celsius to 70 degree Celsius. On the other hand the Parallax BS2sx's operating temperature is 32 degree Celsius to 158 degree Celsius. The Parallax BS2sx is available in a 24-pin DIP (Dual In-line Package) with a 20 pin SIP (Session Initiation Protocol) package. It can take on an input of 5 to 15 V DC, although when using the wall-pack power supply for battery the voltage is limited to 7.5 V. The Parallax consumes 65 mA in running mode and 200 µA in sleep mode. The BASIC Stamp II has 16 I/O pins and 2 dedicated serial ports pins. The I/O pins is capable of sourcing and sinking 30 to 150 mA. The BASIC Stamps can execute its code in 10000 instructions per second. The programming language for this board is a variation of BASIC programming language.[50]

The Motorola 68HC11 is an 8-bit microcontroller developed in 1985 that stemmed originally from the Motorola 6800 microprocessor but is now being produced by Freescale Semiconductor. It runs at a speed of 2MHz by an oscillating crystal. It is a Complex Instruction Set (CISC) microprocessor with two 8-bit accumulators (A and B), two sixteen-bit index registers (X and Y), a sixteen-bit stack pointer, and a program counter. The 68HC11 comprises of many devices with configurations of Random-access memory, Read-only memory, Erasable programmable read-only memory, and Electrically Erasable programmable read-only memory.[51] This device has several features, including: [51] [52]

- 256 bytes of on-chip static random access memory
- 512 bytes of on-chip electrically-erasable programmable read-only memory,
- 8 kilobytes of on-chip read-only memory,
- 3 input-capture functions (ICi)
- 5 output-compare functions (OCi)
- 8-bit pulse accumulator circuit
- Serial communication interface (SCI)
- 8-channel, 8-bit analog-to-digital converter
- Serial peripheral interface (SPI)
- Real-time interrupt (RTI) circuit
- Computer operating properly (COP) watchdog system
- 16 bi-directional input/output pins
- 11 input-only pins and 11 output-only pins

The 68HC11 is designed to run at (ideally) 5 V and an ambient Operating temperature is 0-70 degrees Celsius. [51] [53] In the 68HC11 family there are different models with different pin arrangements, for example the 64 Pin QFP, 56-Pin SDIP, 48 Pin DIP, etc. Every model has a Reset pin that can initialize the microcontroller to a known startup state or as an open-drain output to indicate an internal failure has been detected. A word of warning is that one should not connect an external resistor capacitor power-up delay circuit to the reset pin because the circuit charge time constant can make the device misinterpret the type of reset that occurred. When the input voltage drops below the minimum operating voltage level the reset must be controlled, a low-voltage inhibitor circuit should be implemented to prevent damage to mostly the electronically-erasable programmable read-only memory. The Seiko S0854HN is a good low-voltage inhibitor that runs at the low power of 2 micro-amps. [51] The 68HC11 also has five ports, A through E, that have multiple functionalities, certain pins are bi-directional while others are fixed-directional, if this microcontroller is selected for use then it is suggested that these ports be explored more intricately. [52]

The 68HC11 is becoming increasingly more difficult to find these days and are mostly found on second hand websites. Freescale.com, the official website of the manufacturer, is selling 68HC11 microcontrollers for about $7 each, but in very large bulk quantities. However, on ebay.com, a second hand 68HC11 processor is being sold for $19.99. The issue of concern then becomes whether or not the group wishes to rely on chance to obtain the parts necessary for the completion of this project.

An alternative choice for the primary microcontroller would be the Cypress CY8CKIT-003 PSoC® 3 FirstTouch™ Starter Kit. PSoC stands for Programmable System-on-Chip and is a family of integrated circuits developed by Cypress. The microcontroller under scrutiny is a third generation part. It has a port attached that directly connects to a 9V DC battery that provides power, but it can run at a minimum of 3.3V. [54] This chip includes a CPU with various analog and digital peripherals. Other features included in this starter kit are: [54]

- PSoC Creator development software
- USB-based Serial Wire Debugging protocol programmer and debug interface
- Accelerometer analog sensor
- Thermistor analog sensor
- Proximity analog sensor
- CapSense® analog touch-sensing interface
- 28-pin general purpose I/O pins
- 12-pin wireless module header

This is a very dynamic microprocessor and can be useful if a multitude of impressive features are desired for the final device. The 28 general purpose I/O pins could be useful, since the LCD screen requires so many, the more pins the better. The built-in accelerometer could also detect if the solar tracking device is experiencing too much vibration and cut off battery discharge so as to not harm the battery. This microcontroller connects directly to a PC through USB and can be programmed using C language. It also features a Schematic design creator for a visual representation of the logic flow. [54]

2.6 Motors

For the collection of energy to be most efficient the panels need to remain parallel to the sun at all times during the day. Tracking the sun as it moves across the sky will require the solar panels to freely move across two axes. Motors will be controlled using a microcontroller to determine when the panels need to move to remain parallel with the sun. Several types of motors and ways to control the motors are discussed in detail below.

2.6.1 Servo Motors

Servo motors are commonly used in low power situations and projects such as this one because they easily interface with microcontrollers. Servos are controlled using a three wire interface, power, ground, and a signal line. The main component of a servo motor is a potentiometer. The potentiometer is then connected to an output shaft. When a signal is received it is translated into an angle for the potentiometer by an internal circuit. The potentiometer then rotates to the angle specified or in the case of a continuous rotation servo, rotates the desired amount of time at the specified speed. There are two main types of servo motors that will be researched in this project, continuous rotation and fixed rotation. Continuous rotation servos are able to rotate in full increments of 360 degrees, while fixed rotation servos are only allowed to rotate a certain specified amount (i.e ±90 degrees). Based on the research in this section, a specific motor will be selected for use in our project. [55]

2.6.1.a Continuous Rotation

The SM-S4303R servo made by Spring Model Electronics is a continuous rotation servomotor and part of the 43R robot series. The S4303R has an operating voltage between 4.8V and 6.0V. At 4.8V the top speed is 60 revolutions per minute (rpm), and the top torque is 3.3kg.cm (45.8 oz.in). At 6.0 Volts power the top speed is 70 rpm, and the top torque is 4.8kg.cm (66.7 oz.in). Inside the casing the motor moves using 4 plastic and 1 metal gear. The dimensions are 42 x 39.5 x 22.5 mm and the overall weight of a single motor is 44g. The S4303R is controlled using a Pulse-width modulation (PWM) analog signal line with a standard 3 wire interface. The S4303R's rotation direction is determined by impulse width. When the impulse width is above 1.5ms the output shaft rotates clockwise, and when the impulse width is below 1.5ms the output shaft rotates counter clockwise. When the impulse width signal matches the new input signal the output shaft stops spinning. On the S4303R there is a hole on the outside of the case so the middle point of the output shaft can be adjusted. [56][57]

The Parallax #900-00008 made by Parallax is a continuous rotation servomotor that is manufactured by Futaba specifically for Parallax. The 900-00008 operates anywhere from 4.8V to 6.0V and has an average maximum speed of 60 rpm at 6.0 V. At a voltage of 4.8 the 900-00008 outputs a torque of 2.4 kg.cm (33.3 oz.in) while the output is 3.0 kg.cm (41.7 oz.in) at 6.0V. The overall size of the servo is 40.5 x 20.0 x 38.0 mm and the weight is 43g. The 900-00008 is controlled using a PWM signal analog signal and a traditional 3 wire interface of power, ground, and signal. The 900-00008 has an operating temperature range of 14 to 122ºF (-10 to 50ºC). The maximum current draw with no load on the servo while rotating is 140 ± 50 mA at 6.0V. The maximum current draw while not rotating is 15mA. The 900-00008 also contains an access port to be used to center the servo. When the impulse width signal received by the 900-00008 is less than 1.5ms, the servo rotates in the clockwise direction The further from 1.5ms the signal is, the faster the servo output shaft will rotate in a clockwise direction. The opposite is true for a PWM signal greater than 1.5 ms. A signal with an impulse width over 1.5 ms will cause the output shaft to rotate counter-clockwise, increasing in speed the further the signal is away from the 1.5ms signal. An impulse width of 1.5 ms will cause the output shaft to go to a non-moving position. For the 900-00008 to rotate smoothly pulses should be sent 20ms apart. Traditionally the impulse width signals demonstrated above are used to operate the servo, although using the access port to center the servo, these values can be calibrated to different values. [58][59][60]

The Hitec HSR-1425CR is made by Hitec RCD. The 1425CR weighs a total of 45.36g and measures a total of 40.4 x 19.6 x 36.6 mm. While all Hitec servos operate safely in the range between 4.8V and 6.0V, the 1425 is shown with specifications at 6.0V and 7.4V. At 6.0V the top speed is 16 rpm, while the top speed is 19 rpm at 7.4V. The maximum torque is 46 oz.in (3.3kg.cm) at 6.0V and 57 oz.in (4.1kg.cm) at 7.4V. The mechanical configuration consists of a dual ball bearing design. The 1425-CR operates on the traditional three wire interface and communicates with the microcontroller using PWM. [61]

Table 2.4 below displays the main characteristics of the three continuous rotation servos described above. If a continuous rotation servo is chosen, the table will be analyzed to determine the best choice for use in the solar tracker project.

Name	Torque	Speed	Additional	Available	Price
SM-S4303R	@4.8V-3.3kg.cm @6.0V-4.8kg.cm	@4.8V-60 rpm @6.0V-70 rpm	4 - Plastic Gears 1- Metal Gear Weight - 44g	965-Pololu	$13.95
900-00008	@4.8V-2.4kg.cm @6.0V-3.0kg.cm	@6.0V-60 rpm	Temp Range - 14º - 122º F Max Current Draw - (Idle) 15mA Weight - 43g	30 - Pololu	$13.95
HSR-1425CR	@6.0V-3.3kg.cm @7.4V-4.1kg.cm	@6.0V-16 rpm @7.4V-19 rpm	Dual Ball Bearings Weight - 45.4g	Yes	$16.49

Table 2.4 Continuous Rotation Servo Specifications [56] [57] [58] [59] [60] [61]

2.6.1.b Fixed Rotation

The Hitec HS-322HD is a fixed rotation servo motor built by Hitec RCD. The HS-322HD has an operating voltage range of 4.8 to 6.0V. At 4.8 V, the operating speed with no load is 0.19sec/60º. When the voltage is 6.0V, the no load operating speed is 0.15sec/60º. The stall torque is 3kg.cm (41.66 oz.in) at 4.8V, and 3.7 kg.cm (51.38 oz.in) at 6.0V. When the servo is sitting idle the current draw is 7.4mA and 7.7mA, at 4.8V and 6.0V respectively. When the servo is operating with no load the current draw is 160mA/60º at 4.8V while the current draw at 6.0V is 180mA/60º. The range of the servo is 180º, 90º in either direction from the neutral position. The dimensions of the HS-322HD are 40 x 20 x 36.5 mm and the total weight is 43g. Mechanically the servo is constructed with 2 heavy duty resin gears and a 4 Slider/Direct Drive potentiometer. The HS-322HD is controlled using PWM signals with 1.5ms being the neutral point of the servo. The operating temperature of the servo is -4º to 140º F (-20º to 60º C). [62][63]

The S9405 made by Futaba is a fixed rotation servo designed for high torque. The S9405 operates at a top speed of 0.13 sec/60º at 4.8V, and 0.11 sec/60º at 6.0V. The torque at 4.8V is 5.8 kg.cm (80 oz.in) and is 7.2 kg.cm (100 oz.in) at 6.0V. The overall weight of the S9405 is 55g and the dimensions are 41 x 20 x 38 mm. The mechanical design of the S9405 includes a coreless motor which replaces the solid core of the output shaft with a thin wire mesh. The advantage of not having a solid core provides smoother operation and quicker response time. The S9405 is controlled using a PWM signal with 1.5ms being the zero point. The temperature range of the servo is -4º to 140º F (-20º to 60º C). [64][65]

The S3001 is built by Futaba as a standard servo. The operating voltage is between 4.8V and 6.0V. When the voltage received is 4.8V the top speed is 0.28 sec/60º and the maximum torque is 2.4 kg.cm (33 oz.in). When the voltage received is 6.0V the top speed is 0.22 sec/60º and the maximum torque is 3.0 kg.cm (42 oz.in). The outer dimensions of the motor are 40 x 20 x 36 mm and the weight is 44g. The mechanical design features a 3-pole motor and nylon gears. The motor also makes use of a single top ball bearing. The servo is controlled via PWM signals received from the microcontroller. The temperature range of the S3001 is -4º to 140º F (-20º to 60º C). [66][67]

Table 2.5 below displays the main characteristics of the three fixed rotation servos described above. If a fixed rotation servo is chosen, the table will be analyzed to determine the best choice for use in the solar tracker project.

Name	Torque	Speed	Additional	Available	Price
HS-322HD	@4.8V- 3.0kg.cm @6.0V- 3.7kg.cm	@4.8V- 0.19sec/60º @6.0V- 0.15sec/60º	Idle Current Draw @4.8V - 7.4mA @6.0V - 7.7mA 180º Range	Yes	$9.99
S9405	@4.8V- 5.8kg.cm @6.0V- 7.2kg.cm	@4.8V- 0.13sec/60º @6.0V- 0.11sec/60º	Temp Range - -4º - 140º F Coreless Motor Weight - 55g	Yes	$64.99
S3001	@4.8V- 2.4kg.cm @6.0V- 3.0kg.cm	@4.8V- 0.28sec/60º @6.0V- 0.22sec/60º	Temp Range - -4º - 140º F Single Ball Bearing Weight - 44g	Yes	$16.49

Table 2.5 Fixed Rotation Servo Specifications [62] [63] [64] [65] [66] [67]

2.6.2 DC Motors

DC motors are also being investigated and researched for use in keeping the solar panels perpendicular to the sun at all times. DC motors generally provide greater power and thus torque which is an important factor required when moving the solar panels. The motor is powered using only two lines, power and ground. There is no signal line to tell the motor which way to turn and the desired speed, so using a DC motor will require the use of either a motor controller, or motor driver which will be researched in the next section. When choosing a DC motor there are two different designs, brushed DC motors and brushless DC motors. Brushed motors are powered by creating a magnetic field when electricity is connected to an electromagnet. Magnets on the stationary part of the motor are then attracted and repelled as the electromagnet rotates, which cause the shaft to rotate 180º. When the electromagnet spins 180º the poles of the electromagnetic must be reversed to keep the shaft rotating. Brushes are used to make contact with the electromagnet which then reverses the polarity keeping the output shaft rotating past 180º. In contrast brushless motors are made by attaching magnets to the output shaft and the electromagnets are moved to the stationary part of the motor. Then using high power transistors, the electromagnets are charged up as the output shaft rotates. [68]

As with most things with two options there are advantages and disadvantages for each design. Brushed motors are generally cheaper, and more easily available at the sizes and voltage ranges being considered. Brushless motors while more expensive are much more reliable and energy efficient. Both brushless and brushed motors will be listed together below. The step motor is a specific type of brushless motor which will also be researched below.

2.6.2.a Brushed and Brushless Motors

The GM14a made by Solarbotics is a mini metal gear motor. The gear ratio for this motor is 298:1, which means 298 revolutions by a smaller gear inside the motor results in one revolution of the output shaft. At 3V there are 33.33 rpm without a load and a current draw of 40 mA. The stall current at 3V is 456mA and the stall torque is 1.64 kg.cm (22.7 oz.in). When the voltage received is 6V the motor does 75 rpm and draws 50mA. The stall current is 830mA and the stall torque is 3.23 kg.cm (44.9 oz.in), when operating at 6V. The dimensions of the GM14a are 35.2 x 12.0 x 10.1 mm and the weight is 9.7g. The output shaft is 3mm. [69]

The GM21 also made by solarbotics is similar in design to the GM14a but can provide much greater torque at the sacrifice of speed. The gear ratio is 360:1 and the dimensions are 49.3 x 15.5 x 15.5 mm. The motor weighs 26.3g and uses a 3mm output shaft. When tested at 3V the unloaded rpm was 11 and the unloaded current was 38mA. The 3V test also resulted in a stall current of 360mA and a stall torque of 3.57 kg.cm (49.6 oz.in). When the GM21 was tested at 6V, the unloaded rpm was 23 and the current draw was 42 mA. 6V also resulted in a stall current of 692mA and a torque value of 7.43 kg.cm (103.2 oz.in). [70]

Pololu offers the 1109, a 154:1 metal gear motor which is designed for high performance. The 1109 can operate between 3V and 9V but is recommended to run at 6V. When operating at 6V and no load, the top speed is 90 rpm and the current draw is 250mA. The 1109 also has a stall torque of 8.8 kg.cm (122 oz.in) and a 3300mA stall current at 6V. The outer dimensions of the 1109 are 47.0 x 20.32 x 20.32 mm and the 1109 weighs in at 52.4g. The 1109 also features a 7.01 mm long output shaft with a 4mm diameter D-shaped output shaft. [71]

Table 2.6 below displays the main characteristics of the three brushed and brushless motors described above. If a DC motor is chosen, the table will be analyzed to determine the best choice for use in the solar tracker project. It is important to note that all torque and speed values displayed in the table below are without a load on the motors.

Name	Stall Torque	Top Speed	Additional	Available	Price
GM14a	@3.0V- 1.64kg.cm @6.0V- 3.23kg.cm	@3.0V- 33.33 rpm @6.0V- 75 rpm	Gear Ratio- 298:1 Weight - 9.7g Shaft - 3mm	Yes	$15.95
GM21	@3.0V- 3.57kg.cm @6.0V- 7.43kg.cm	@3.0V- 11 rpm @6.0V- 23 rpm	Gear Ratio- 360:1 Weight - 26.3g Shaft - 3mm	Yes	$19.75
1109	@6.0V- 8.8kg.cm	@6.0V- 90 rpm	Gear Ratio- 154:1 Weight - 52.4g Shaft - 4mm	63- Pololu	$19.95

Table 2.6 Brushed and Brushless Motor Specifications [69] [70] [71]

2.6.3 DC Motor Controllers

Selection of a DC motor to keep the solar panels perpendicular to the sun will require a motor controller to interface with the microcontroller selected. The standard DC motor that will be used in this project only has two signals, power and ground, therefore it is necessary to use a motor controller to tell the motor specifics such as speed, distance, direction, and timing. When signals are received from the microcontroller they are then sent power depending on the signals received, such as speed, and direction by the motor controller.

The Qik 2s9v1 is a dual motor controller made by Pololu. The Qik 2s9v1 uses PWM to send signals to two separate motors. The controller itself requires a voltage between 2.7V and 5.5V to maintain operation and provides reverse voltage protection on the motor supply. If the controller voltage drops below 2.7V the controller will power down and reset. The voltage supplied to a motor can range from 4.5V to 13.5V and can output 1A of continuous current per channel with a peak output current of 3A. PWM frequencies available to use include 31.5 kHz, 15.7 kHz, 7.8 kHz, and 3.9 kHz. Direction is controlled by either grounding the negative pin while sending the PWM signal to the positive terminal for one direction or the opposite convention for the opposite convention. For the Qik 2s9v1 it is recommended to run the logic and motor voltage separately to avoid the logic receiving false signals from the noise introduced by the motors. In the case that the same power supply for logic and the motors, the separate lines should be decouple by a regulator or large capacitors. In addition the 2s9v1 features a reset pin which is initially not connected and an error line connected to a separate LED which will we driven high if an error is detected. [72]

Pololu offers a dual motor driver carrier built made with a Toshiba TB6612FNG dual motor driver chip. The TB6612FNG has the ability to control two DC motors independently or instead control one bipolar stepper motor. The TB6612FNG carrier operates anywhere between 2.7V and 5.5V and outputs a continuous 1A of current per channel with the ability to output 3A peak per channel. Motor voltages can range between 4.5V to 13.5V. The maximum PWM frequency is 100 kHz and the board also offers reverse voltage protection. The TB6612FNG is designed for use in integrating smaller DC motors including gearmotors which are researched above. Additional features include a built-in thermal shutdown and filtering capacitors on the supply lines. The TB6612FNG also features a standby mode for use in low power projects. The overall size of the TB6612FNG is 15.3 x 20.4 mm. The operating temperature range of the TB6612FNG chip is -4º F to 185 F. [73][74]

Pololu features the TReX Jr Dual Motor Controller DMC02. The DMC02 is designed specifically for use in low-power and low-cost projects similar to the one it is being researched for. The DMC02 consists of the MC33887 motor driver chip and is capable of controlling 3 separate motor channels. The minimum operating voltage is 5V and cannot exceed 24V. The DMC02 also features 2.5A of continuous output current per channel with a peak output current of 5A. The DMC02 uses PWM signals with a maximum frequency of 10 kHz to control the motors. While the DMC02 can operate three separate motors, only two of the motors can operate bi-directionally. The third motor must be connected with a diode because it can only be operated in one direction. The speed is controlled via 128 steps in each direction. Additional features of the DMC02 are RS-232 serial interface and a radio control receiver which can both be used to control the motors. The DMC02 also features reverse voltage protection. The overall size of the DMC02 is 44.5 x 44.5 x 12.7 mm and weighs a total of 15g. [75]

Table 2.7 below displays the main characteristics of the three brushed and brushless motors described above. If a DC motor and motor controller is chosen, the table will be analyzed to determine the best choice for use in the solar tracker project.

Name	Output Voltage	Output Current	Additional	Available	Price
Qik 2s9v1	4.5V - 13.5V	1A - Continuous 3A Peak	4 different PWM frequencies	110 - Pololu	$24.95
TB6612FNG	4.5V - 13.5V	1A - Continuous 3A Peak	Reverse Voltage Protection 100 kHz Max PWM Frequency	677- Pololu	$8.45
DMC02	No Information Available	2.5A - Continuous 5A Peak	10 kHz Max PWM Frequency	10- Pololu	$59.95

Table 2.7 Dual Motor Controller Specifications [72][73][74][75]

2.7 Gyroscopes

A primary feature of the solar collector project will be to display the current angle the panel is facing relative to the earth. For this project the panel configuration will be able to rotate across 2 axes. Figure 2.12 below displays the collector and which axes will be measured and displayed. To be able to most efficiently measure the angles the panels are facing there will be a common zero point relative to the case the panel configuration is mounted on. From the common zero point, the angles will be displayed as two separate readings, one corresponding to each axis. The main characteristic of a gyroscope is the rotational speed with the units of °/s. The greater the °/s of the gyroscope the higher speeds the gyroscope can handle. On the other hand as the °/s gets higher, the precision decreases. The gyroscopes used in this project will not need to measure a high rotational speed, so instead will provide greater precision.

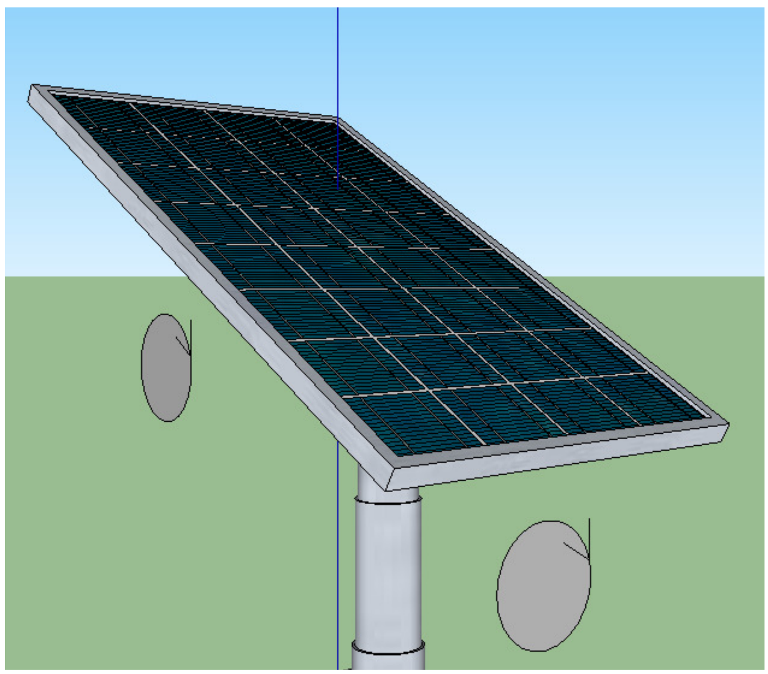

Figure 2.12 Solar panel able to rotate on 2 separate axes.

Pololu manufactures a single axis gyroscope breakout board using the LISY300AL gyroscope sold by ST Microelectronics. The gyro has the ability to measure rotational speeds ranged from +300 to -300 degrees/second (°/s). The gyro is mounted to the board so that rotation measured is about the z-axis (yaw). When rotation is measured the output of the LISY300AL gyro board is an analog voltage ranging from 0 to Vdd. When Vdd is set to 3.3V no rotation is traditionally measured at a voltage of 1.65V. When Vdd is 5V, a common value used with microcontrollers, the output voltage ranges from 0 to 3.3V. The sensitivity of the LISY300AL is 3.3 mV/(°/s). The board also features a 3.3V regulator which means it is ready to be interfaced with most microcontrollers. Another useful feature of the LISY300AL is an optional power down pin for use in low power applications such as this project. Overall size is 17.8 x 17.8 mm and weighs a total of 1.3g. Operating temperatures range from -40º F to 185ºF. [76][77]

Pololu also manufactures a dual axis breakout board constructed with the LPY550AL gyroscope made by ST Mircoelectronics. The LPY550AL dual axis gyroscope provides angular velocity ranges between ±500º/s for the pitch(x-axis) and ±2000º/s for the yaw(z-axis). Sensitivities of the LPY550AL are 2mV/(º/s) and 0.5mV/(º/s), for pitch and yaw respectively. Maximum operating voltage is limited to 16V with operation beginning at 2.7V. Already incorporated onto the breakout board is a 3.3V regulator for easy integration with 5V microcontrollers, along with low pass filters on the outputs for noise reduction. The outputs of the gyroscope are two separate analog voltages. The zero rate of rotation for the LPY550AL requires the output equaling the reference voltage, instead of being dependent of the 3.3V as the LISY300AL described above. Featured on the LPY550AL is a pin which provides 4X the output voltages for both pitch and yaw. The LPY550AL also provides a power-down pin on the breakout board. If the power-down function is implemented it must be done by making the I/O lines inputs and then pulling them up to 3.3V. The overall size of the LPY550AL is 12.7 x 25.4 mm and can operate at a range from -40º F to 185º F. Total weight of the LPY550AL is 1.2g. There are also velocity ranges of ±100º/s and ±400º/s (LPY510AL)(LPR510AL) available from Pololu in the same configuration. Additionally Pololu also offers breakout boards with these same velocity ranges but measure pitch(x) and roll(y), instead of pitch(x) and yaw(z) (LPR550AL). [78][79]

The IDG500 made by Sparkfun consists of an IDG500 gyroscope built by InvenSense on a breakout board for easy microcontroller integration. The IDG500 has two independent outputs per axis which can measure rotational speed at ±500º/s and with a sensitivity of 2.0mV/(º/s), or when the 4.5X output pins are used can measure rotational speed at ±110º/s and a precision of 9.1mV/(º/s). The IDG measures rotations of pitch(x) and roll(y). Included on the board are also low-pass filters to reduce output noise and an on-chip temperature sensor. There is also an onboard EEPROM which is used for on-chip factory calibration. The IDG500 operates at a voltage between 2.7V and 3.3V and a temperature between -4º F to 185º F. Thanks to an on-board 2.8V regulator, the IDG500 can handle a voltage between 3.0V and 7.0V when it is mounted to the breakout board. [80][81]

Table 2.7 below displays the main characteristics of the three gyroscopes described above. To chose the which gyroscope is best for use in this project, the table below will be used to analyze the advantages and disadvantages of each option.

Name	Rotational Speed	Sensitivity	Additional	Available	Price
LISY300AL	±300 °/s	3.3 mV/(°/s)	Single Axis - Yaw Power Down Pin 3.3V Regulator	79 -Pololu	$17.95
LPY550AL	±2000 °/s - Yaw ±500 °/s - Pitch	0.5 mV/(°/s)- Yaw 2.0 mV/(°/s)- Pitch	Dual Axis - Pitch and Yaw 3.3V Regulator Power Down Pin 4X Outputs	79- Pololu	$19.95
IDG500	±500 °/s- Pitch ±500 °/s- Roll	2.0 mV/(°/s)	Dual Axis - Pitch and Roll 2.8V Regulator 4.5X Outputs	258- SparkFun	$39.95

Table 2.7 Gyroscope Specifications [76][77][78][79][80][81]

2.8 Compass

A secondary feature which is intended to be included with the solar tracker is a compass. A compass was chosen to be included because being able to tell direction is very important when being outdoors during the day. An electronic compass will be mounted onto the solar tracker and will provide the direction on the LCD screen. There will be an indicator on the solar tracker so that the user will know where the direction being reported is located. Information regarding several electronic compasses will be shown below.

Sparkfun offers a simple breakout board compass which uses the HMC6352 developed by Honeywell. The HMC6352 works using 2-Axis magnetic sensors. The HMC6352 can operate between 2.7V and 5.2V and allows the user to select an update range between 1 Hz to 20 Hz. There is a heading repeatability of 1º, with a heading resolution of 0.5º. Interfacing with the HMC6352 uses the I2C communication protocol. The I2C uses a 2 wire interface, serial clock and serial data. All of the serial data transitions occur when the serial clock is low staying true to traditional I2C protocol. The HMC6352 also has 3 unique modes of operation, Standby, Query, and Continuous. Standby mode waits to receive a signal from the microcontroller before performing measurements and computing results. This mode allows users to get data only when data is requested. Query mode receives a signal from the microcontroller to measure and calculate data, but does not output the data back to the microcontroller until a read command is received from the microcontroller. Both standby and query modes were created for use in low power projects such as this. Continuous mode performs continuous data measurements and calculations at a user selected rate between 1 Hz and 20 Hz and continually updates the output data. The overall size of the HMC6352 on the breakout board is 15 x 15mm. [82][83]

Parallax offers a digital compass in the form of the Hitachi HM55B. Parallax used the dual axis magnetic field sensor built by Hitachi and incorporated it into a breakout board for easy use with microcontrollers by adding a 3V voltage regulator. The HM55B can operate safely between voltages of 3.0V up to 6.7V. The HM55B draws a maximum of 13mA when active, but only 1µA when operating in standby mode under 140º F. The maximum measuring time is 40ms. The overall size of the HM55B including the breakout board is 10.2 x 12.7 x 11.4 mm with an operating temperature range between -4º F to 185º F. [84][85]

Sparkfun.com uses the Honeywell HMC5843 digital compass to offer a 3-axis magnetometer breakout board. The HMC5348 breakout board can operate between 2.5V to 3.3V and will require a voltage regulator for use with most standard microcontrollers. The I2C interface is used with this device and operates on two pins, serial data and serial clock. The HMC5348 offers 5 different operating modes, continuous measurement, single measurement, idle, sleep, and off. Continuous mode continuously takes measurements and calculates data which then is put in the output registers. Single measurement mode, the default mode, takes a single measurement and places the data in the output registers. In single measurement mode, once the data is placed in the output registers the chip is set to sleep mode. Idle mode preserves the values held in the registers, but disables high power consuming elements. When the device is placed in sleep mode, the device does not hold the values in the registers and does not operate the internal clock. Sleep mode watches the I2C bus for instructions sent to the HMC5348 only and then executes the instructions once they are received. Off mode has the device placed in an off state, and only exists to allow the I2C bus to be used by other devices. The typical current draw varies between the different modes being highest in continuous measurement mode at 0.9mA and lowest in sleep mode at 110µA. The HMC5843 operates between -22º F to 185º F and measures 12.7 x 12.7 mm. [86][87]

Table 2.9 below displays the main characteristics of the three gyroscopes described above. To choose which gyroscope is best for use in this project, the table below will be used to analyze the advantages and disadvantages of each option.

Name	Operating Voltage	Axis	Additional	Available	Price
HMC6352	2.7V - 5.2V	Dual Axis	Heading Repeatability - 1º Heading Resolution - 0.5º 3 Modes of Operation	No 4/25/10	$34.95
HM55B	3.0V - 6.7V	Dual Axis	Standby Mode 1 µA Current Draw in Standby Voltage Regulator	Yes	$29.99
HMC5843	2.5V - 3.3V	3- Axis	5 Different Operating Modes I2C	551-SparkFun	$49.95

Table 2.9 Compass Specifications [82][83][84][85][86][87]

2.9 Photoresistor

Photoresistor is commonly used in many light sensing applications such as camera exposure, beam breaker, night light control, and color sensor.[88] [91] It's popular in many applications because of its low cost, very responsive, and low noise distortion capabilities. In addition, it's applicable for both DC and AC circuits, and can withstand large amount of voltage up to 400V.[91] Even though it has numerous beneficial characteristics, in this project, it will only be use to detect the sun's position. Photoresistor or light dependent resistor, it is made of cadmium sulfide (CdS) cell a high resistance semiconductor that transfers bounded electrons into the conduction band when it has enough energy from the absorbed photons.[88] In high intensity lights, resistance is minimal, electrons are free to flow from one terminal to another. In low lights, the resistance can be extremely large because not enough photons absorbed for the electrons to jump into the conduction band. The amount of lights the device receives is measured in lux, and as the lux increase, resistivity of the device decrease. In a moonless night, the lux is about 0.1 and in this condition the photoresistor's resistance can be as high as 10M ohms. In direct sunlight, the lux is about 32,000 to 130,000 and at this range the resistance diminish to just 300Ω.[88] The graph below shows a logarithmic and an inverse relationship between resistance and illumination of common photoresistors. Since the solar tracker will only be operational when the sun is above the horizon, the characteristic of the photoresistor is significant only when the brightness level is at 10 lux or above. Figure 2.15 shows a typical characteristic of resistance vs. illumination.

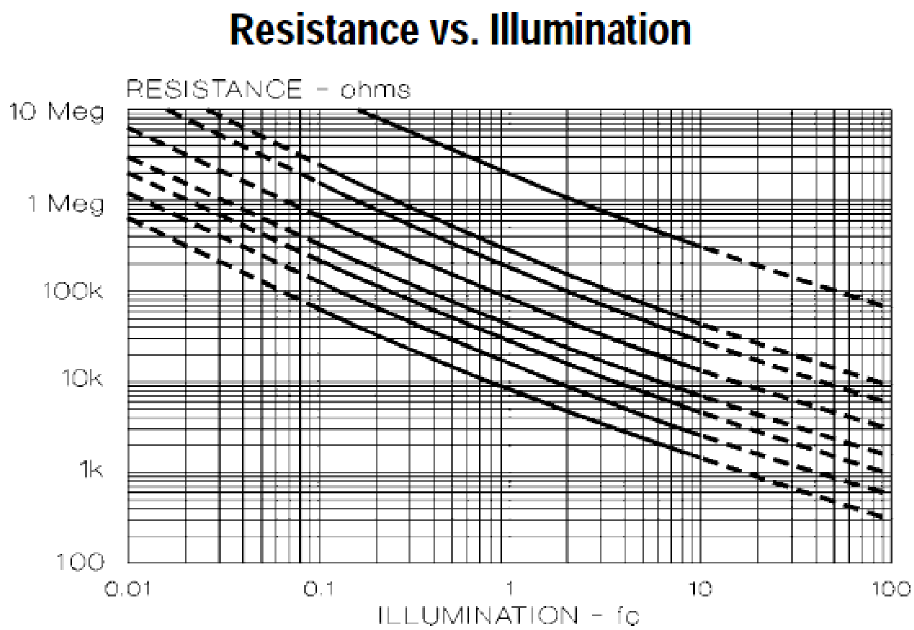

Figure 2.15 Resistance characteristic of VT500
Reprinted with permission of PerkinElmer Inc.

The main concern with using photoresistor to track to the sun is its sensitivity. Since most of the time it will be operating in a well lit environment, it needs to able to differentiate the type of brightness. Sensitivity will be the main factor in choosing the proper photoresistor for this project. Each type of photoresistor has its own sensitivity and the equation below depicts how it's calculated. R100 and R10 are the resistances at 100 lux and 10 lux, respectively. E100 and E10 are the luminance at 100 lux and 10 lux, respectively. In Equation 2.3 sensitivity is measured in terms of Ω/Lux.[89]

Equation 2.3

$$S = \frac{\log(R100) - \log R10)}{\log(E100) - \log(E10)}$$

Not all photoresistors have similar characteristics. Even if they cam from the same batch, with the same specification, the discrepancy could be as large as 50%.[88] The only way to select the right one is to acquire each different models, measure their resistance in varying brightness, and observe the responses. Some of the photoresistors that is currently being exami are the PDV-P9203 from Advance Photonix Inc. and the VT series from Perkin Elemer Inc. The P9203 is designed to sense visible light from 400nm to 700nm. This device is suitable for the solar tracker because it has a sensitivity of 0.9Ω/lux. In a lighted area, it has a resistance of 20kΩ, and in dark area it's 20MΩ. The maximum voltage that can be applied to is 150V.[90] For the VT series, there are two kinds of photoresistor; type 0 material and type 3 material. Type 0 is designed for common applications. It has good temperature coefficient and fast response time. The only downfall for this not to be use in the solar tracker is that it performs especially well in the dark environment. Type 3 is use for high speed response application, suitable for switching from one light level to another.[89] The VT83N1 is a type 3 material with a sensitivity of .95 which is the highest compares to other photoresistor examined. The maximum voltage can apply to this resistor 100V, and the resistances in darkest and brightest conditions are 6kΩ and 100kΩ respectively. The VT83N1 is currently a favorable choice to be use as sensors to monitor the sun's movement, but until further testing and prototyping, this could be change.

2.10 LCD Module

Tracking the sun and effectively collecting its energy are crucial parts of the design, but knowing the status of the solar tracker is also important. Being able to monitor the condition of the battery, the angle that it's pointing, and the amount of power absorbed and dissipated can provides useful information as to what the components are doing. This information can make troubleshooting and calibrating for efficiency effortless. If a component in the solar tracker is defected or unable to perform of what it expected, then it can easily be indentified and adjusted. To present this information to user, the design calls for a liquid crystal display module. LCD is an integral part of technology; it allows users to understand what the machine or electronic is doing by displaying the information in a comprehendible form, either by text or graphic. When displaying the status of the solar tracker on the screen, is has to be short and understandable for the reader. It should print in this format: Battery ___%, Angle ___°, Input power ___ W, and Output power ___ W. The underscores represent value that will be calculated by the microprocessor. In choosing the proper LCD for the solar tracker; there are two important specifications that required of the display, it must have low power consumption and minimum number of connections. Other factors that needed to be considered the size, function, colors, and backlighting. Different LCD modules come in variety of sizes and functions. Some have the capability of adjusting the brightness of the backlighting, and some are multicolored or mono-colored, capable of producing graphics other than text. All these features can enhance the quality and the attractiveness of the solar tracker, but they are unnecessary. Plus, they require additional power which is a big factor in creating an efficient system. A suffice LCD for this project would be a 1x16 or 2x16 screen without backlighting and just one color. Another important factor that needs to be considered is the number of I/O ports connecting between the MCU and the display panel. A common 8-bit parallel interface LCD requires 8 ports for data transfer and three additional ports for read/write, for power supply, and for ground. Problem will occur when the chosen MCU has limited numbers of I/O ports. A portion of the ports will be occupied for important interfaces with the solar tracker and the remaining ports will be used for the LCD. If the remaining ports are not more than 8 then the display cannot be use. Hence it is best to find an LCD module that has the least number of pins.

After an extensive research for a suitable LCD module, it is narrowed down to choosing one of three brand of LCD (will be mention later in this section) or have a custom made LCD. With custom made, a LCD can be built that's suitable for the solar tracker. The problem with this method is that there a lot designing aspects need to be defined such as the display format, the technology, viewing mode & polarizers, viewing angle, logic interface voltage (3V or 5V), temperature range, type of interface (serial or parallel), and much more. In display format, there are three choices of how the information can be presented, either by lines of characters, graphic dot-size array, character segments, or icons. The type of display technology also can be selected, they are: [92]

- Twisted nematic (TN): the least expensive with a decent contrast level but has poor visual quality, and viewing angle. The coloration is usually black character on a gray background.
- Super twisted nematic (STN): a medium price technology that works well at high multiplex rate with average viewing angle and contrast. It can display black on green, or dark blue on gray color
- Film compensated super twisted nematic (FSTN): more expensive than STN, but has good viewing angle, excellent contrast, and high multiplex rate. Its coloration can be black character with white or gray background.
- Double-layer supertwist nematic (DSTN): a technology that uses two display layers to offset the color shifting that exists in the other supertwist display. The DSTN is high cost but has superb viewing angle and contrast with high temperature tolerance. It displays black character with white background.
- Thin film transistor (TFT): also known as active matrix LCD. It provides the best resolution of all technologies, but it also the most expensive.

Because the LCD will be use outdoor, the type of mode and polarizer also must be decided. For the mode, it can be positive image or negative image. With positive image, the pixel is transparent when it's off and opaque when it's on. This gives a good contrast in bright light condition because the pixels absorb light (appearing to be dark) and the background reflexes light (appearing to be bright) therefore enhancing the darkness of the pixels.[92] With negative image, the pixels are opaque when it's off and transparent when it's on. It's preferably use for dim light condition with a backlight. When the pixels are transparent, the backlight will glow through the pixels making the characters brighter.[92] Using the LCD outdoor, the sunlight can wash out the backlight making the characters hard to distinguish. Therefore negative image LCD is not favorable for this project. For polarizer, there three types to be choose from.[92]

- Reflective: uses ambient light to illuminate the LCD, mostly for positive image. This type of polarizer has excellent contrast and wide viewing angle. It is suitable for well lit environment and battery dependent system since backlight is not required.
- Transmissive: require backlight and use for negative image. Has excellent contrast in low light but very poor in bright light.
- Transflective: is a compromise between reflective and transmissive. If uses both ambient and back light. This polarizer is best for all lighting conditions.

There are companies such as www.lcddesigns.com and www.densitron.com that do custom display. So far the cost of buying a custom LCD is unknown until an order has been placed, but it's pretty much depends on the display's specifications. It's estimated that the LCD will cost a lot more than buying a pre-designed one. An alternative to buying a custom display is to get a cheaper already made LCD. There are three brands of LCD that were being investigated, they are: the touch screen Optrex F-51854, the 128x64

Samsung KS0108B Graphic LCD, and the 2x16 Hitachi HD44780. The F-51854 is the higher end of the three and it can be acquired at www.tvielectronics.com for $105. It has a TC51854 controller with 4.7-inch diagonal viewing area capable of displaying both character and/or graphic simultaneously. The controller uses an ATMEGA16 microcontroller and an AT45DB041B flash memory.[93] Some of its features are:

- Touch screen controller with the screen divided into 16 boxes (40x32 pixels each). The controller send digit from 1 to 16 depending on the touched location.
- 4Mb of flash memory divided into 2048 pages; each page contain 256 bytes. The lower 40 pages are use to store text fonts, the remaining pages are use to store full-screen images up to 2000. A program is available to convert and download 160x128 bitmap images into the display.
- Multiple display modes (normal, reverse or mixed).
- Allow auto alternation of images stores in flash for animation.
- 4 built-in font sizes and they can display simultaneously.
- Built-in voltage regulator.

To interface with the F-51854, it can be connected by using the RS-232, or the Atmega16 UART.[93] One major problem with using this module is that need at least 9V to power. An alternative to this is to use the KS0108B from Samsung. It has a large 62x33mm screen with a built-in color backlight, the cheapest one available online is $24. One great feature about this LCD is that there are no limitations term of what it can be displayed. Unlike the HD44780 where it can only display characters, the KS0108B can display images by using special programs such as LCD Assistant. This program converts black and white bitmap images to data array to be use with programming languages.[94] For connections, it has a total of 20 connections, 8 data bus lines, 3 instruction lines, and the reset are use for powering and brightness adjustment. Problem with using this LCD is that it requires large amount of power, it needs at least 5V to be powered, 8V to drive the LCD and an additional 5V for the LED backlit.[95] The HD44780, on the other hand, is about three times smaller and less features than the KS0108B. It can be acquired from eBay.com for $3.50. The reason this display was interested because of its low operating power between 2.7 and 5.5V, and its ease of communication with any type MCU.[96] Compare with other two LCDs mentioned, the HD 44780 is not packed features. Some of its limited instruction functions are: clear display, cursor home, display on/off, cursors on/off, display character blink, cursors shift, and display shift. The HD44780 has on-board ram that can store up 80 character and can display 240 types of characters with each character is a 5x8 dot matrix. Each character represents in 8-bit ASCII code and the ram has the capacity to store 80x8 bits. Although the ram can hold 80 characters, only a limited number of characters can be shown. If the LCD is 2x16, then 32 characters can be display at the same time. [96] Since the HD44780 is limited to 2x16 characters, the information can be print one at a time or it can be scroll across the screen from right to left. The HD44780 has a total of 16 connections, 11 of them are needed to interface with the MCU, two are for power and ground, and the other three can be disregarded since they are for brightness adjustment. Figure 2.16 below shows the HD44780 and its connections, two were disregarded. V_{DD} and V_{SS} are power supply and ground, respectively. V_{EE} is for brightness adjustment. The RS is the register select signal and it tells the controller of the LCD to treat the received 8-bit information as either data to be stored for printing or instruction that's need to be executed. RW is for read or write, but write mainly be occurs. E is the enable signal that tells the controller to execute the instruction after data is sent. D0 to D7 is the 8-bit bus connection.

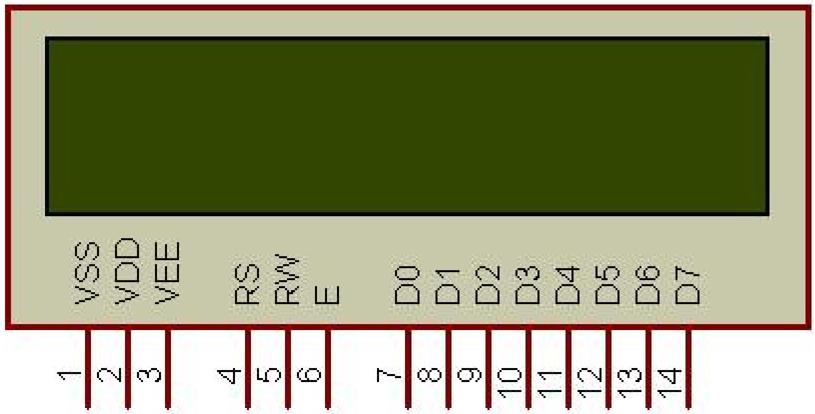

Figure 2.16 HD 44780 and its connections, reprinted with permission of Ajay Bhargav http://www.8051project.net

2.11 Optics

The primary goal of the solar tracker is to increase the power received from photovoltaic cells. Photovoltaic cells have a high cost to power output ratio, and it will be the focus in this section to discuss ways to decrease this ratio without adding additional photovoltaic cells. The research below will focus on mirrors and lenses, and how they may be used to increase power output.

2.11.1 Mirrors

When investigating mirrors it is important to note that for use in the project, three shapes will be considered. The first shape to be considered will be a traditional flat, rectangular mirror called a plane mirror. The plane mirror will be mounted to the solar panel at a specific angle to maximize reflection onto the photovoltaic cells. Figure 2.17 below demonstrates. The second mirror shape being considered is parabolic. Using a parabolic mirror allows a wider range of light to gather on the collector, but because of the parabolic shape will most likely require the photovoltaic cell to be mounted facing the opposite direction from the sun. Figure 2.18 below demonstrates a parabolic mirror with a photovoltaic cell mounted in a probable location to maximize light received. The third shape to be considered is an open cylinder shape. The photovoltaic cells will be laid across the bottom of the cylinder in a narrow line to allow direct sunlight to reach the panels. Light will also be reflected from the sides of the cylinder onto the cells to increase the amount of incident light received by the panel. Figure 2.19 below shows an open cylinder mirror design.

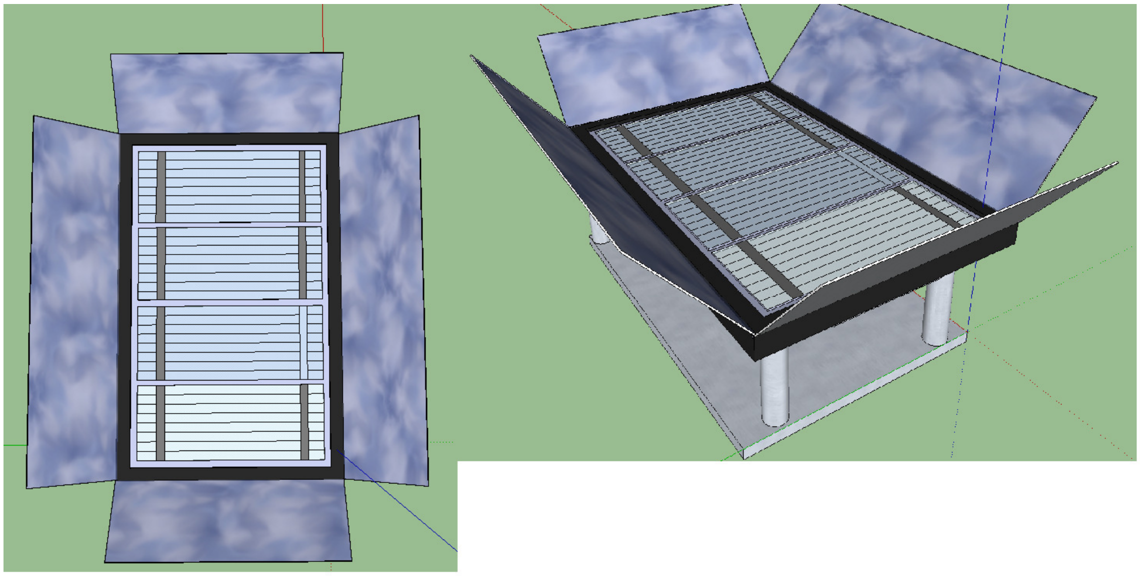

Figure 2.17 Plane Mirrors Mounted around Photovoltaic cells

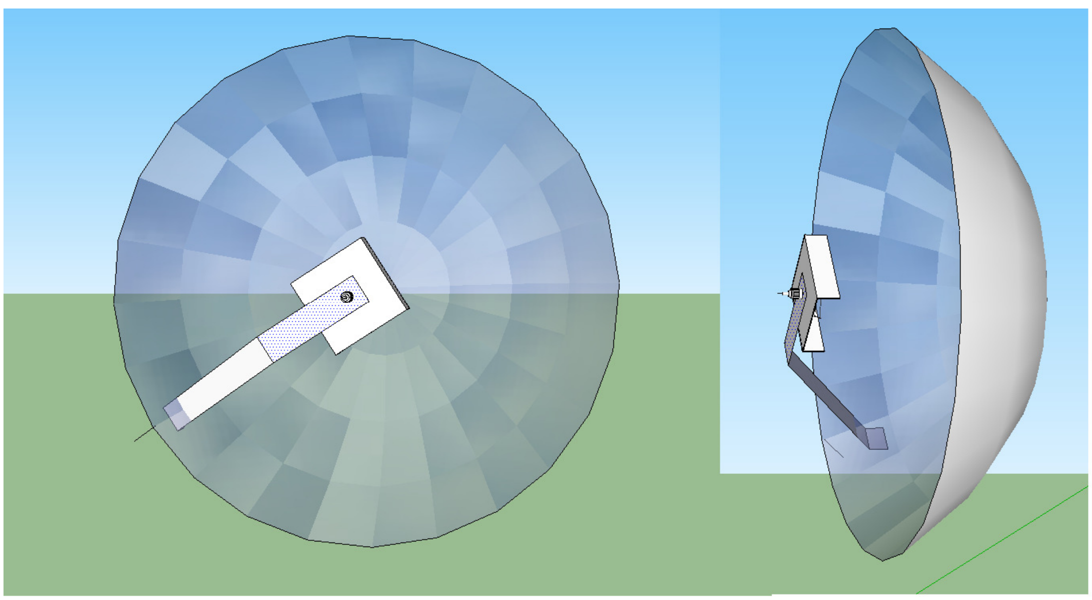

Figure 2.18 Parabolic Mirror with Photovoltaic panel mounting

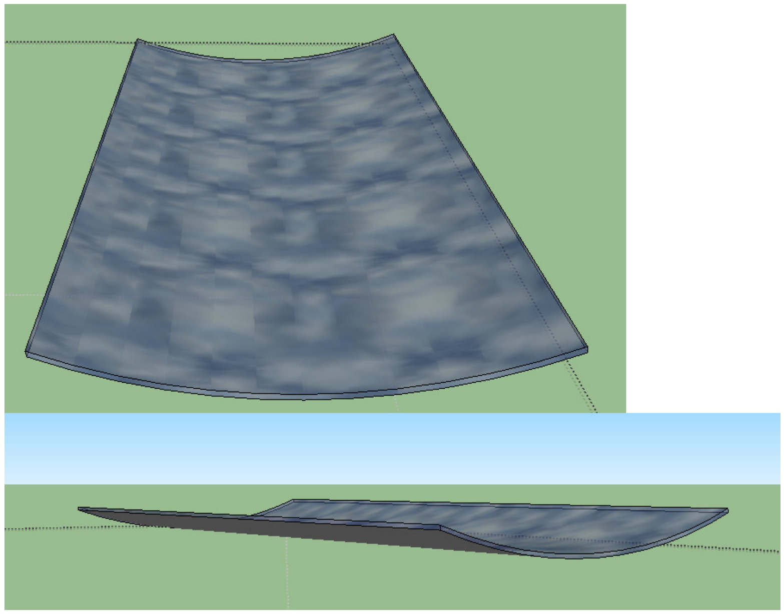

Figure 2.19 Open Cylinder (Parabolic Rectangle) Mirror Design

The material of a mirror can also affect how much of the incident light is reflected. Mirrors can be made from either glass, metal, or plastic sheets coated with metal. Glass mirrors, by far the most common mirror, are created by chemically coating the glass with either silver or aluminum. Silver and Aluminum are used because they offer the highest amount of reflectivity, or percent of incident radiation reflected. [97]

Before the advantages and disadvantages of the mirror shapes are discussed, a brief explanation of a few important properties of mirrors and optics will be introduced. A chief principle in understanding plane mirrors and their reflection is the law of reflection. The law of reflection states that given a line perpendicular to the point of impact, the angle of incident to impact will equal the angle of reflection after impact. Figure 2.20 below displays how the law of reflection works. It is important to note that regardless to the orientation of the mirror surface, the law of reflection still holds. [98]

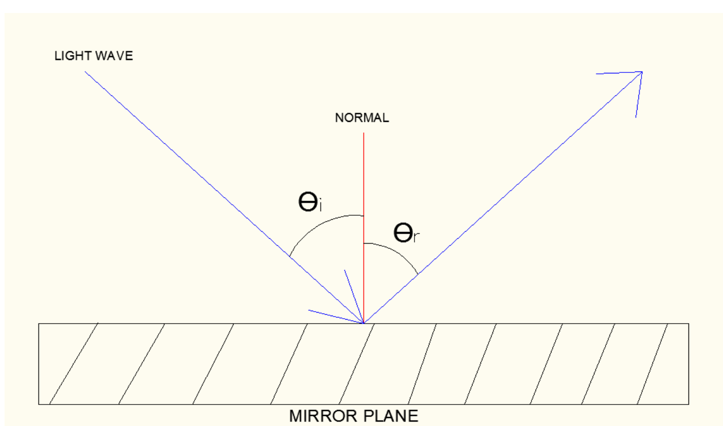

Figure 2.20 Plane Mirror and the Law of Reflection

When dealing with mirrors it is important that the surface of the mirror be smooth. A smooth flat mirror will result in specular reflection, whereas a rough surface on a mirror will result in diffuse reflection. If a beam of light, which is composed of many parallel rays of light, strikes a smooth surface at incidence then the resulting reflecting light rays remain concentrated in a beam. When a mirror with a rough surface is used, the light rays will become scattered or diffused resulting in many individual beams at many different angles after reflection. Every individual ray of light obeys the law of reflection. Figure 2.21 below shows examples of how a rough surface causes the incident light to be scattered. [98]

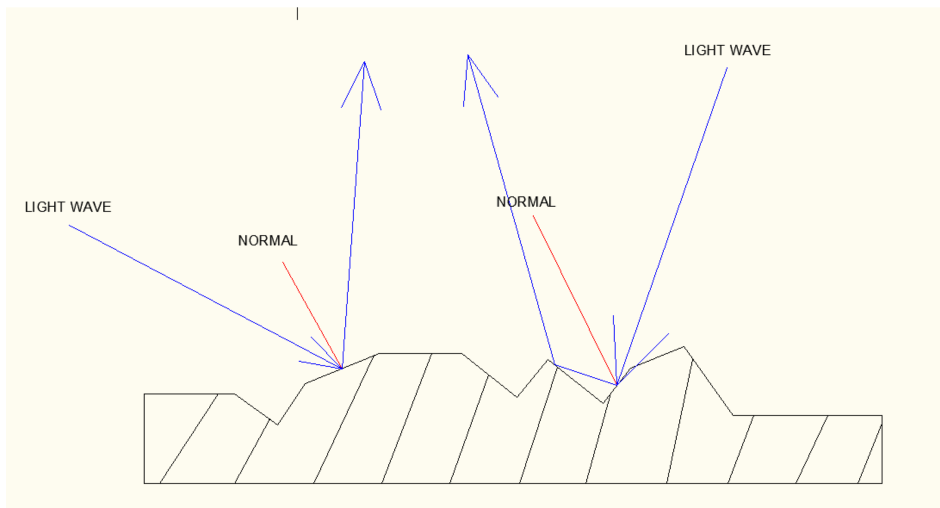

Figure 2.21 Plane Mirror with Rough Surface

Investigation into parabolic mirrors will begin by introducing a few properties of spherical mirrors. There are two distinct types of spherical mirrors, concave and convex. Concave mirrors are defined as bulging inward, away from incident light, whereas convex mirrors are defined as bulging outward or towards incident light. Convex mirrors receive incident light and then because of the bulging towards the incident light, result in diffusing or scattering the light into different directions. Concave mirrors, because of their bulging away from incident light shape, take incident light and cause it to converge to a single point called the focal point. A few defining characteristics of optics will be listed below to clarify this discussion followed by Figure 2.22 displaying both concave and convex mirror shapes. [99]

- Principal Axis: Line passing through the center of curvature and intersecting at the precise center perpendicular to the mirror
- Center of Curvature: Point in the center of the sphere the mirror was cut from
- Vertex: The point on the mirror surface that the principal axis intersects with
- Focal Point: The midpoint between the Center of Curvature and the Vertex on the principal axis
- Radius of Curvature: The distance from the Center of Curvature to the Vertex

- Focal Length: The distance from the focal point to the Vertex

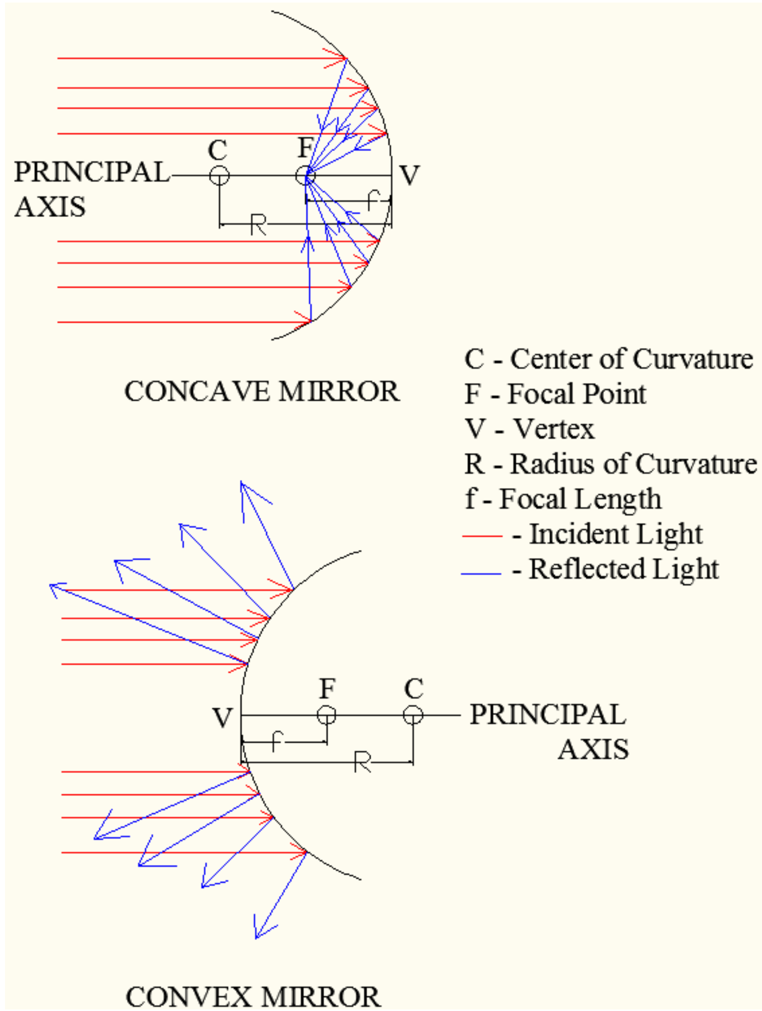

Figure 2.22 Concave Mirror (Top) and Convex Mirror (Bottom)

It is easy to see that for use in this project a parabolic mirror must have a concave shape. A parabolic mirror can best be explained by saying that it results from a concave mirror rotating around its vertex. For use in this project, a photovoltaic cell will be placed facing the mirror at the position of the focal point, because this is where all incident light will be reflected. It will also be necessary to make sure the principal axis is pointing in the direction of the sun, so that the most incident light will be received to focus on to the photovoltaic cell. The largest solar collector which uses a parabolic dish design that is similar to the one which is being investigated in this project is used in Sde Boker, Israel. The parabolic mirror collector at Sde Boker, is under the authority of David Feiman who claims that a 10 x 10cm photovoltaic cell that traditionally produces one watt of electricity can now output close to 1500 watts using their parabolic mirror system. [100] If the intense heat created by the parabolic dish is causing the photovoltaic cells to become damaged or extremely inefficient, it will also be an option to place the cells at a certain distance away from the focal point, to lessen the amount of reflected light reaching the cells.

A mirror with an open cylinder design (parabolic rectangle) closely resembles the behavior of a parabolic mirror design with a few distinct differences. An open mirror design allows the photovoltaic cells to be positioned in two different locations. One location is placing the cells facing the vertex of the cylinder. The incident light from the sides of the cylinder would be reflected up to the focal point where the cells will be located, but because the cells would be suspended over the cylinder in a narrow strip, a portion of incident light will be blocked by the solar panels. The second location the cells could be placed is at the vertex of the cylinder facing the sun. This will allow incident light to reach the panels, but the incident light received by the mirror will not be directly reflected to the cells. Although light traveling parallel to the sun's rays will not be reflected by the mirror, incident light received from other angles will be reflected onto the panel, but harnessing this additional energy is not being considered for this project.

Advantages and disadvantages will be discussed below for use in comparing the different designs. Plane mirrors because of their traditional flat rectangular shape are much easier to use for storage. Hinges can be placed on the mirrors so that they may be folded for easy storage and because a goal of the project is to make the collector as portable as possible this is a huge advantage over a parabolic mirror. A parabolic and open cylinder shape mirrors because of their shape would be very difficult to store because there is no easy way for them to be folded or stored. It may be possible for the parabolic and open cylinder mirror to be cut in a certain way to allow it to be folded to become smaller or more compact, but the curvature of the mirrors will still raise problems for storage and mobility. Another disadvantage of the parabolic mirror design is the heat created by focusing the reflected light to the focal point. All the light energy being focused on the panel will create an intense amount of heat, and solar collectors become less efficient the hotter they become.[101] While the use of any kind of mirror will result in the photovoltaic cells to become hotter and thus less efficient, the parabolic mirror focuses much more incident light onto the cells and will in result make the cells much less efficient than plane or open cylinder mirrors. This is a trade-off between plane mirrors and parabolic mirrors. Mainly the question that arises is will the intense heat on the panel cause the parabolic mirror design to be outperformed by a panel with plane mirrors because less incident light on the panel will result in less heat and thus better efficiency of the plane mirror panel? In either case methods of cooling the panels for greater efficiency are researched and discussed in a section below. Another disadvantage of the parabolic mirror design is the design itself. When incident light from the sun is received by the parabolic mirror design it is reflected to the focal point. At the focal point a solar panel will be facing the vertex of the mirror, which results in incident light being blocked by the back of the solar panel. In addition to some incident light being blocked by the back of the panel, the panel will also have to be held by some apparatus at the focal point.

The apparatus itself will block additional incident light from reaching the parabolic mirror. To help offset the energy being lost due to the blocking of incident light, additional solar panels could be added to the back of the solar collector but facing towards the sun. The plane mirror on the other hand will be anchored to the side of the panels resulting in no incident light being blocked by a mechanical apparatus. An advantage of the parabolic mirror is that it will require less precision because it covers a full 360º range around the panel. If the plane mirror gets off center from the sun by just a few degrees, the incident light received by the mirrors could end up being reflected to a location other than the solar panel. On the other hand all incident light received by the parabolic mirror is reflected towards the focal point and the solar panel no matter the position.

Home Depot offers a 24” x 30” frameless rectangular mirror with a ½” beveled edge. The total weight of the mirror is 9.17 lbs (4.16kg) and is available locally and online.[106] Delphiglass.com offers a 12” x 16” front surface mirror with an aluminum coated surface. [106] Although plane mirrors are available in only specific sizes such as the few listed above, plane mirrors can be easily cut and modified to any size required by the group with easily available tools. This could allow different sizes and rectangular shapes to be tested to determine what sizes and at which angles the plane mirrors will make the solar energy collection most efficient.

Arbor Scientific offers a silver backed, non-aluminized 24" diameter concave parabolic mirror. The mirror comes with an aluminum frame, base, and mounting bracket and is highly polished. [108] There are also various sizes of concave parabolic mirrors on eBay with various pricing. There are several available that also have various diameters center holes that can be used to mount the panel up through the middle of the mirror. If a parabolic mirror with a specific focal length is needed, it is also possible to create a parabolic mirror using various parabolic items, such as satellite dishes, and coating it with a reflective material such as aluminum or silver. Small flat pieces of mirror can also be used to line the parabolic shape, but then the parabolic shape would not be perfectly smooth and thus not be most efficient.

Open cylinder (parabolic rectangle) mirrors are not easily available for purchase. Although the design seems to be quite common among solar trackers and collectors, the use for this kind of mirror is limited to few applications. If an open cylinder style design is to be used with this project, it will most likely have to be created. The mirror can be created using two techniques, either by cutting up small plane mirrors and lining the inside of the frame or taking an existing open cylinder shape, such as a satellite dish, and coating it with a highly reflective material. The first technique of cutting up the small plane mirrors as mentioned above would result in an unsmooth surface and thus not be most efficient for use in this project, so most likely the second technique would be used.

2.11.2 Lenses

Besides using mirrors, another option for increasing power output from the solar panel will be using lenses to focus light onto the panel. Lenses are made from transparent materials with either one or two curved surfaces which alters the way light rays converge. As with mirror shapes, lenses too have two different types. There are convex and concave shapes which result in converging and diverging lenses respectively. Converging lenses are roughly defined as lenses that are thin on the edges and thicker in the center. Diverging lenses are just the opposite, thicker at the edges and thinner in the center of the lens. Converging lenses force light that is traveling parallel to the principal axis to converge to a single location. Diverging again does the opposite and forces light traveling parallel to the principal axis to diverge into different directions. Some basic characteristics used to describe lenses will be described below followed by Figure 2.23 and Figure 2.24.

- Principal Axis **-** Imaginary line traveling through the exact center of the lens
- Vertical Axis **-** Imaginary line that splits the lens vertically into two symmetric halves
- Focal Point (Principal Focus) **-** Point where light rays traveling parallel to the principal axis will converge after passing through the lens
- Focal Length **-** Distance from lens to the focal point
- Real Image - Image formed after light rays travel through lens and converge. The real image always ends up inverted and reversed left to right

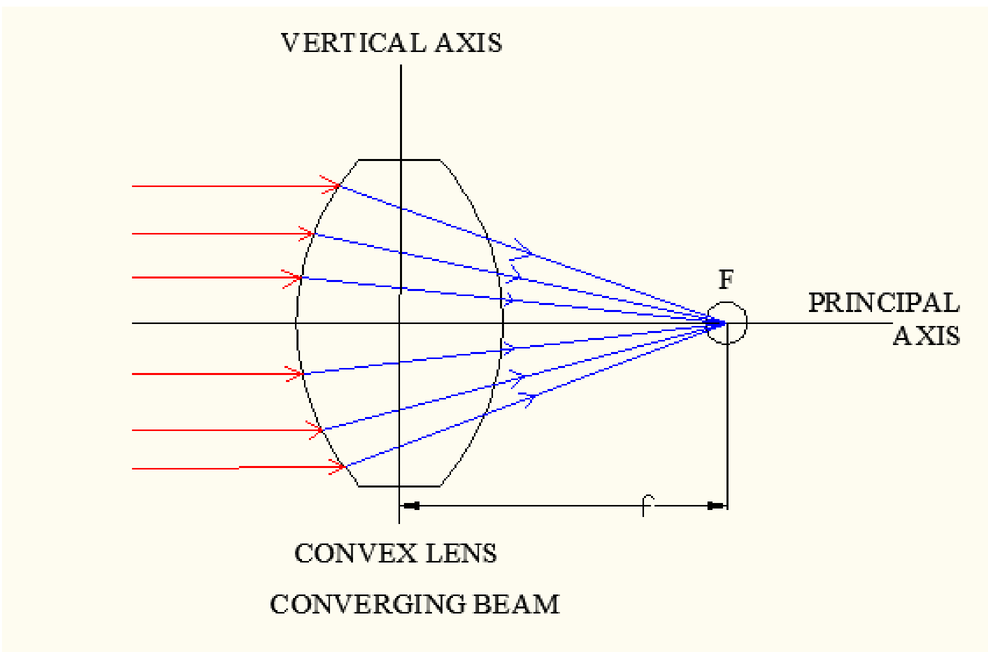

Figure 2.23 Convex Lens

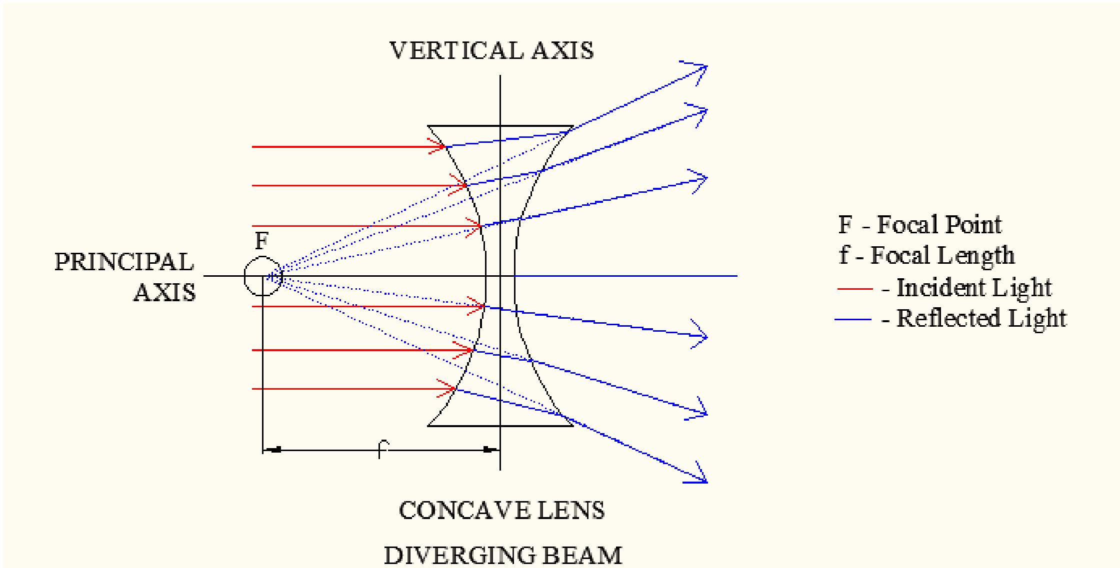

Figure 2.24 Concave Lens

For use in this project a converging lens will be used over a diverging lens because a converging lens will focus more light onto the photovoltaic cell. It is important to remember with a lens that light can enter from both sides. For converging lenses there are two refraction rules that govern its behavior. The first rule states "any incident ray traveling parallel to the principal axis of a converging lens will refract though the lens and travel through the focal point to the opposite side of the lens."[102] The first rule is presented below in an example to clarify. In a converging lens where both sides are convex, light that reaches the lens at a direction parallel to the principal axis will refract towards the normal to the surface. The lens is more dense than air and thus the light will travel slower inside the lens and as a result the light ray will bend towards the normal line until it reaches the rear lens face. At the rear face the light ray will be entering a less dense medium and thus the light ray will bend away from the normal to the surface. The second law states "any incident ray traveling through the focal point on the way to the lens will refract through the lens and travel parallel to the principal axis."[103] A similar example to clarify the second law is described below. Light traveling through the focal point towards the lens will refract towards the normal upon reaching the lens because it is entering a denser medium. Once in the lens the light will travel to the opposite side of the lens where it will bend away from the normal because it is entering a less dense medium and thus travel faster.

2.11.2.a Fresnel Lenses

Now that the basic principles of lenses have been discussed a few types of lenses will be discussed starting with the Fresnel lens. Fresnel lenses were developed in the early to mid 1800's by Augustin Fresnel and were originally used for lighthouses. The Fresnel lens involves taking the design of the double convex lens and then using cut-ins along the surface which reduce weight but still provide the same focusing strength. The cut-ins allow the surface of the lens to appear jagged but still provide the same focusing strength because the curvature of the surface remains the same.[104] Figure 2.25 below shows a simple Fresnel lens and how its surface curvature remains the same. Early Fresnel lenses were made entirely of glass but because of advances in technology are now made with plastic to again reduce weight. There are two different kinds of Fresnel lenses, linear and spot lenses.

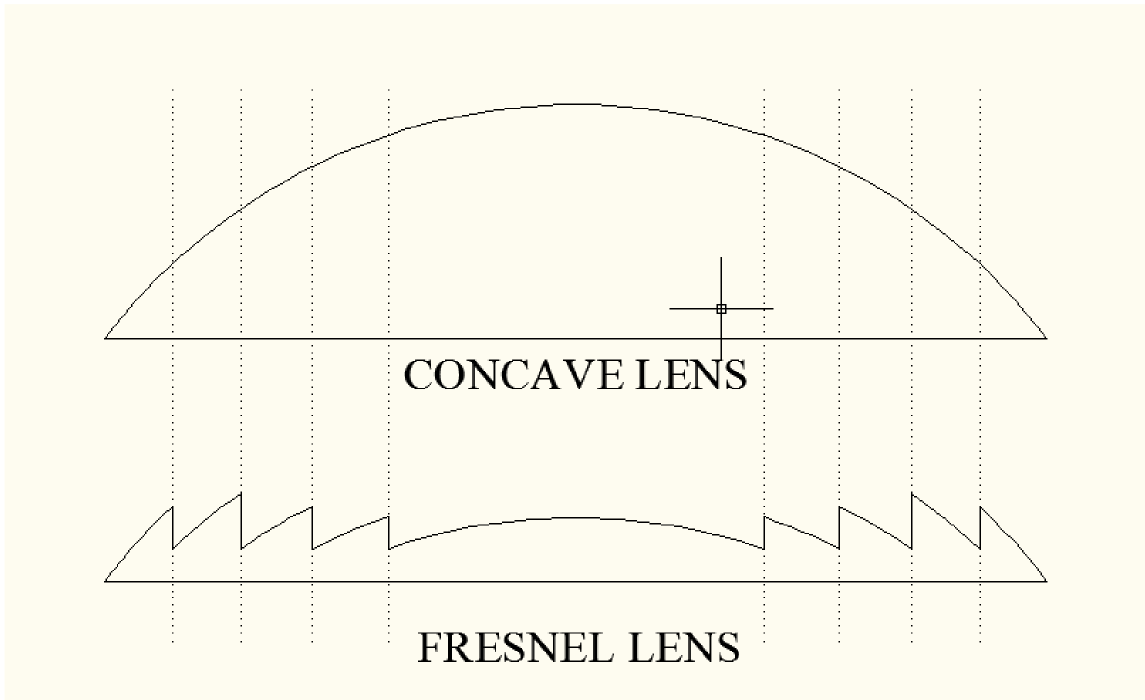

Figure 2.25 Surface of Curvature between Concave and Fresnel Lenses

Fresnel lenses are available for purchase on the internet from several places. First an 11" x 11" x 1/16" lens is available for $29.95 from Scientificsonline.com.[105] Other various sizes of Fresnel lenses are available from places like Amazon.com and Ebay.com starting around $3.00 up to around $30.00.

In this project a lens will be mounted above the photovoltaic cell separated by a distance of the focal length. The lens must be mounted on the panel so that the lens is always parallel with the panel as it tracks the sun across the sky. Fresnel lenses are able to during full sunlight cause temperatures to reach up to 2000º F, which would cause serious damage to the solar panel and the entire solar tracking structure. To prevent overheating a method of cooling must be used which will be discussed in a following section.

2.11.3 Mirrors and Lenses

Depending on the shape or the mirror and the size of the lens, it is also an option for use in this project to combine the use of lenses and mirrors. A lens could be used either before or after incident light is reflected from the mirror. Light could be focused onto the mirrors using a lens, and then reflected onto the photovoltaic cells. A lens could also be placed at or near the focal point of a parabolic mirror, which would result in the reflected light being focused through the lens. It is important to remember though that only light traveling parallel to the principal axis of the lens is reflected to the focal point. Whether this combination of mirrors and lenses is a viable option will have to wait until testing can be conducted and results can be collected and analyzed.

2.12 Mechanical Systems

Discussed in this section are the mechanical systems of the solar tracker. The mechanical systems include structure of the solar panel, frame, and methods of dispersing heat. In this section, ideas were gather to design several ways of optimizing the solar tracker. The structure of the solar panel includes, and not limited to, several different arrangement of the solar panel and frames. This section also describes the structural of the mechanical design, whether it will be durable or cost effective. This section also takes into consideration of the solar panel into the design as well. Discussion will be made on methods of dispersing heat and structural design of such methods. Overall the aim is to be as efficient as possible.

2.12.1 Solar panel Structure

As you know the purpose of this project is the optimization of a solar panel and or that of a cost-efficient photovoltaic panel(s). There are several ways to go about in doing so. For this project, it will be a solar tracking device with attached enhancements to improve the solar panel itself. Solar tracking have been implemented it improve and optimize the solar panel tremendously. Besides it being a solar tracking device, this project will try to optimize the solar panel using other methods. One of these methods is to using some kind of parabolic mirrors or lens as a focusing catalyst to focus as much of the sun's rays to a confined solar panel(s). This method utilizes the concept of solar concentration. Similar to using solar thermal to get electricity, this design will allow much of the sun's energy to be focus on a smaller yet localize and more efficient photovoltaic panel. Another computation that needs to be look into is that of the panel's temperature. Like any other devices, temperature can dramatically affect it operation and condition. For photovoltaic devices, change in temperature can lower its efficiencies. Also like any other devices, the lower its core temperature the more efficient the device operates and vice versa. Therefore the panel(s) must be somehow cooled. Some of the designs will consist of heat-sinks. For the design that implements the heat-sink, the heat-sink will most likely be attached on the back of the solar panel. The material for the heat-sink will be made from aluminum. Due to the weight of aluminum, this will be a good choice; that way the material can be both cheat and weights less, but also durable.

2.12.2 Cooling System

Properly cooling the solar panel(s) is accentual to keeping the performance of a solar panel(s) at optimal efficiency. As explain earlier in the temperature section, the temperature changes on a photovoltaic panel(s) is important in keeping the efficiency up. Temperature outside of 60 degree Celsius for a photovoltaic panel(s) can lower its efficiency. As the panel(s) are expose to outside environment and tremendous heat exposure, keeping it properly cool by any means can help the efficiency.

One way of doing so is to attach a heat sink of the panel. The only wall to this achievement is the placement of the heat sink. You can't attach the heat sink at the source of the panel, where sun light hits the panel(s), due to that that is the spot where the panel(s) is absorbing the solar radiation. The only option is to place it on the back of the panel(s), two problems that will occur if attach on the sides of the panel(s). One is that if the projects consist of mirrors it will mostly be attach on the sides. As for the other problem, having heat sink on the sides wouldn't relive a lot of heat from the panel(s). The design of the heat sink will consist of multiple fins that are relatively long. The reason is to better transfer the heat out of the panel to the surrounding area. Figure 2.24 below shows the placement and construction of the heat sink.

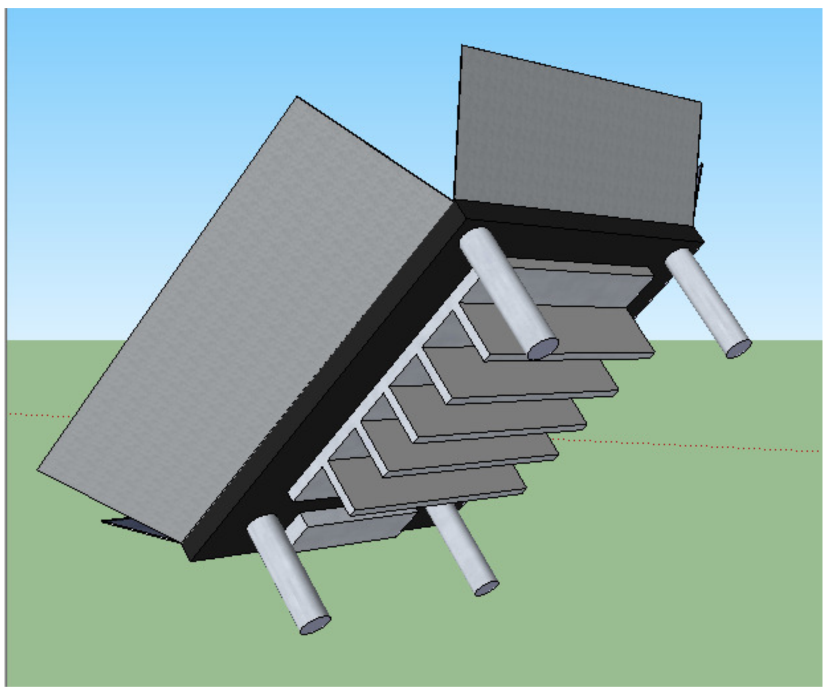

Figure 2.24 Heat Sink Constructions and Placement

Another option is to use water cooling. Water cooling over the decades has been used in a variety of electronics equipment, systems, and automobile. For instants, computer enthusiastic used water cooling to transfer heat from their PC components, mainly the CPU, GPU (graphic processing unit), and Northbridge or any other temperature sensitive chipset. In cars, the radiator systems help cools components inside the car. As for integrating this component to the photovoltaic panels, the most like scenario is to place the photovoltaic panels to some kind of water systems. The water systems will consist of a piping system; piping will be of PVC tube, which will transport water to the panel. A water pump will transfer water through the PVC pipe and into a metal pipe that will make direct contact with the panel. The metal pipe transfers the heat absorbs by the panel and transfers that to the water. From there the water travels to a radiator where the heat is dissipated. Another method to utilized water cooling is to submerge it in a tank filled with some kind if electronic friendly coolant, like mineral oil or vegetable oil. Viewing other works that involved liquid coolant, these types of coolant help tremendous in reliving heat from components. A water tight frame will have to be built in order to fill it with water. From there the panel will be submerging in it. Heat from the water can be dissipated on its own or it can be dissipate using other method.

2.12.3 Frame

The frame is an important piece of the model. The aim of the frame design is to choice the most efficient and manageable design that will either help boost efficiency or to help in supporting the solar tracker. For the frame, it will be constructed to support a certain weight, size, integrity, and durability. The following section will cover some of the design for a solar tracker.

2.12.3.a Pole Axis

The frame for the photovoltaic panel(s) will be made from either wood or metal, given the circumstances and the budget. The panel(s) will be incased in a picture type frame of the same dimension as the panel. This will then be mounted on a single pole axis, where it can only rotate in the horizontally at the base of the frame (i.e rotating the pole) and the panel will be place perpendicular to the sun (similar to the one shown below). Another type of design is the same design but have it mounted on a double pole axis where it can move in both the vertical position on the pole and the horizontal position was in the previous design (as shown in Figure 2.25). Both of these designs allow optimum efficiency because it allows the solar panel to be perpendicular to the sun all year long. With the two axis it can farther adjust to the position of the sun, thus allowing more ray to concentration on the panel(s) especially during the winter and summer season where the sun changes position in the sky. The only thing that is needed to consider is the load on the pole and it center of mass. The pole must be durable and build to hold around 20 lbs max. Along with the weight, the center of mass must be taking into consideration. Since the panel will be mounted on the pole there is a concern of the tracker tipping over. Balance is a must if the design takes into consideration of putting too much weight on the upper portion of the pole.

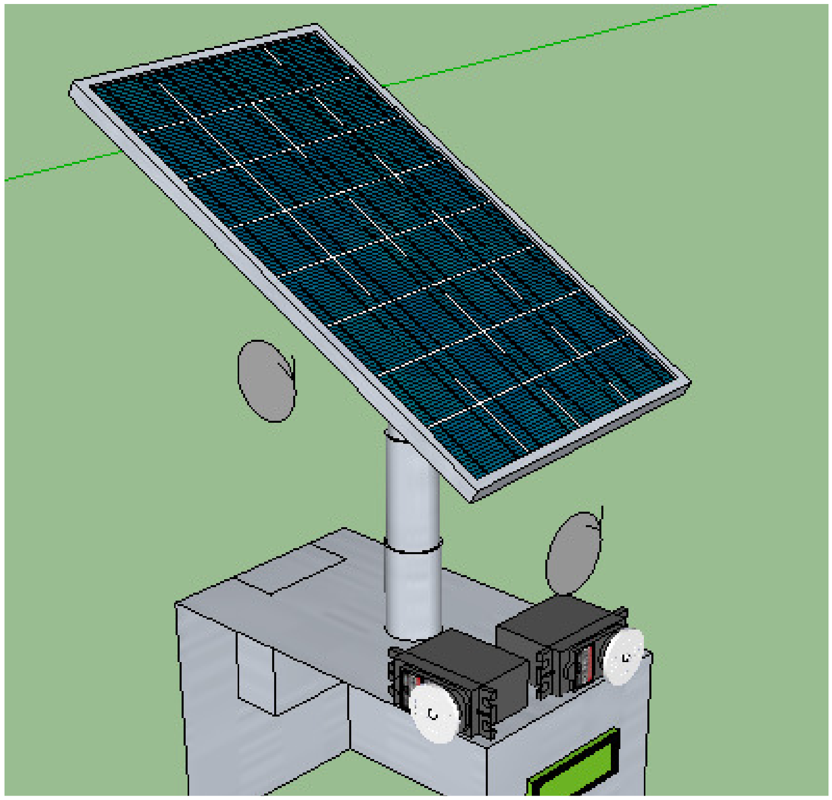

Figure 2.25 Single and Double Axis Solar Tracker

2.12.3.b Horizontal Axis

Horizontal axis is the design seen in some solar power plant and in individual solar tracker. In the Horizontal axis design the solar panel is place on a horizontal metal pole or rod where it can freely rotate vertical in a 360 degree angle. Mounted on a stand or base frame with support on both side of the rod, the rod can then be driven to rotate either clock wise or counter clockwise by a single motor (more if necessary). The rod can be hollow, so that the wiring can be organized within the rod, or it can be tie along the bottom of the rod. The motor can be attached to either end of the rod to drive it. With the horizontal axis frame there needn't be consider for center of mass or weight limit if it is attached to a rotating base. Since for weight two motor can be use to rotate the panels, but for the center of mass the weight is distribute over the pole instead of at a localize point. The only thing that is needed to take into consideration is the material and the structural integrity. With this design, the material that will give it integrity and durability is steal or aluminum. Aluminum will be used because it is cheaper.

2.12.3.c Mirror Frame

Some of the more recent addition with solar panel is the use of attaching mirrors to focus the sun's rays directly to the panel. Using the idea of solar concentration, the mirrors direct more sun light to at high efficient panel giving it more sun light per area. The frame of the mirrors will be attached on the hinges on the side of the panel(s). The important part is to place it in the right position in order to focus the light. As for how the base of the frame design will be, it can mount on either the pole design for the horizontal design. Likewise center of mass will be taking to consideration since the mirrors will add more weight to the panels, probably 5 lbs or more. Also the integrity of the panel will be poorer due to the fact that having the mirror attach will compromise the panel. The mirror will be sensitive to weather depending of the material makeup of the mirror. Structurally it should be stable.

2.12.3.d Parabolic Mirror Frame

The parabolic mirror frame is only applicable when implementing mirrors. With the parabolic mirror frame, a high efficient photovoltaic panel is place in a frame similar to a radar dish. The panel is place on the foci point of the parabolic mirrors, so that all the rays that are bouncing off the mirror are converging to the panel. With the parabolic mirror frame, it will then be mounted on either a single axis or a double axis surface; double axis will be better, that way it can be exact at collecting sun light. The photovoltaic panel will then be mounted on aluminum rods or on a base attached to the dish. Ideally it would be mounted on a rotating table top, where it will be supported on with metal bar on each side. The table will rotate to the general direction of the sun, while motor on the bar support will give it more precision.

Another implementation of parabolic mirrors is to set it up in the trough frame. In this frame the parabolic mirrors is mounted on a horizontal bar of a certain length. The photovoltaic panel or a ribbon strip thin film photovoltaic cells will then be place at the focal point of the mirror(s). The trough is then place to rotate in the direction of the sun's movement. The motor(s) will be attached to the bar to rotate it. This design will be similar to the horizontal axis frame except it uses the idea of solar concentration. Also this design will provided the most stable and solid frame of the entire frame.

2.12.3.e Parabolic Lens Frame

Another way to of using solar concentration is to have a parabolic lens focus the sun light to a certain spot or on a highly efficient photovoltaic panel. For this design, it will be similar to a magnifying glass. The lens will be placed directly over the photovoltaic panel and far enough so that the panels are that the focus point of the lens. This design can be using in combination with other design. Many possible makeups are possible with this design. The only design that is hard to implement this is the trough frame. As for the structural integrity of this design, the only problem that will occur will be damage to the lens, since like the mirrors it will be sensitive to the weather. Maintenances will be needed to keep this frame in top condition.

3 Design

Now that the initial research of methods and components has been concluded, the following section will describe how the components and methods researched will be combined to make a complete solar tracker. The design section will also include the reasoning and thought process behind the final design configuration and demonstrate and display the facts and specifications analyzed.

3.1 Selection of Components

In the two subsections below will be the rationale behind the components that were selected for use in this project. Each component selected was carefully compared with other products with a similar purpose and was selected because it offered an advantage over other components researched. In the event that any of the components selected cannot be integrated correctly, or other events such as product availability and budget considerations, alternative components will also be listed for easy reference and information in the subsequent section. Following the rationale for component selection and alternative component selection will be Table 3.1 and 3.2 respectively, displaying all the components to be used with some primary characteristics.

3.1.1 Rationale for Component Selection

Rationale for component selection for each individual component will be described in this section and summarized in Table 3.1.

Component Selection	Part Name	Reason	
Battery	Lithium-ion Battery (ies)	• High energy storage capacity • No memory effect, critical to maintain capacity	Available at OnlyBatteries.com with variation in capacity or and size
LCD	HD44780	• Low power usage • Minimal connections, 4 pins minimum/ 11 pins maximum	
Motor	Hitec HS-322HD	• Fixed rotation servo • Draws 7.4mA at 4.8V sitting idle • Operation	

		temperature -4 to 140 ° F	
Gyroscope	LPY510AL Dual Axis Gyroscope Breakout Board	• Easy adaptability for MCU • 180 ° so constant update isn't necessary • Usage of power down pin to keep power consumption to minimum • Greater precision	Made by Pololu Available online at $27.95
Compass	HMC6352	• Operating at 2.7V idle and 5.2V on • Easy programmed and operated by MCU with I2C protocol • Standby mode	Available at Sparkfun.com
Optics	Parabolic mirror	• Better concentration, collection	
	Fresnel Lens		

Table 3.1 Main Components

3.1.1.a Solar panel

The solar panel of choice will be a .55 V, 3.6A polycrystalline photovoltaic cell. Consideration were made due to the fact that this photovoltaic panel provide 3.6 A, which is good enough to charge a variety of small batteries. In order to amply charge a storage device, solar panel with high current is of good choice. Also helping in the decision making, is that it comes in a box of 36 solar cells. That fact that it comes in a box of 36 cells, you can make use of it by constructing your own custom solar panel array. You can put those cells in an array of parallel or series to create a solar array of choice, whether if you want more voltage or current or a mix. With this project considering the design of the structure and the curvature of the parabolic lens, those cells are a good choice. This project will probably require a 12x12" solar panel that can charge a 12V max battery. They are 3x6" so creating a small solar array wouldn't be a problem with them. The only con to this is that they are slightly damage, but as long as it whole cell is intact issue shouldn't be a problem.

3.1.1.b Battery

It has been decided that lithium-ion batteries will be the primary source of energy storage to implement into the solar tracking device. This choice was made based on this type of battery's high energy storage capacity; this satisfies the goal to achieve the highest quality energy storage for the device, as well as for its light weight in order to achieve the goal of device portability. Like Nickel-Metal Hydride batteries this type exhibits no memory effect, which is critical to maintaining capacity, but compared to Nickel-Metal Hydride this type of battery has a longer storage life and storage capacity. In fact, lithium-ion outshines every other battery type in terms of capacity. The particular battery being considered is also readily available; there are many vendors that offer multiple varieties of sizes and energy capacities. For instance, the Samsung 7.2V 2.6C battery pack being considered from OnlyBatteries.com has other varieties in its own family that are the same size but with different specifications, so if any adjustments need to be made when the device components are implemented then there are alternatives to choose from. Samsung is also a reputable name and because of this they should have a developed infrastructure and available customer service.

There are also many other benefits to this project that the lithium-ion battery pack can bring. Its physical size, for instance, is not an issue for concern. The Samsung battery pack is only 2.8" long, 1.45" wide, and 0.8" high, finding a place for it to fit should not be a problem. This battery is also only supposed to weigh about a quarter of a pound, the lightweight category can definitely be considered fulfilled with this spec. There is also an integrated circuit incorporated into the battery pack that eliminates many of the typical problems encountered with lithium-ion batteries. For instance, this chip will prevent overcharge and overdischarge so that the battery chemistry does not deteriorate and the goal of reliable operation and the specification of a minimum 500 uses can be fulfilled. An installed polyswitch will also cut off the power if it is discharging more than 2 amps, a quality that no other battery can exhibit upon purchase. This amp rating is also good because most of the electronic devices that will be charged by the device are incapable of handling more than 2 amps on a charge (an iPod® is rated for a 1 amp maximum charge rate). This discharge control should also help eliminate the rare problem of lithium-ions exploding, so this way the goal of having reliable functionality in conjunction with the number one goal of having a device that adheres to modern safety standards can be achieved.

3.1.1.c LCD Module

After evaluating the pros and cons of each LCD module, it is found the HD44780 is the most suitable and a must for the solar tracker. Even though the display is small and not feature rich, they can be compensated for its low power usage, its minimal connections, and interfacing simplicity. The HD 44789 lower power operation can support from 2.7V to 5.5V which is fitting for solar tracker if its power source is a 12V battery. Compare to the Optrex F-5185 and the Samsung KS0108B, these two modules require least 9V to be operational. Even though the LCD's 11 connections can fill up the available ports in the

MCU; it is only for 8-bit mode. Numbers ports required can be reduced by communicating in 4-bit mode. In this mode, four bits can be send one at a time with the higher nibble send first and then the lower nibble. Thus utilizing only 4 data bus pins, so 4 ports can be saved.

3.1.1.d Motor

The Hitec HS-322HD fixed rotation servo was chosen for use in this project. A fixed rotation servo was chosen over a continuous rotation servo because it will be easier to use and operate. The solar tracker will track the sun from sunrise to sunset, so a 180 degree range of motion is all that is required because the solar tracker is designed for use on the ground, thus the curvature of the earth does not need to be accounted for. A DC-motor was not chosen because along with the motor, a motor controller was required, which requires additional power. Relative to the earth the sun moves relatively slow across the sky, so the high speed of a DC-motor was not required, and because power is the biggest consideration in this project a DC-motor and motor controller were considered overkill that would consume much more power than a servo motor. The HS-322HD was chosen above the others because of data that was available. Idle current draw information was available on the HS-322HD which was a primary consideration. The HS-322HD draws 7.4mA at 4.8V and 7.7mA at 6.0V while sitting idle, data that was not available for other fixed rotation servos. This data proved important for choosing a motor because it showed that the servo motors would use minimal power when not in use, giving it a significant advantage over the other servo motors. The HS-322HD also had the same operating temperature range of -4º F to 140º F that the other fixed rotation servos had. Top speed, along with operating voltage range were not considered because of the relatively slow speed of the sun traveling across the sky, and the operating range of all servo motors were the same (4.8V-6.0V). The dimensions and weight of all the servo motors were very similar and thus was not a main consideration when selecting a motor. The Hitec HS-322HD is available online at a price of $9.99. [62][63]

3.1.1.e Gyroscope

The LPY510AL dual axis gyroscope breakout board made by Pololu will be used in this project. The LPY550AL, LPY510AL, LPR550AL, and LPR510AL are all dual axis gyroscopes that measure different combinations of rotation with different range combinations, but are otherwise identical. The LPY510AL was chosen because of it offers the easiest adaptability for use with a microcontroller and its onboard power down pin. The range of the solar tracker, being only 180º per day, does not require constant updating so the power down pin will enable the gyroscope to calculate and update the position every few minutes instead of continuously. Using the power down pin will help to keep power consumption to a minimum. The breakout board on the LPY510AL allows for easy integration with the microcontroller selected for this project, because it contains an onboard voltage regulator. The angular velocity ranges available for the LPY510AL are also an added bonus. The range of ±100º/s and ±400º/s will be used because they will provide much greater precision than the ±500º/s and ±2000º/s (LPY550AL) range and the solar tracker will only move at approximately 180º per day, which is easily measurable by the ±100º/s and ±400º/s range. The operating temperature range of -40º F to 185º F was standard between all the gyroscopes researched. The size and dimensions were all relatively the same and thus were not taken into consideration when selecting a gyroscope. The LPY510AL is available online from Pololu for $27.95. [78][79]

3.1.1.f Compass

The HMC6352 compass with breakout board offered by Sparkfun will be the compass used in this project. The HMC6352 can operate off a voltage between 2.7V and 5.2V which will allow easy interface with our microcontroller. The HMC6352 also operates using the I2C standard communication protocol which will allow it to be easily programmed and operated with the microcontroller. The three separate modes available for performing calculations and receiving data were important when deciding which compass to use. Using the standby mode will enable the compass to be accessed only when data is being requested by the microcontroller, which will help to keep power consumption as low as possible. For this project data does not need to be calculated constantly, and so the standby mode or the query mode will be used so that the data is available only when it is requested. All compasses considered were of similar size and weight so both were not considered for selection of a compass. The compass will also not be attached to the solar panel configuration so the compass will not need to be as resistant to extreme temperatures that could occur near or around the solar panels. The HMC6352 and breakout board are sold online by Sparkfun at a cost of $34.95. [82][83]

3.1.1.g Optics Configuration

After analyzing and debating the three mirror designs along with several lens configurations, no configuration was definitely better than another. Resulting from this conclusion, it was decided that a parabolic mirror would be the main optical configuration to be tested. A parabolic mirror with a hole cut in the center will be used to allow a mechanical pole to be inserted up to the focal point. The pole will not stick straight up through the center, but instead be on an angle so that the pole will block the least amount of incident light possible. Attached to the end of the mechanical pole will be the solar panel mounted to a arm so that it can be adjusted to different angles. The mechanical pole will also be adjustable so that the panel can be placed at different distances from the focal point to allow the efficiencies of the panel because of the heat generated from the light to be measured. The design will also include a Fresnel lens that can be placed at the focal length away from the panel to focus the light reflected from the mirror onto the photovoltaic cells. This will be able to be easily removed in the event that the temperature on the panel is too high. Figure 3.1 and 3.2 below will demonstrate what the optic configuration will look like. In addition to the optic configuration above, the alternative optical configuration described below will be tested in unison with the parabolic dish, to make sure that the main optical configuration is indeed the most efficient. In the event that the alternative configuration is more efficient, the alternative configuration will be used because the goal of the project is to increase the efficiency of a solar panel.

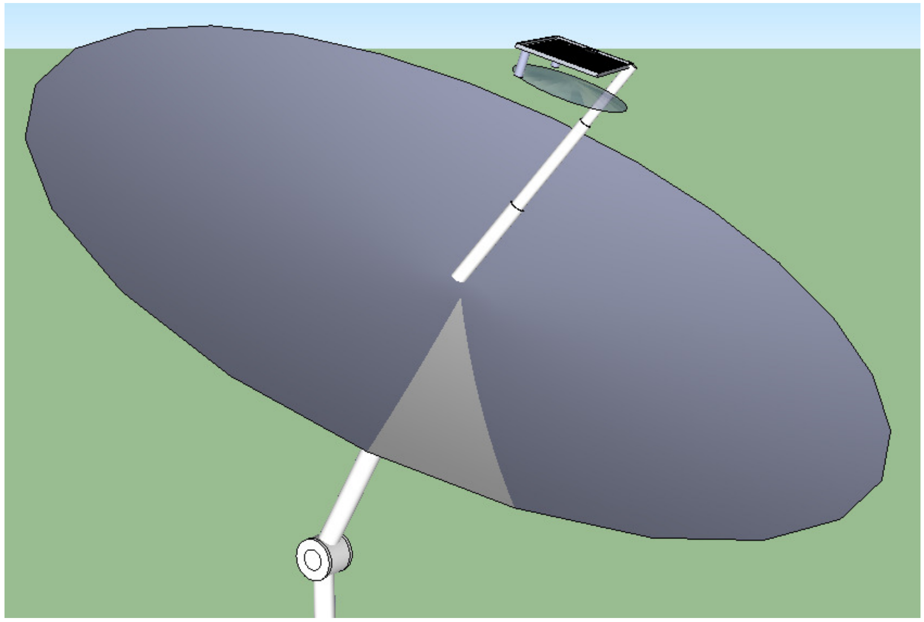

Figure 3.1 Optical Configuration

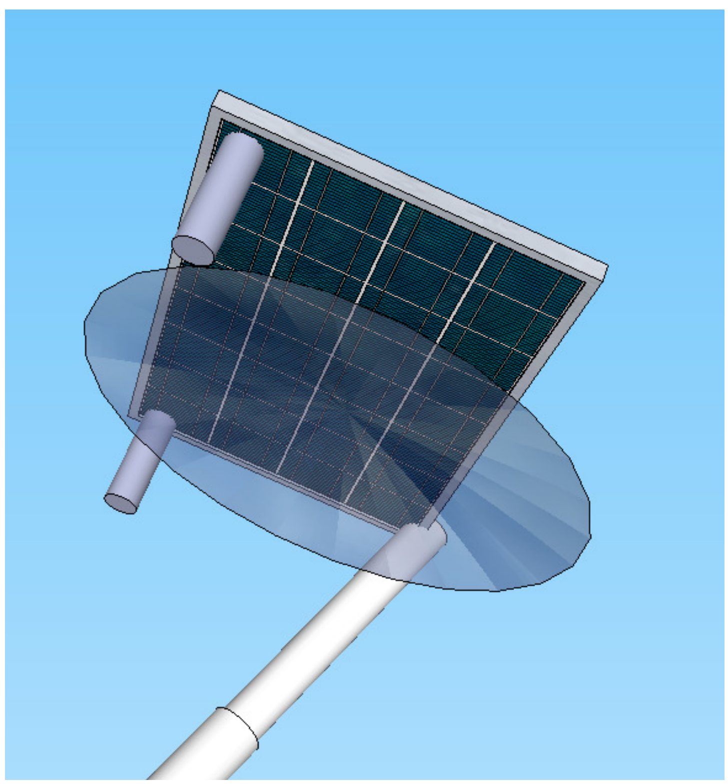

Figure 3.2 Optical Configuration Alternate Angle

3.1.2 Alternative Component Selection

The alternative components that will be used in the event that any of the main components cannot be used are described in this section. Table 3.2 is shown to easily display all the information described below.

Alternate Component	Part Name	Pros	Cons
Battery	Lead-acid Battery (ies)	• Low cost • Durability, can be abused physically	• Lose of portability • Nowhere near the capacity per weight ratio of lithium-ion
Motor	Futaba S9405	• Fixed rotation servo motor • High torque operation Similar size, dimension, and operation temperature to HS-322HD	• 4.8V to 6V, so power consumption will be issue • Heavier, 12g heavier than HS-322HD Price $64.99
Gyroscope	LISY330AL Single Axis Gyroscope	• Easy to interface with MCU because of onboard voltage regulator • Similar to the LPY510AL • High precision compared to other gyro • Pin for low power	• Two gyro will be needed due to being one axis
Compass	HMC5843	• Between 2.5V and 3.3V operation voltage.	• No on board voltage regulator • More expensive, $49.95
Optics	Plane mirror	• Reliable design	•

Table 3.2 Alternative Components

3.1.2.a Alternative Solar Panel

An alternative solar panel for this project in case of unforeseen circumstances is a box of 24 polycrystalline solar cell from goldmine-elec-products.com. Since the aim is to design a solar array that can charge a battery, this will be a second best for the price; which is $24.95. It also comes in a box, 24 panels will be provided. This gives an option to play around with various configurations. Although not giving anywhere near the 3.6A current that the main choice provides it will suffice with the given price, which is much cheaper than other available ones. This is also second best because for the primary cells it comes in a box of 36 and this one it comes in a box of 24. Unlike some that was found, they were either low current and single cell or they were over the top expensive, $100+, with the option of providing tremendous current.

3.1.2.b Alternative Battery

In the event that the lithium-ion battery does not work, stops working, or some unforeseen complication arises due to its own specifications, a lead-acid battery may be the backup. This type of battery has nowhere near the capacity per weight ratio that a lithium-ion or even nickel-cadmium battery can exhibit, but compromises will have to be made for the ultimate design goals if this battery is used. The device will essentially lose its aspect of portability with a lead-acid type, but it will make up ground in qualities such as low cost and durability. A lead-acid battery can be purchased at a much lower cost than that of a lithium-ion but only if it is determined that energy capacity can be sacrificed. Lead-acid batteries are also very durable; they can be abused physically as well as in terms of charge cycles. This type would still need to be protected from water and the rusting of the leads, but it will still achieve the goal of strength and withstanding elements of the weather better than any other type.

An alternative being considered for the design of the device would be like the design with plane mirrors shown in Figure 3.3 and Figure 3.4, however this design would have a servo motor controlling the orientation of each plane mirror. This would be an optimization attempt to focus light rays that are scattered, likely from cloud cover overhead, and focus them as efficiently as possible. These planar mirrors will require their own respective photo-detectors and a servo motor will need to be connected to each. These servo motors will require pins to be utilized from the microcontroller, and pins are supposed to already be limited for what has already been proposed. Not to mention the extra cost that will be incurred when four more motors are required along with extra photo-resistors and wiring. This extra cost will go against one of the principal goals set out for this project, to construct a device with the best quality for the lowest price. If the overall efficiency increased is minimal then it could considered a trade-off for achieving a lower cost and likely more reliable device. This optimization will be tested through experimentation and the voltage of the precise plane mirrors with motors will compared against the output achieved when the solar tracker is in its standard form.

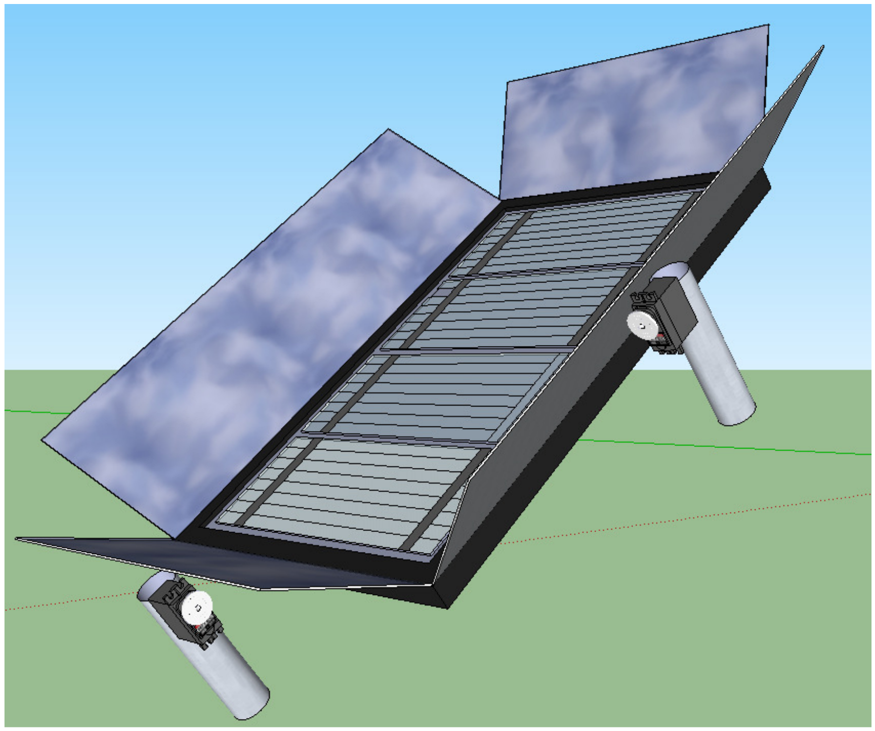

Figure 3.3 Alternate panel configuration

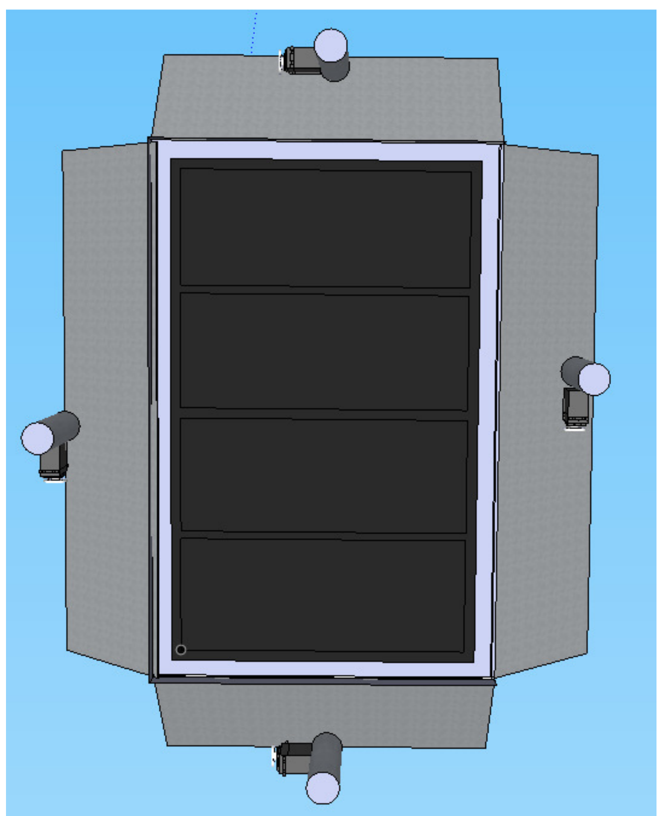

Figure 3.4 Alternate panel configuration, alternate view

3.1.2.c Alternative Motor

The Futaba S9405 will be the alternative servo motor used in the event that the HS-322HD servo cannot be used for this project. The S9405 like the HS-322HD is a fixed rotation servo motor that operates on the traditional 4.8V to 6.0V range. The S9405 is designed for high torque operation. At 4.8V the S9405 outputs 5.8 kg.cm (80 oz.in) compared to the 3kg.cm (41.66 oz.in) stall torque of the HS-322HD. At 6.0V the S9405 outputs 7.2 kg.cm (100 oz.in) of torque compared to the 3.7 kg.cm (51.38 oz.in) stall torque of the HS-322HD. The greater torque enables a larger solar panel and mirror/lens configuration to used. While the greater torque of the S9405 makes it a good component for use in this project, the current draw data, while not available, will be much higher than the HS-322HD. Power consumption being the biggest consideration for a motor, made the S9405 chosen as an alternative instead of the main motor used. The S9405 has similar size and dimensions while being about 12g heavier than the HS-322HD. Both the HS-322HD and the S9405 have the same temperature operating range of -4º F to 140º F. The Futaba S9405 high torque servo is available online starting at $64.99. [62][63][64][65]

3.1.2.d Alternative Gyroscope

The LISY330AL single axis gyroscope and breakout board made by Pololu will be the alternate gyroscope used in the event that the LPY510AL cannot be used with this project for any reason. The LISY330AL offers an onboard voltage regulator so it can easily be interfaced with most microcontrollers similar to the LPY510AL. The operating range of the LISY330AL will match the LPY510AL at -40º F to 185ºF and offer a similar size and weight. Two separate LISY330AL will be used to measure the rotation, meaning the two LISY330AL will be mounted in different locations so that both axes are still measured. Using two LISY330AL gyroscopes was chosen over other dual axis gyroscopes, because it offers near identical features and specifications when compared with the LPY510AL, and comes mounted on breakout board with voltage regulation and a power down pin for low power consumption. The angular velocity range of ±300º/s on the LISY330AL will provide high precision compared to other gyroscope that can measure higher angular velocities. The LISY330AL is available online from Pololu at a price of $19.95. [76][77]

3.1.2.e Alternative Compass

The alternative compass in the event that HMC6352 can for some reason not be used will be the HMC5843. Sparkfun offers a breakout board for the HMC5843 digital compass made by Honeywell. The main reason for this being selected as an alternative is that there is no voltage regulation on the break out board. A voltage between 2.5V and 3.3V will be required to power the HMC5843 which would require an additional voltage regulator so the HMC5843 could interface with the microcontroller. Similar to the HMC6352, the HMC5843 offers several operating modes, including idle and sleep. Idle mode would most likely be used for this project because it retains the values in the registers but disables the high power consuming elements. The HMC5843 also has a wide operating temperature range of -22º F to 185º F, and is similar in size to the HMC6352. The HMC5843 is available online from Sparkfun at a price of $49.95, considerably more expensive then the HMC6352. [86][87]

3.1.2.f Alternative Optics Configuration

The alternative optical configuration will be a plane mirror configuration surrounding the panels on all four sides, assuming the panel configuration being in the shape of a rectangle. This was chosen as the alternative because it is the configuration with the least amount of questions, and has the most reliable design. The mirrors will be mounted to the side of the solar panel, in a way that they are held at the angle they are set. The angle will be able to be changed and will be determined during the prototype and testing stages. For this design there are no plans for a lens of any kind to be used. The mirrors will remain at the set angle relative to the solar panel, and will track the sun as it crosses the sky. The size of the mirrors used will depend on the size of the solar panel used, and the final shape of the panels. In the event that this optical configuration is more efficient then the main optics configuration, the alternative optics configuration will be used.

3.2 Overall Design

An overview of the entire design will be described below to explain how the components will be assembled and what their purpose is for the project. To begin the section figure 3.5 will give an overview of how the solar tracker will work followed by an explanation.

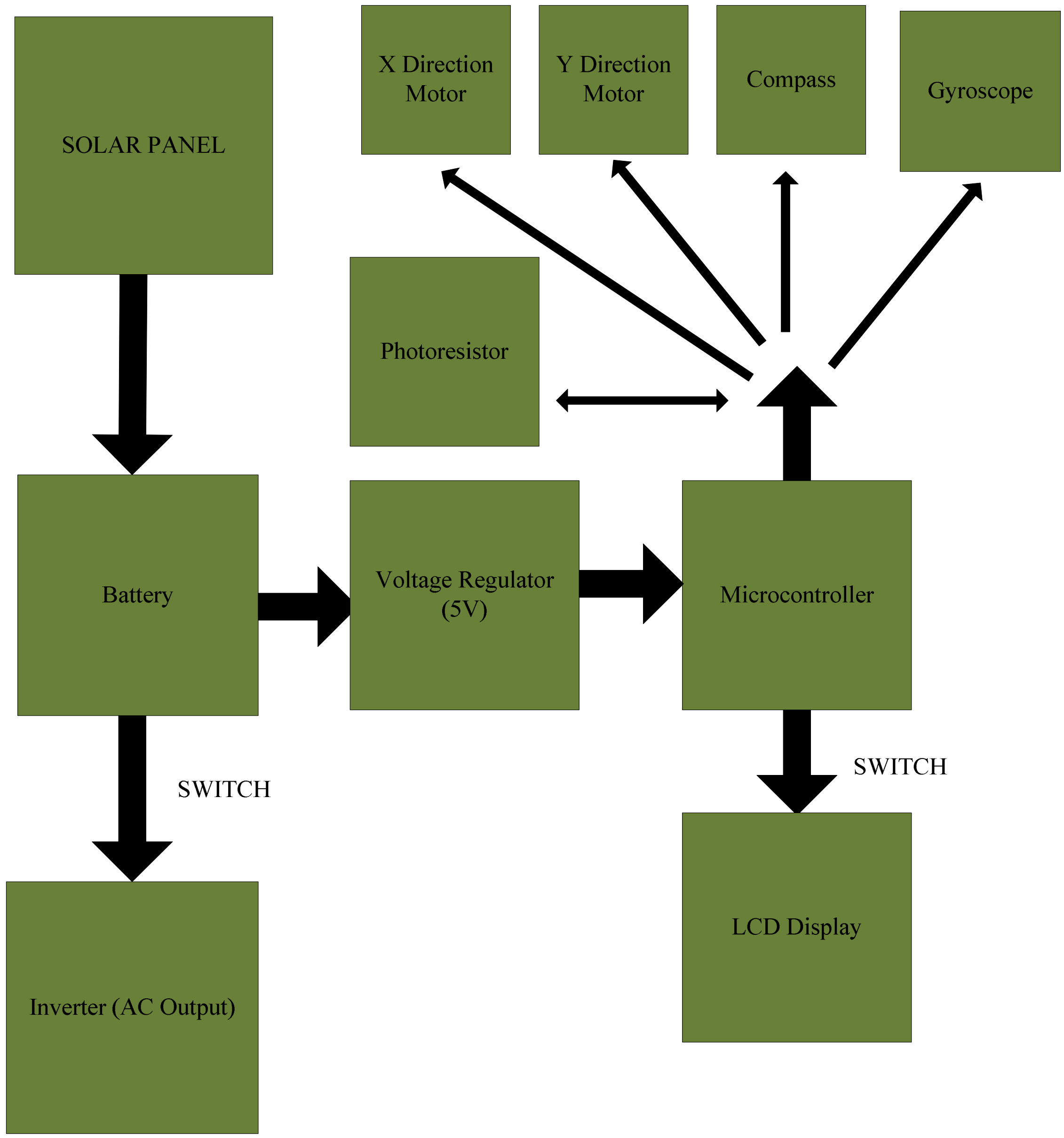

Figure 3.5 Overall System Flow Chart

The solar panel will convert the sun's rays into energy which will then flow into the battery. In between the solar panel and the battery will be diodes to prevent current from flowing back into the solar panels once night time is reached and the solar panel is no longer generating any power. From the battery a voltage divider will split the power between powering the microcontroller and an AC-DC inverter. In between the battery and the inverter, there will be a switch so that power is only sent to the inverter when a switch is thrown on the outside of the mechanical housing. This will make sure power will only be available at the output when the user needs it. The power from the battery that goes to the microcontroller will first enter a voltage regulator to bring the required voltage down to the voltage required by the microcontroller. The microcontroller will essentially be the heart of the solar tracker. Photo-resistors will be positioned on select places on the solar panel configuration. The values from the photo-resistors will then be sent back to the microcontroller to analyze and determine the suns position in the sky. Based on the values of the photo-resistors the microcontroller will in response send signals to the servo motors telling them to move the solar panel configuration to be perpendicular to the incident light from the sun. This process will repeat at specific intervals throughout the day so that the sun is followed across the sky. While this is occurring throughout the day, the microcontroller will be keeping tabs of the sun's position. Connected to the microcontroller, will also be an LCD display, separated by a button. When the button is pressed, the microcontroller will get data from a dual axis gyroscope that is attached to the solar panel configuration, along with a digital compass mounted on the mechanical frame of the battery. This data will then be output to the LCD Display along with the current power input being received from the solar panel and the battery charge level. This allows the user to exactly determine the sun's location in the sky, as well as the direction that the frame is facing.

3.2.1 Programming Design

The heart of the solar tracker project is the microcontroller. The microcontroller has the duty of controlling all of the sensors and outputs along with controlling the panel configuration. The designers of the solar tracker project are all electrical engineers, and thus do not have a computer programming specialty. A working microcontroller will require a program that can interface all of the sensors and output the data to an LCD display. The Arduino Duemilanove is the microcontroller chosen to be the heart of the solar tracker. The Arduino is programmed using code that is similar to the C programming language but with a few important differences. Several of the designers are somewhat familiar with programming for the Arduino, including operating servo motors and interfacing with LCD displays. Included below will be block diagrams and pseudo-code that will lay a foundation for Arduino programming. Figure 3.6 below displays all the responsibilities of the microcontroller.

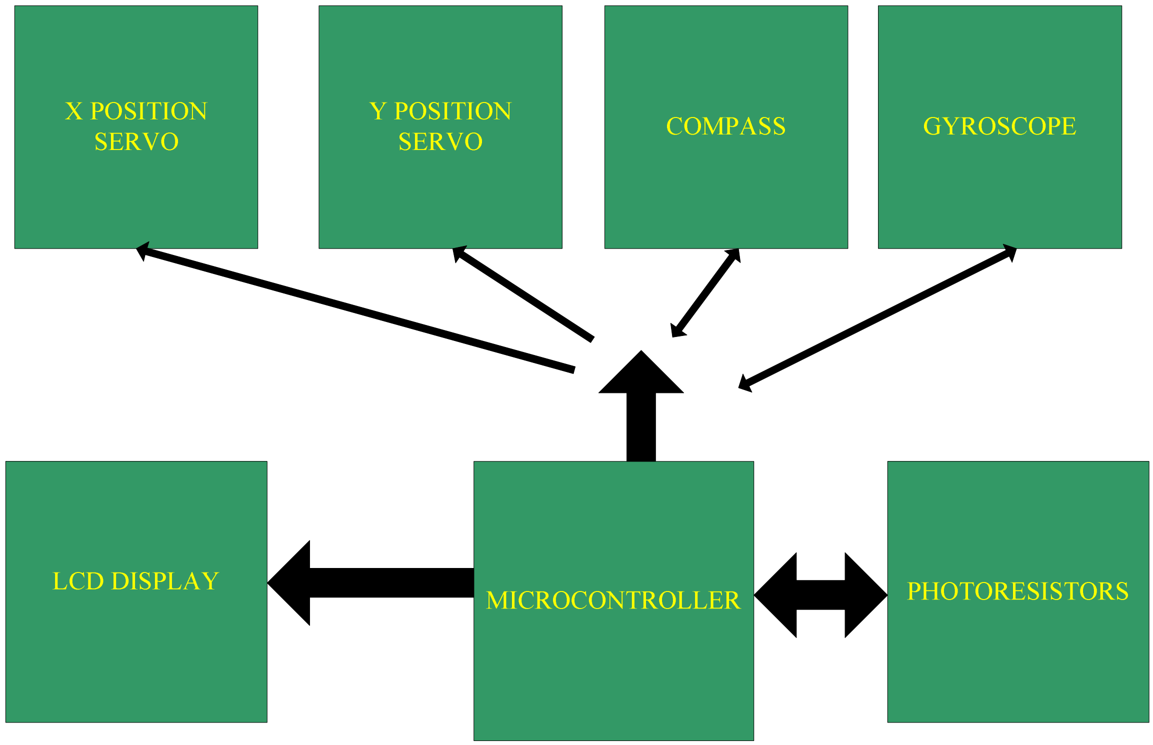

Figure 3.6 Microcontroller Responsibilities

The Arduino will provide power to the servo and interface with it using PWM signals. The servos will need to connect to the 5V and GND pins on the Arduino. The PWM signal can be sent on either the analog or digital pins, but will be connected to digital pins because they are designed for use with PWM. The compass will also receive 5V power from the Arduino, and interface by connecting the serial clock (SCL) and serial data lines (SDA) to two of the Arduino's digital pins. The gyroscope will use the 3.3V power line on the Arduino, and interface using the X (pitch) and Y (roll) lines on the gyroscope. These lines output an analog voltage and will be planned to connect to two of the analog pins. The power down (PD) pin will also be pulled up to 3.3V so it may be used. The LCD display will be powered off the 5V line as well along with the backlight pin which is used to illuminate the screen. The RS, R/W, and EN along with 4 data pins will connect to digital pins on the Arduino. The photoresistors will be connected to analog pins and will be used to compare resistance values. The power lines from the battery lines will be sent through a voltage divider to scale the voltage down. This scaled voltage will then be input to the analog lines to be output on the LCD display. The efficiency of the solar panel will also be calculated in a similar manner by scaling down the power then dividing that value by an average value of the voltage at that position without the optical configuration.

When interfacing components that depend on other components calculated values, it is important that the code flows seamlessly between components. Figure 3.7 below will display how the code will flow through the Arduino microcontroller to the components followed by an explanation.

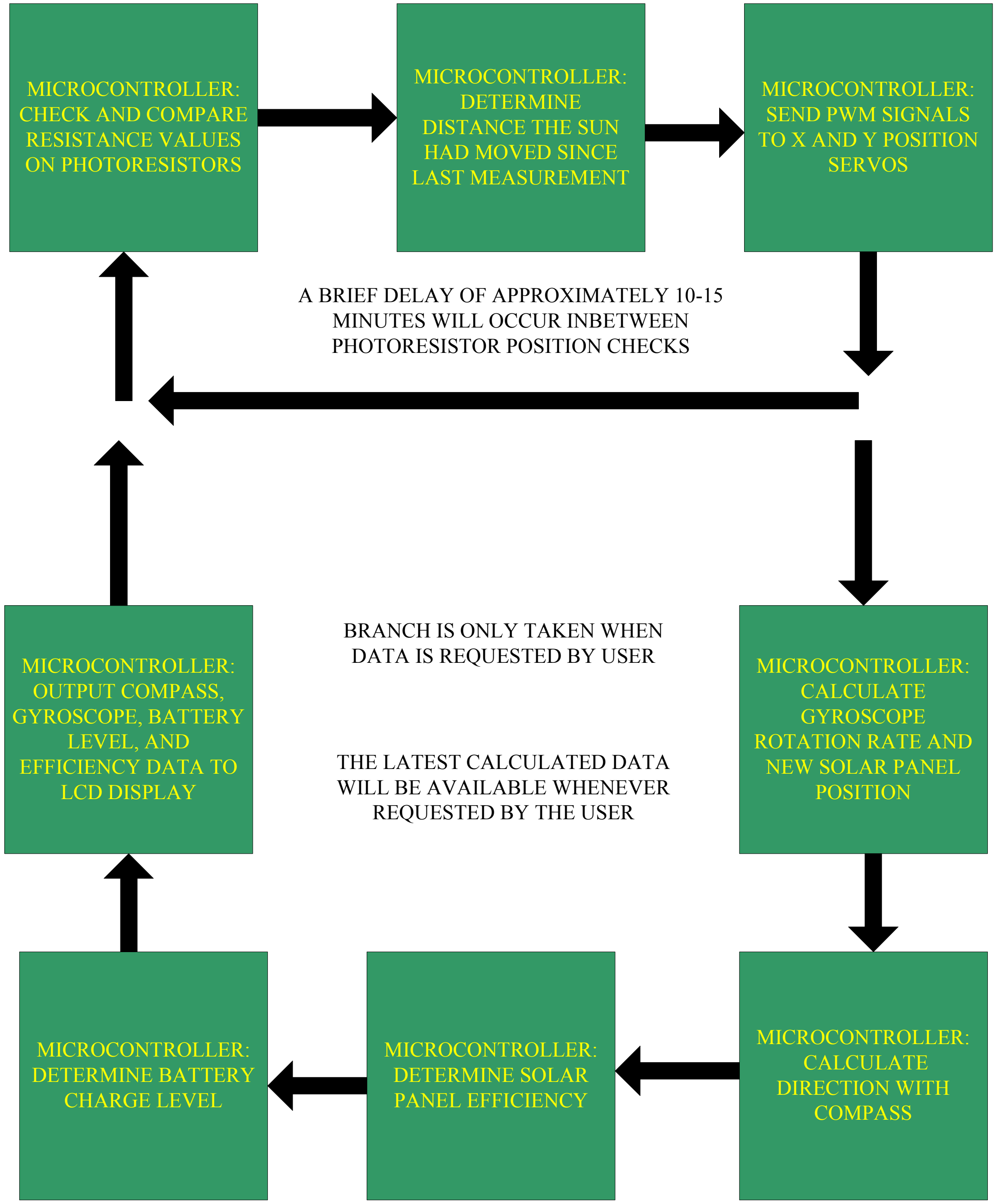

Figure 3.7 Flow Chart of Programming

The solar tracker code will begin with checking the value of the photoresistors. A comparison between the values will be able to determine which photoresistor is receiving more light. Once the photoresistor that is receiving more light is determined, the microcontroller will calculate the period since the last movement. Depending on the period the microcontroller will then send PWM signals to the x position servo followed by the y position servo to move the solar panels so that the photoresistors are now receiving near identical values. The microcontroller will then power off for a specified period of time. When the time expires the microcontroller will repeat the process to calculate the new position. This will repeat throughout the day until either a comparator or timer is used to calculate sundown. The process will then begin at sunrise using the same method of either a comparator or timer. The user may at any time request data of the position of the solar tracker and battery and efficiency levels by pressing a button or flipping a switch. When the user signals, the microcontroller will power up and calculate the position from the compass and the gyroscope. Then a few operations will be done to calculate the charge level of the battery along with efficiency of the solar panel. This data will then be output to an LCD display on the outside of the mechanical frame.

3.2.1.a Pseudo Code

The information below will briefly explain and display how the code will run, including code examples from the Arduino programming language. To begin, the software used to program the Arduino microcontroller will be the latest version available on the Arduino website, Arduino 0018. The Arduino 0018 software can be used on Windows, Linux, or Mac OS X operating systems. To interface with hardware certain code libraries will be included in the code. The LiquidCrystal.h library will be used to interface with LCD display. There is also a Servo.h, and a SoftwareServo.h which can both be used to easily interface with the two servo motors using PWM. EEPROM.h can also be used if the EEPROM on the Arduino needs to be used. The libraries are included at the top of the code and are added to the code by typing for example " #include <LiquidCrystal.h>". There are two main sections the code can be placed in void setup and void loop. Void setup runs once when the code is first run, while void loop continuously runs as long as the Arduino has power. Functions are also declared similar to the C-programming language by entering for example void Function1( ). These functions then can be run by inserting them into either setup or loop. Below, in Figure 3.8 will be a pseudo code example for the photoresistor comparison function and the resulting movement of the servo motors.

```
Void Photocheck1 ( )
{
  if (photo1 < photo2)
   {
    if (timeelapsed < 10000)
      {
        rotateXservo (10)
      }
     else if (timeelapsed < 150000)
      {
        rotateXservo (15)
      }
      else
```

```
{
 }
}
}
```

Figure 3.8 Pseudocode for Photoresistor Comparison

First the values of the photoresistors will be compared. If the second value is greater, the amount of time elapsed between the last check will be checked. If the time elapsed was for example 6 minutes ago, then move the x rotation servo an amount of 10. If the time elapsed was 10 minutes ago move the x rotation servo an amount of 15. Otherwise if the time elapsed has been over 10 minutes do nothing. In the actual code additional checks would be made but are not shown due to the nature of the example. Figure 3.9 displays a pseudo code example of how the LCD display will output the gyroscope and compass data, along with the solar panel efficiency and battery level.

```
LiquidCrystal lcd (7,8,9,10,11,12);

void setup ( )
{
serial.begin(9600);
lcd.begin (2,16);
lcd.clear ( );
lcd.setCursor (0,0);
}

void loop ( )
{
lcd.clear ( );
lcd.setCursor (0,0);
lcd.print (Xposition);
lcd.print ("N");
lcd.print (Yposition);
lcd.print ("E");
lcd.print (Compass);
lcd.setCursor (0,1);
lcd.print (BattLevel);
lcd.print (PanelEfficiency);
delay(25000);
}
```

Figure 3.9 Pseudocode for LCD Display of Data

The code begins with the declaration of which pins are connected to the Arduino. The code then sets up a clear LCD display in the setup section of the code. When loop is executed the position is reset to the first character of the LCD screen. Displayed on the first line of the LCD screen is the X position from the gyroscope followed by a direction. Then following the X position is the Y position of the gyroscope followed by a direction. The compass direction is then output on the first line of the display. The cursor is then set to the first character of the second line. Once on the second line, the battery level is output followed by the panel efficiency. All the data is then held on the screen for a specified amount of time.

3.2.2 Methods of Tracking

As the sun rise and set across the sky, it is essential for the solar tracker to maintain a consistency in aiming at the sun in order for it to be effective. Having the sun's rays hit directly at the collector can maximize the energy being absorbed. There are three designs that are considered to be suitable for capturing the sun. The first plausible method is to have the collector rotate to a predetermined angle every 15 minutes. Another one is to use two photoresistors and compare their voltage outputs. If their values are different, it means that the collector is not aiming correctly and needs to be adjusted until the values are equal. An alternative to these two methods is to use IR camera. Since hot bodies radiate infrared and the sun is the produce the most, a tracking system could be developed using an IR camera to the follow the hottest object in the sky. To decide which method is appropriate for the project, there are parameters that these designs must adhere to; they are ranked from the most significant to least.

- High precision, for maximum effectiveness it's imperative for the energy collector to face exactly at the sun. The three tracking methods must be able to maintain a ±3 degree tolerant during the day.
- Low power consumption, it must be minimal as possible. Using more than 10% of the battery capacity is unacceptable.
- Low cost, the budgeted amount for the materials must be under $30.
- Simplicity, assembly and programming of the design should not utilize more than 1/3 of the building process.

3.2.2.a Predetermine Position

The most inexpensive yet inconvenience method of tracking is having the device automatically adjust itself to the sun by a timer. Relative to earth, the sun always travels from east to west and usually it's directly overhead during noon. With this pattern, it's possible to determine where the sun is without having to use sensors that are high cost and consume power. The solar tracker would place and orient in an assigned location facing east, and throughout the day, the energy collector would increase its elevation by certain amount to synchronize with sun's position. To have maximum absorption, a mathematical calculation of the sun's positions must be done and there are three variables that are associated with them are: the location of the tracker, day number and time.[109] Once the positions of the given time intervals are known, it could be programmed into the MCU. Within the MCU is a timer that's synchronized with the current clock, and at every 15 minutes it would run a program that instructs the motors to rotate the energy collector to the preset degree. For example, if the sun is 45 degrees from the horizon at 9 o'clock in the morning, then the timer would set to rotate the collector's elevation of 45 degrees.

The problems with using this type of method for tracking are the inaccuracy and immobility. The sun's position is not permanently fixed throughout the year due to the 23.5 degrees tilt of the earth's rotational axis.[109] It can be north or south depending on the location and season where the device is set. In the equator, the amount of sunshine is basically the same year round. It takes 24 hours for the earth to rotate a full 360 degrees which means at a rate of 15 degrees per hour. If the solar tracker is to operate at the equator, then the energy collector has to rotate 3.75 degrees every 15 minutes. For the Southern and Northern hemisphere, it's more complicate. The sun's duration is longer in summer than winter and its position also changes. At summer in the Northern hemisphere, the sun is more in the north direction, whereas in the winter, it's more to the south. Table 3.3 below shows the azimuth and elevation of the sun on two separate days, for a 12 hour period in Orlando. These data was taken from the Nation Oceanic and Atmospheric Administration's solar position calculator. If the solar tracker is to place in Orlando, then certain time these are the direction and elevation the track must be facing. Notice that in one month the sun's position can change as much as 20 degrees especially during noon. To have an effective absorption, the pointing angle of the collector must be updated regularly at least every two weeks to minimize the different or when the solar tracker has been displaced.

4-Jul-10	Azimuth	Elevation	4-Aug-10	Azimuth	Elevation
7:00 AM	72.74	17	7:00 AM	77.89	14.23
8:00 AM	78.52	29.874	8:00 AM	84.32	27.21
9:00 AM	84.26	42.75	9:00 AM	91.17	40.36
10:00 AM	22.84	55.9	10:00 AM	99.72	53.47
11:00 AM	110.48	69.01	11:00 AM	113.42	66.11
12:00 PM	128.35	81.2	12:00 PM	145.77	76.52
1:00 PM	231.81	81.17	1:00 PM	211.41	76.88
2:00 PM	259.53	68.96	2:00 PM	245.5	66.71
3:00 PM	269.19	55.86	3:00 PM	259.65	54.11
4:00 PM	275.72	42.7	4:00 PM	268.34	41.01
5:00 PM	281.46	29.68	5:00 PM	275.23	27.85
6:00 PM	287.23	16.94	6:00 PM	281.65	14.84
7:00 PM	293.54	4.7	7:00 PM	288.32	2.33

Table 3.3 Azimuth and elevation of the sun in Orlando.
Taken from Noaa.gov's Solar Position Calculator.

3.2.2.b Differentiating Photoresistors

In a clear sky day, photoresistor receives maximum lux when the angle of incidence of the sun's ray strikes at 0 degrees. As the sun shifts, the angle of incidence increase causing the amount of lux absorbed to lessen. Since change in lux is correlates with change resistance, it can be use to indicate whether the sun has moved from its original position. By using two photoresistors, they can be implemented to follow the sun; their outputs can be used to determine which direction the sun is moving. A simple design of this is to place two photoresistors about a foot apart from each other on a flat surface along with the collector. And when the sun's ray is orthogonal to that surface, the amount of lights exerts on the resistors is the same. But when the sun changes its position, one resistor will receive more lights than the other due to smaller angle of incidence. This difference indicates that the sun is currently locating on the side that has the least resistance. When the solar tracker is not align with sun, the motors can be use to correct it. But in order to do so, the MCU must first read the values of the photoresistors through the analog-to-digital ports and quantize it. These input signals must be measured in term of voltage. MCUs are not capable understanding resistance or lux value; a design must be implemented to translate resistance to voltage. Once to voltage is quantized, an algorithm in MCU would takes these numbers and determine if there is any discrepant between two. If there is, the MCU would drive the motors to face the collector in the direction of the sun. As the collector moves, so do the photoresistors. This process repeats until the MCU sees that the outputs of the photoresistors are equal. To have a higher precision than just placing two photoresistors apart, another method could be use is to have a plate insert between the resistors. As demonstrated in figure 3.10, when sun is directly above, both sensors is receiving the same amount of light and it's in stable state. As the sun shifts, one of the sensors will experience a decreasing amount of light because of the plate's shadow while the other experience full sunlight. The tracker would then adjust itself, following sun's direction until the sensors reach equilibrium.

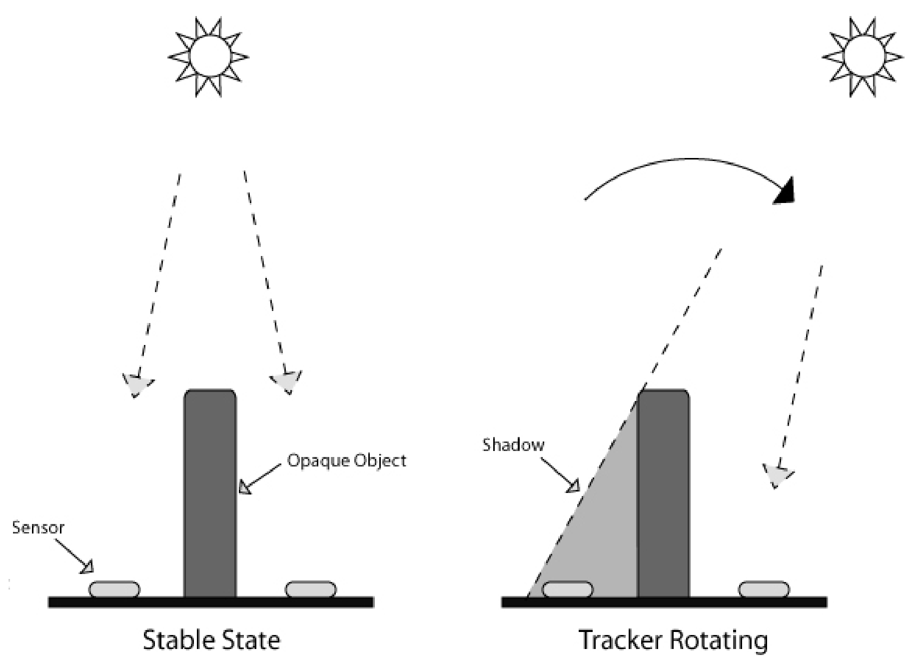

Figure 3.10 High precision detection, reprinted with permission of Mridul Kashatria http://solarwebworld.com/blog/2006/04/18/knowing-sun-tracker

3.2.2.c Differentiating Phototransistors

Similar the photoresistor, the phototransistor is a light dependent device that can be used to track the sun position. A phototransistor is basically a regular transistor with two additional features. It has a transparent window so that light can shine on the junction and its body is modified to maximize the light capture area. Also, it has much larger base and collector areas than the regular transistor. The base connection is not connected because the levels of current depend on the levels of light intensity. As light enter the base region of the phototransistor, it causes hole electrons pairs to be generated and moved under the influence of the electric field. This causes a base current, injecting the electrons into the emitter.Like ordinary transistors, the phototransistor can be used as common emitter or common collector, depending on the purpose of the circuit. Common base is rarely used because it's often left open. There are two mode of operations can be use with the phototransistors circuits and can be implement to the tracking design. They are called linear mode and switch mode. In linear mode, the output acts proportionally to light density. With this mode, the tracking technique is similar to that of the photoresistors (mentioned in section 3.2.2.b). The values to the phototransistor can be use as a gain detector. By comparing their outputs, the position of the sun can be determined, and the direction of the collector can be adjusted accordingly. In the other mode, transistor functions as on and off switch. When there is little or no light, current is unable flow through the transistor; nearly zero output. But as the light increase, current will start to flow and eventually becomes saturated, keeping a constant output.[110] This type of mode it suitable of detecting objects, and can be use to identified whether the sun is in certain position or not. Figure 3.11 below shows how the transistors can be set up to use as a detector. The transistors are place in parallel with the energy collector to experience the same amount lights. The yellow circle represents the sun and its position with respect to the transistors. The horizontal bar is a plate that positioned over the transistors and the gray area is its shadow. When the sun is not directly over the plate, then a shadow is casted at an angle that's corresponding to the sun's ray blocking one transistor while uncover the other one. Referring to the figure, there are three possible states to indentify the sun's position throughout the day. State A can be considered as the condition when the sun rises from east and it is to the left of the detector. At this current condition the plate's shadow is blocking the right transistor while the left transistor is being shine on. Once the difference of the transistors can be distinguished, the solar track will adjust itself until they are equal; that is when they are in state B. The plate covers both transistors from the sun. As the sun head west, it is now to the right to the right of the detector shining on the right transistors and the left transistors is blocked. The tracker would then try to position self back into state B and this process is keeps repeated when the sun is moved its original position.

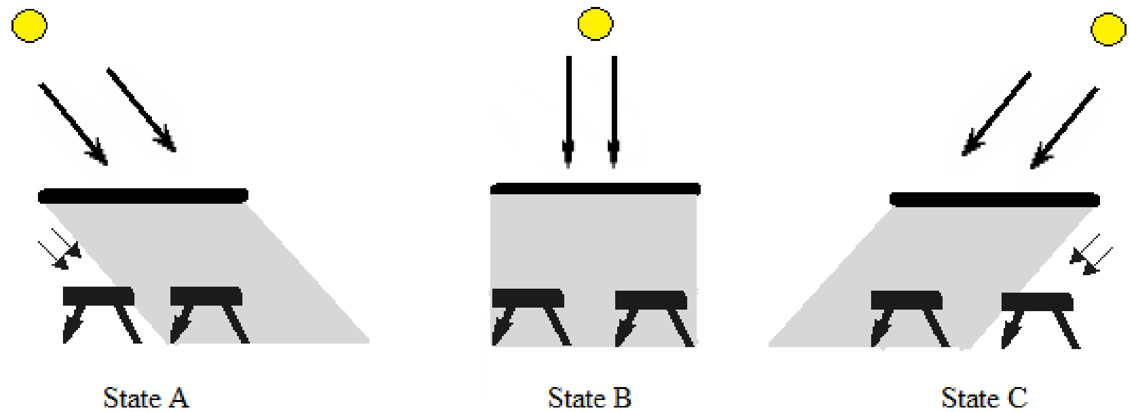

Figure 3.11 Differentiating phototransistors using the cover method.

On the feature of the plate, its width must be equal to the separation of the two transistors, measuring from their farthest ends. The plate's distance from the transistors can control the amount in degrees that the sun can shift before any different in the transistors can be detected. Placing the plate further away has a smaller angle tolerance than placing it closer to the transistors. It is desired for the transistor produce a 0V when the shadow is casted on it and 5V when it receives direct sun light. For the selection of transistor, it is preferred to have the ones that have lower power consumption, high sensitivity, and be able to produce an output within the range of 0 to 5V for the MCU to able to quantize it. Panasonic PNA 1605F silicon NPN phototransistor; this can be acquire from Digikey.com for $1.50. Some of its features are: high sensitivity, wide directional sensitivity, average response time at 8us, and side-view type package. This device looks actually the same as a regular transistor, about 16mm tall and 4.5mm wide. It's a sidled design, meaning that the sensor is located to the side parallel with the pins. For maximum ratings at 25ºC, the collector to emitter and collector to base voltage are 20V and 30V respectively. The emitter to collector and emitter to base maximum voltage are 5V. The maximum allowable collector current 10mA and collector power dissipation is 100mW. For optical performance; when the voltage across the collector and the emitter is 10V, the highest possible current in no lighting environment is 2uA and has peak sensitivity at 900nm.[111] Another phototransistor that has been looking at is the OP800SL from OPTEK. This one is a more expensive (cost about $3 at Digikey.com) and has a different form factor than the PNA 1605F. It shapes like a LED but with three pins and its body is encased with metal except for the top part where the detector is located. It has a total length of 19.56mm and 5.84mm in diameter. Some of its features are: narrow receiving angle, has variety of sensitivity ranges, and enhanced temperature range. For maximum ratings at 25ºC, the collector to emitter and collector to base voltage are 30V. The emitter to collector and emitter to base maximum voltage are 5V. The maximum allowable collector current 10mA and collector power dissipation is 100mW.[112]

3.2.2.d Infrared Camera

To get a precise aiming, using infrared camera as a sun sensor seems to be the best method compare to the other two that were mentioned. Thermal imaging has been utilized in many scientific and military applications as way to view the heating distribution of the surrounding. It gives a different perspective that cannot be seen with the human's eye. The camera contains special designed lens and detectors that focus and scan the infrared radiation. A temperature map is developed in the camera and translated into electric impulse that can be turn into data by the signal process unit.[113] Every object produces heat; even if it's super cooled, it does radiates some thermal energy as infrared. The sun, being the biggest source of thermal energy, produces more than half of its power output in the form of infrared light.[113] An IR camera can be mount on the apparatus facing the same direction as the collector, and with a special algorithm in the MCU, it can determine the most intensive spot on the image. When the data is send to the MCU, it would be analyzed to determent where the sun is with respect to the middle of the image. If the sun is at one of the corners of the image, then the MCU would control the motor to change the direction of the camera until the sun's position in the center of the captured image. As the camera tills, the collector also tills along with it making it more efficient to absorb the sun. Another benefit in using the IR camera is that even if the sun is blocked by clouds or any thin layer object, it's still possible to detect it. In choosing an appropriate IR camera, there are factors that have to take into consideration. The camera has to be small and light weight so it wouldn't be a burden the structure or the motors. The coding must be simple; since it needs to track only one object, programming should not be time consuming. Also, it needs to inexpensive; the maximum amount to be spent on the camera is $30.

After some extensive research, it was concluded that the majority of IR camera available are for industrial and security purpose. These cameras cost at least $50 and they are bulky not suitable for the solar tracker. An alternative method that is been being look into is to use the Nintendo Wii Remote. This device has a little IR camera about less than ¼ of an inch located front that can be stripped out to use for other imaging processing purpose. The remote cost about $39, but a broken one can be bought for cheap on eBay.com as long as camera is still works. The Wii IR camera has been use by many hobbyists in projects such as tracking movement, color sensing and heat sensing. This camera is great for tracking infrared sources because of its simplicity. Interfacing with the MCU requires an I2C for the two components to communicate. Figure 3.12 below shows the I2C on the left, and the Wii IR camera on the right with its eight pins (four pins are partial blocked). The I2c contains a 25MHz quartz oscillator, two 1N4148 diodes, two 10uF electrolytic capacitors, a 100nf capacitor, a 22kΩ resistor, and two 2.2kΩ resistors. The resistors serve as pull-up resistors since the camera is a 3.3V device and most MCU connections are 5V.[114]

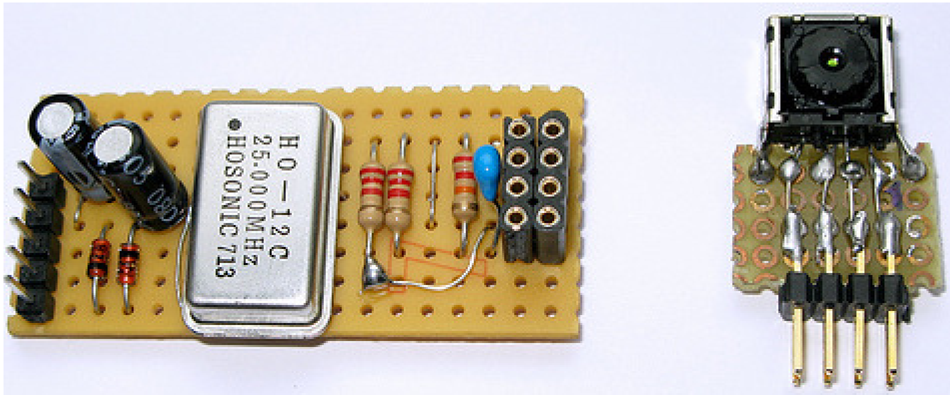

Figure 3.12 I2C and IR camera from Nintendo Wii controller.
Reprinted with permission of Peter Recktenwald.

The IR camera can tracks four independent objects at the same time. It sends the information to the MCU as to where the objects are in the X and Y coordinates, and their intensity.[113] To indentify which object to follow, there are some initializations must be made beforehand. The first step in to send sequences of bytes to initialize the camera. Once it's done, the sensitivity parameters need to be defined. These parameters declare what's the minimum and maximum size the tracking objects to be detected. They also declare the sensor gain and the limit of that gain. Since the sun is the only thing to track, the parameters can be set to focus mainly on the sun's characteristics. During the building process, an experiment must be made using the camera to see its perspective on the size and infrared of the sun in term of the data that is sent to the MCU. Once the data available, it can be used to refine the parameters that needed to get a precise detection of the sun's position.

3. 2.3 Photoresistor Circuit

There are two approaches to design a sun position detector using photoresistors; either by converting analog signal to digital using a microcontroller or straight through analog by using op-amps. With the A/D approach, the detector can be functionally only when it is needed to save power, plus the circuit configuration is rather simple. All that's needed is a voltage divider to produce an output voltage that's dependent on the photoresistor. A voltage source applies to the photoresistor and a pull-down resistor. The voltage between these two resistors is the output to be measured for change in brightness. In a dark environment the photoresistor can increases it's ohm by a factor that's much greater than the fixed the resistor, thus producing an output voltage that's close to zero. In a bright environment it's vice-versa, the resistance decrease, making the output voltage as high as the supply voltage. Figure 3.13 below is circuit diagram of the photoresistors are connected to the MCU. The voltage reading from the two A/D ports will be quantized and compare for any difference. For example, if the A/D port1 has a higher quantized value than port 2, it means that sun is locating closer to the left photoresistor.

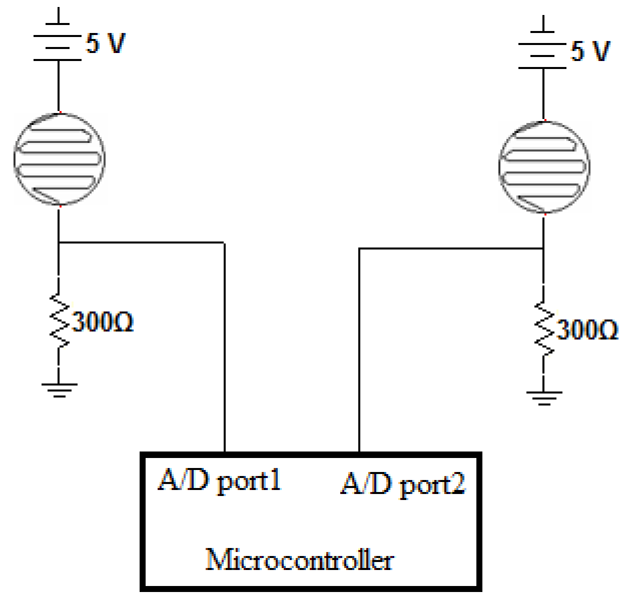

Figure 3.13 Sun detection circuit using MCU

In some MCUs, the analog reading is from 0V to 5V and in this range the controller has more level of precision in detecting light intensity. It is desire to have a 5V difference to represent the minimum and maximum lighting condition that the solar tracker will be in. For this to work, there are three things must need to be calculated: the resistances of the photoresistor when it's in the darkest and brightest situations, and the values of the fixed resistor. After acquiring the photoresistor and performing a couple of outdoor experiments, it is found that at noon, in direct sunlight the resistance is around 100Ω. And during sunset the resistance is 750Ω. Once these values are known, they were entered into the Photoresistor Maximization spread sheet from Societyofrobots.com. What spread sheet does is, it calculate value of the fixed resistor that can give the largest range of voltage. For precise reading from the MCU, the voltage difference needs to be close to 5V as possible and is shown in Figure 3.14. But from the spread sheet, it indicates that the maximum possible voltage different is 2.3V by using a 300Ω. Using any resistor greater or less than 300Ω would result in a shorter voltage range for the MCU to quantize.

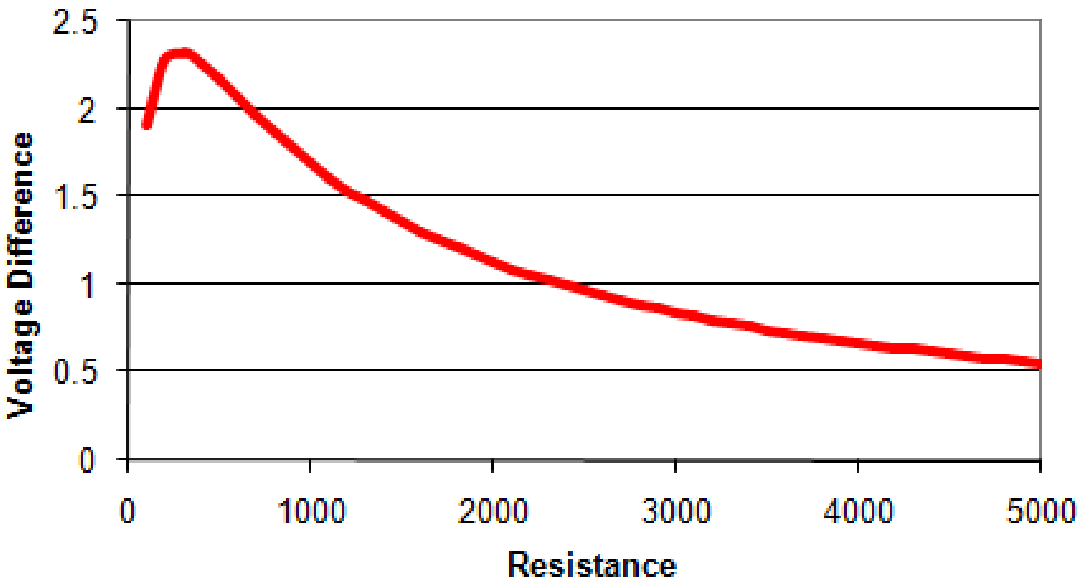

Figure 3.14 Resistance vs. voltage difference

For the analog approach, there are many possible circuit designs; the more precise it needed to be, the more complex it gets. Figure 3.15 is a simple design of how an op-amp can be use to detects the difference between two photoresistors and controls the H-bridge motor. The op-amp acts as a comparator with 2.5V going into the negative terminal and there are three possible outputs that it can produce. When the positive terminal is greater than 2.5V, the op-amps produce a positive voltage and when the input is less than 2.5V, it produces a negative voltage. When the two terminals are equal, there's no output. A 5V is applied across the two photoresistors and the op-amp's positive terminal connects between them. If the sun is located close to the left resistor, the positive terminal voltage is higher than 2.5; if the sun it is closer to the resistor on the right, the voltage will be lower than 2.5V; and if the sun is between the two resistors then voltage will be 2.5V. At the H-bridge, the op-amp's output determines which direction the motor rotate. When P2 and N2 are close and P1 and N1 open, current travels through the motor's terminals from one end to the other. And when P2 and N2 are open and P1 and N1 are close, the current travels in reverse direction.

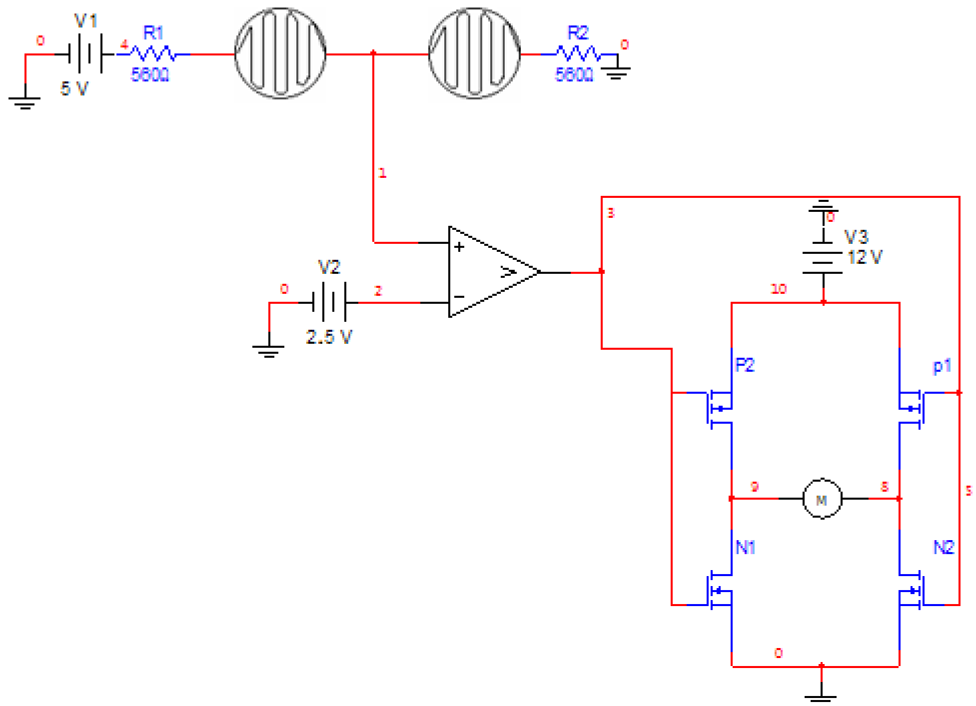

Figure 3.15 Sun detection circuit using op-amp, no copyrights
http://www.sccs.swarthmore.edu/users/06/adem/engin/e72/lab7/

The design has been established in detail in this section. The overall design summary can be found in section 5 and will discuss the important elements from this section as well as some of the aspects of the prototype section that follows.

4 Prototype and Testing

In the following section(s), method of designing a prototype is presented. When finished, the outcome of this section will most likely be integrated into the final design. In this section, material present will consist of ideas to assemble, construct, interface, and test certain or several design. The aim of the prototype section is to outline of getting a working prototype and to implement/test individual components or modules so that it can be integrated into the final model. Interface section will outline methods of what needs to be interfaces. As for the testing section, it will consist of methods to test certain components. Lastly at the end of this section will outline the cost and vendors of some components used in either for prototype or final construction.

4.1 Preparation

In the preparation for the design of the prototype and final model, farther research in the connection of each individual parts together. The microcontroller development board that this project is going to used is the Arduino, which contains the ATmega168 microcontroller. The Arduino has 14 I/O pins and 6 PWM pins. The pins need to be research. Farther research is to be done to determine where and which individual pins are needed to connect to each component use in this project. Other preparation includes the equipment and place to setup. The main portion of building this project will be in the senior design laboratory, meaning the connection of microcontroller and breadboard or pcb design. Also, if the lab has adequate equipment for use, than there is no need to bring extra equipments. As for building frame design and testing of prototype model and final model it will be done outside of the lab. Due that the frame may need to be cut, wield, or any other construction and also the solar panel needs to be outside for prolong exposure in the sun to get accurate measurements. Also parts need to be bought and assemble so that assembly can commence. The frame will need to be set up to determine if it meets requirements. Also, testing equipments will be gathered to record results. The main part of preparation is to build or start on building a working prototype or a working final model.

One of the aspects that will be focused on is the usability of the device. The solar tracker has to be user friendly not just for the builders, but also for anyone who never have any experience with the technology. The learning curve of the device needs to be less than 5 minutes. Within 5 minutes, a person who never uses a solar tracker before must be able to understand what its function is and how to operate it. To make this possible, the device must not be complex in term of controls and functionality. With only one push button, it will be use to manage the whole device. When the button is pressed, the MCU will calculate the sun's position and adjust the collector's direction to it. Also the MCU will turn on LCD to display the information to the user and what is displayed must be comprehendible to the user. To test for usability, a person who is not part of the team play will be ask to operate the solar tracker and read the information from the LCD. During the testing, a careful observation will be made to see how well he/she handles the device and if he/she is able understand information displayed on the LCD. Also a few questions will be asked for feedback such as is the device easy to use, and what needs to change to make it better.

To ensure that the solar tracker can endure any harsh circumstances cause by the weather or human negligence, it will put to rigorous tests to observe how well the structures, the mechanics, and the electrical devices can withstand the stressed situation. The first test would be thermal testing. There are some materials that are not made to be use in a high heat environment such as ICs, transistors and any materials that are made out of plastic. As temperature increase, it can affect their performance and over a long period of time the material will be degraded. The tracker will be set outdoor for a whole week, after that, every components will tested to see if it's still functional. Another test ensure that the tracker can handle any weather condition is the waterproof test. It's to make sure that every electronic device is well covered and that in rainy a weather it is still functional. If rain is not available during the experiment, then a simulation of rain will be made by praying water on the tracker for 10 minutes. Another important test that will be needed to perform is structure rigidity. In some situation the solar tracker might be tip over due to high winds or dropped due a person's carelessness. To make sure the device is still operable in an event these accidents occur, a shake test and a drop test will be performed. The device will be violently shake for 5 minutes, and after that, all the components will be examine to verify that they are still remain intact. Every nut and bolt will be check to see if they are loosening. For the drop test, the procedure consists of raising the device two feet above the ground and releases it. The structure must be sturdy enough, it can withstand the drop.

4.2 Breadboard Construction

Figure 4.1 shows the placement of various components on the breadboard that consist the solar tracker project. There are still some components that are still in the process of being taken to consideration to be put in this project. So far the figure consists of the two servo motors. When adding the motor because of the placements of the motors, the wiring will then be extended so that the motors can be adjusted. As for some of the other components, the photoresistors will be place one of solar panel on opposite ends and is connected to the resistors on the breadboard. As for the solar panel, it will not be directly connected to the microcontroller, instead it will be connected to the battery. The battery will then be connected to the regulator on the breadboard and that will be connected to the microcontroller.

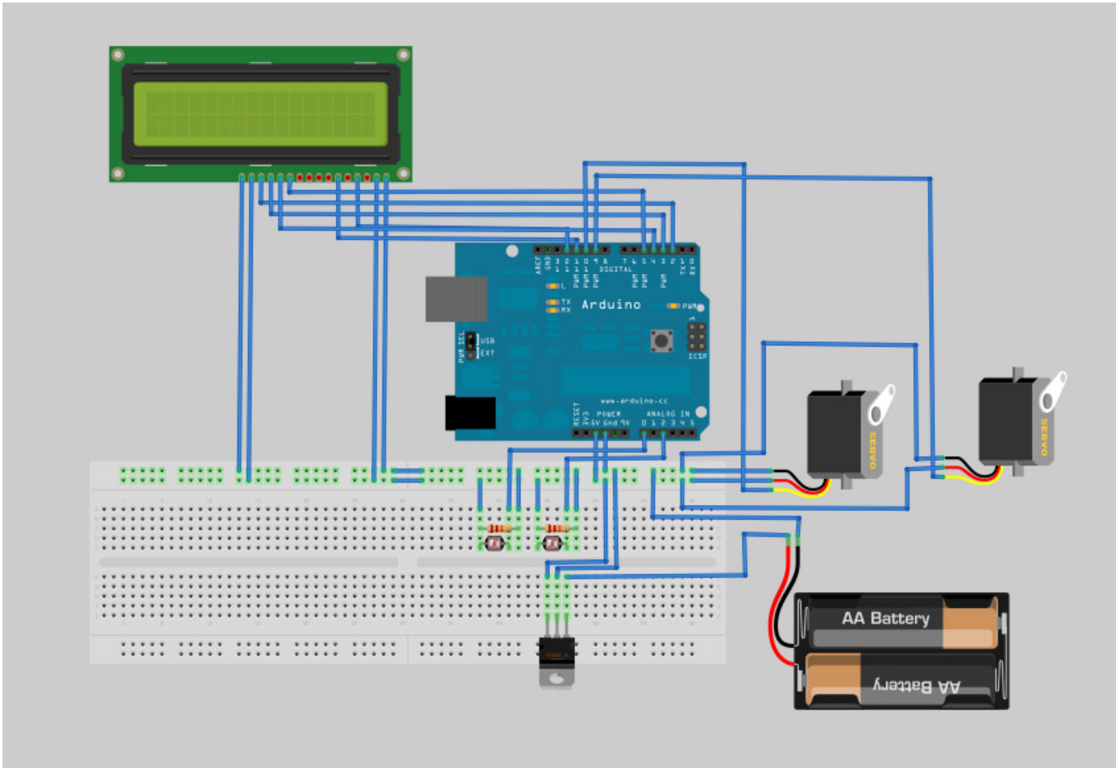

Figure 4.1 Sample breadboard construction of the circuit

4.2.1 Interfacing Components

For the components used in this project, all the inputs will be connected to the microcontroller and from the microcontroller; in this case it is the Arduino Atmega168 microcontroller development board will be used to control all components.

For the LCD components, the LCD uses 6 pins that are connected directly to the microcontroller development board. The connections are made at pin 2-5. That correlates to the data bus for the LCD display; this allows the microcontroller to display information on the LCD. The other connection is for Resistor Select (RS) and it goes to pin 12. The last connection is for Enable and that goes to pin 11, pin 11 is the PWM (Pulse Width Modulation). As for the servos motor, they required only one pin each on the microcontroller development board. The pins are then connected to pin 9 and pin 10, the PWM pins. There might be placements for a regulator, most possibility a 5 V regulator. Since the operating input voltage for the microcontroller is 5 V, if the output of either the solar panel or the battery is 12 V a regulator is needed. This is a precaution just so that the components of the microcontroller do not get damage. The battery is connected to the 5 V power pin on the microcontroller development board, if attach to a regulator the battery is connected to the input pin on the regulator and the output pin of the regulator is then attached to the 5 V power pin on the board. The photoresistors uses 1 pin each. There will be two photoresistor that is use in this project. The photoresistor is use to help take in data to control the motor and they fit into pin 0 and 1. Pin 0 and 1 are part of the 6 analog pins on the microcontroller development board, which are pin 0 through 5. Also there is possibility that a battery level indicator is used in this project to indicate the critical level of the charge left in the battery. If so there will definitely a need for the 5 V regulator. Also there will be three LED, with the color of red, green, and yellow, that is need to connect to the PWM pins (which is pin 3, 5, 6, 9-11) to display the level of the battery. Each LED is connected to one of the PWM pin and the ground. After which the output of the regulator is then need to be connect at anyone of the analog pins, which are pin 0-5. Figure 4.2 shows all the pins placements for the possible breadboard connection.

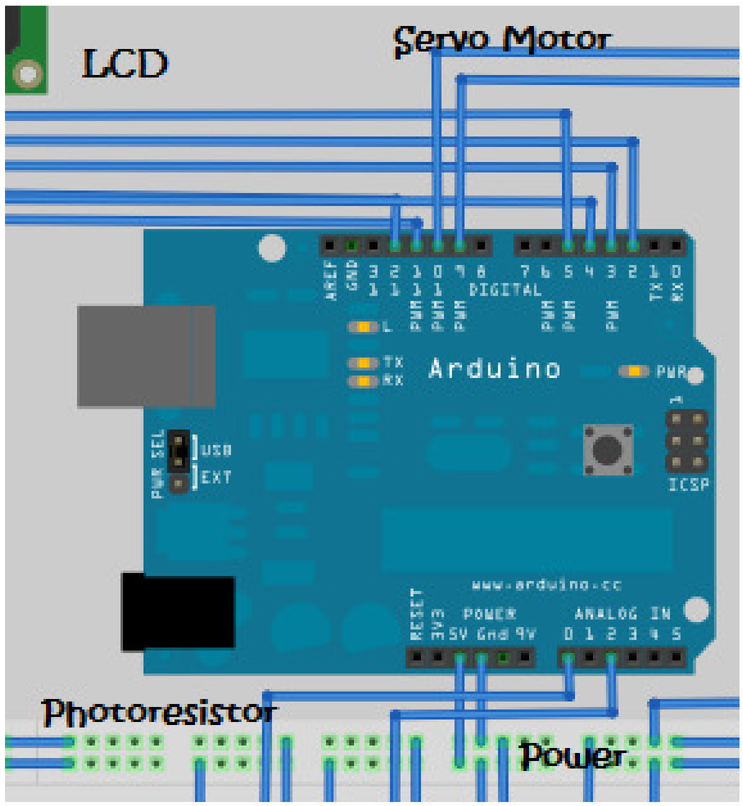

Figure 4.2 Pin Placements of Individual Components

For this project, hopefully, that will be plenty of subsidiary components along with other standard components that can be interface with the solar tracker. This project would like to incorporate a gyroscope and a compass into the solar panel. The gyroscope is used to help determine the altitude of how the panels are moving or rotating, pitch or yawing relative to the earth.). The gyroscope is to be mounted to the board so that rotation measured is about the z-axis. The gyroscope will be controlled by the microcontroller. The gyroscope will sense the rotation in motion of the movement in the frame and will send a signal back to the microcontroller. The microcontroller will then read the input data and then it will display it on the LCD screen. Another component that could be interface is a compass. The compass will serve as a direction finder on the solar tracker. Using the serial clock and serial data lines on the microcontroller, this allows for standby mode and query mode on the compass to get and read data. Sending a signal to the compass, the compass will then receives the signal from the microcontroller to measure and calculate the direction. The microcontroller will then send out another signal commanding it to send the data back to the microcontroller, without a section of the code telling the compass to feedback data it will only that measurement and holds it, not sending any data to the microcontroller so that it can read the data.

In figure 4.3, the flow chart diagram for how the main components will be interface with and by the microcontroller. Readings from the photoresistor is feed to the microcontroller, through the analog pins. From there the microcontroller, from the information given by the photoresistor, determines how to operate the motors. Also taken information from both the battery and the solar tracker or just the battery, the data is then relay to the LCD to display certain information if needed. If not then it just takes in operational voltage from the battery. If attached with optional components, like the gyroscope, the data given to the microcontroller by the gyroscope gets display to the LCD. Also the microcontroller can give information to the gyroscope. The microcontroller can control or activate the gyroscope or the compass. The microcontroller will give direction to when to monitor or record data. As for the servo motors, they will be controlled by the microcontroller and the servos itself will control the solar tracker. The microcontroller will take the data from the photoresistor and direct the motors to the position of the sun. As for the LCD it will display given information taken by the various components.

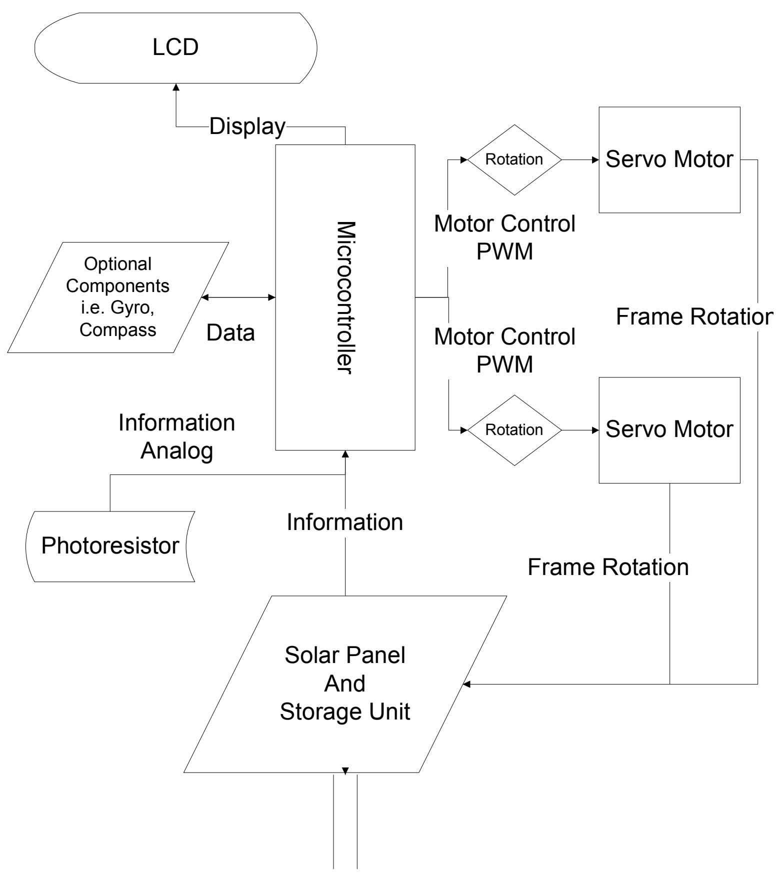

Figure 4.3 Interface of components

A brief introduction to interfacing a 4-bit LCD with the microcontroller will be explained. If the solar tracker is to have many different features such as battery monitoring and directional awareness system, then MCU must have enough analog and digital ports to support them. By using 4-bit interfacing mode on the LCD, it can save the MCU extra ports for other essential connections. Figure 4.4 below shows how a 4-bit mode LCD is connected. A 5V power source is connects to VDD and a variable resistor. This resistor is use to adjust the screen brightness with VEE. Since data is send from the MCU to the display and nothing is need to send back, only writing mode occurs, therefore the R/W can be set to ground. With 4-bit mode, D0 to D3 are unwanted and can also be set to ground. The connections that tie to the MCU are D4 to D7, the enable line and the register select line.[115] An additional component that is not on the figure is a push button. This device is connects to the MCU where is will turn on the LCD when the user wants the information to display. This will help reduce the waste of power since the LCD only operational when it is needed.

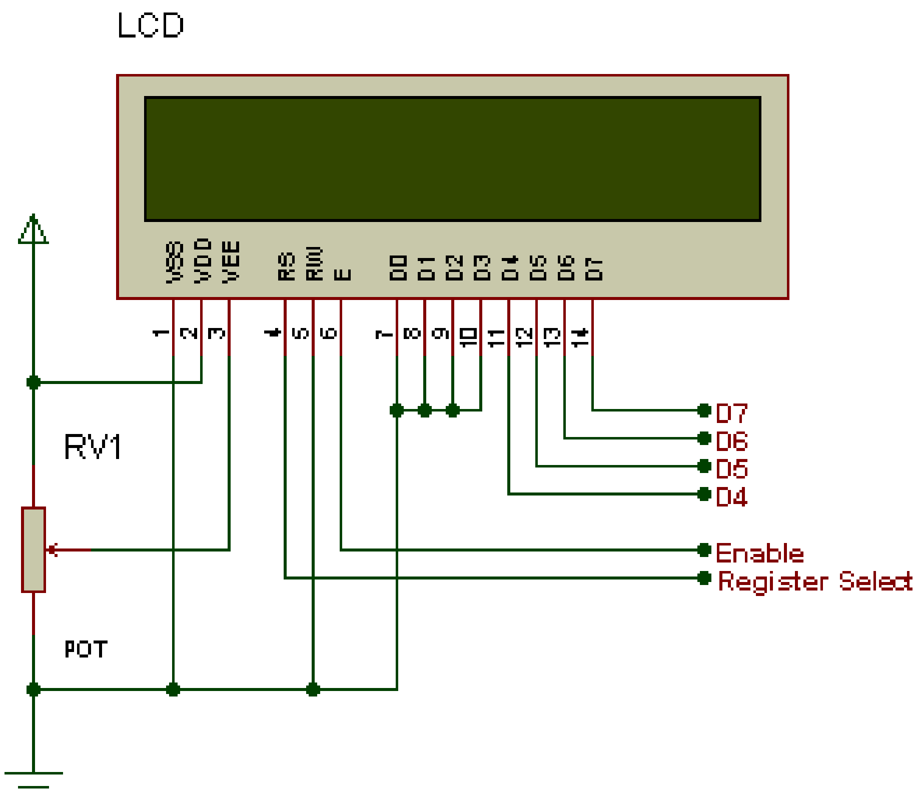

Figure 4.4 4-bit connections of the HD 44780 reprinted with permission of Ajay Bhargav http://www.8051project.net

In 4-bit mode, the data is sent in nibble. The higher nibble is send first, then the lower nibble. To get the LCD to display information send from the MCU there are procedures that must be perform before anything can appear on the screen. Each time the module is turn on, a reset or initialization is required. This also allows the display to recognize that the data will be transfer in 4-bit mode. The following is a sequence of steps the MCU must perform to initialize the LCD. [115]

- Wait about 20ms and send the first init value (0x30).
- Wait for 10ms and send the second init value (0X30).
- Wait for 1ms to send the third init value (0x30), and then delay for 1ms.
- Select bus width (0x30 for 8-bit or 0x20 for 4-bit) in this case it's 0x20, and wait for another 1ms.

After initialization, executing of instructions begins by transferring commands to the 4 pins, and by selecting the RS signal to instruction and turning on the enable signal. To have information to be printed of the screen, the method is similar except that RS signal is switch to data. When RS is on high, the 8-bit information from the MCU is treated as data it is place in the display data Ram (DDRAM). Whatever is stored in the Ram will be displayed on the screen. For example, to print "1", a 31 hex is send to a location in the DDRAM. When the instruction calls for print, the controller will go to that address of where the data store, take the data out and print it on the screen. Below are the common steps of how the MCU send data and command in 4-bit mode.[115]

- Mask lower 4-bits
- Send to the LCD port
- Turn on the enable signal
- Mask higher 4-bits
- Send to LCD port
- Turn on the enable signal

4.2.2 Placement of Components

As for the placements of the components, the main or majority of the components will be place in the base of the solar tracker. As the base will most likely be a box like encasement. The LCD will be place on top of the base. Part of the base will be cut out, the length of the LCD screen, so that the LCD screen can be shown and read. As for the rest of the components, it will be place inside except for the servo motors. As for the servo motors, one will be place on the base so that it will rotate the whole frame for the tracker. In figure 4.5, this shows the motion of how the servo motor at the base will support and move the frame. For this case the motor is directly attached to the base. Attaching the servo to the base can be use in other ways: gears to rotate the frame or the frame will be mounted on a base. If mounted on the base, the base will then be directly attached to the motor. The motor chosen will be able to rotate with a maximum of 20 lb.

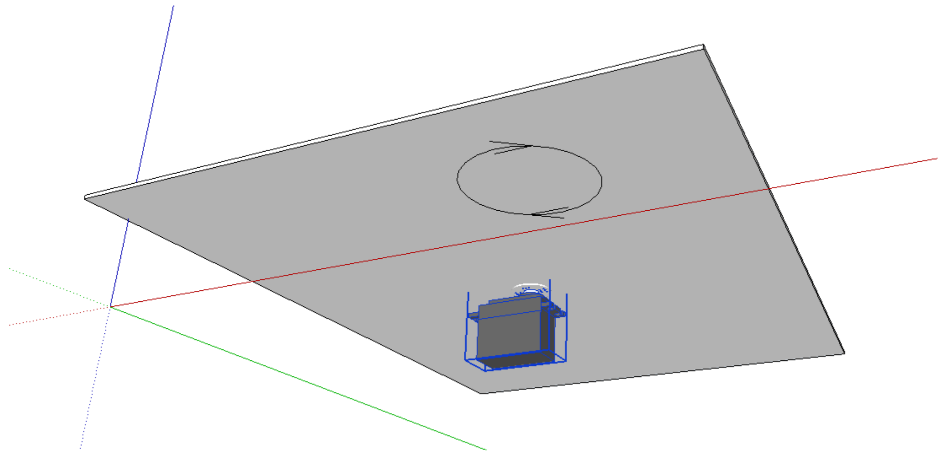

Figure 4.5 Rotation of Base Servo Motor

As for the second motor, it will be then be place at the top of the frame where the frame is connected to the panel. That way, this motor can directly control how the panel moves. It will be mounted similar to how the first servo motor is mounted, if not it will use gears to move it then. As for the placement of the battery, the base will be crafted so that it fits over the battery or the battery can fit in it. This way the whole tracker can be move from one battery to another, if necessary. As for the rest of the components, within the base will be a compartment that will host the rest of the components.

4.2.3 Sizes

Size wise, this project aims to try to make this solar tracker portable. If not, then at least it can be light enough to move around with relatively ease. The size of the parabolic for this project aims to be around your standard size satellite dish you received from Direct TV or similar corporation. While the solar panel itself will probably be handcrafted to be around 1x1 feet max. This way when place in front of the parabolic mirrors, it would not interfere with how the sun light is hitting the parabolic mirrors and reflecting from it. The only thing that might not help in making this solar tracker portable is the weight of the solar tracker. Overall alone the solar tracker shouldn't weight too much. The component that is going to have the most impact of the solar tracker is the storage device, which is the battery. Look at all the option it seems like they all are relatively heavy. Consideration will be taken; wheels will be place if necessary to make it portable or otherwise easy to move around at least. As for the height of the solar tracker, the aim is no higher four feet. The frame design will most likely be compact.

4.3 Implementation Strategies

In order to getting every component to work correctly, each component must be test separately as well as when they are put as a whole. In order to test the solar panel capability and its connection to the battery, the solar panel must first be tested in a small scale. Solar panel, rather each cell will connect to a small battery or several batteries in series. That way, test can be made to measure how much output capability it can have or does. From there calculation can be made to determine the construction of the solar panel. To implement the solar cell, the cell will be connected to a regulator or a voltage division with values depending on how much the storage device can handle. The battery or batteries can be tested to determine the charging time and also the output of the solar cell. Farther adjustment can be made once testing is done.

4.4 Safety with the Device

It is always important to consider the safety of a device as a first priority, whether it be for a technician or an operator. An unsafe device will render it unusable and in the circumstance that the device becomes manufactured, a factory recall of the hazardous device could cripple the organization behind its production. Not to mention a lawsuit that could arise from what is supposed to be "proper use" for the device. This is why adhering to modern standards of safety is listed as the first and foremost goal to be achieved for this project.

The solar tracking device will be omitting unnecessary hazardous and unsafe materials and substances. This is part of the reason why a lead-acid battery was not chosen, because Chapter IV of the Toxic Substances Control Act of 1976 requires the proper management of lead substances and would become a liability if it were implemented into this project. Also, in order for this device to meet the European RoHS (Restriction of Hazardous Substances) criteria this device cannot include the substances lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls, and polybrominated diphenyl ether. [13] The latter three should not be an issue of concern, but the former three might be. If a lead-acid battery were to be implemented than a warning label indicating that proper disposal of the device would be necessary. This is also another reason as to why nickel-cadmium battery cells were not selected for this device. Any form of hazardous coolant subst-ance such as Freon, or hydrochlorofluorocarbons, that might be used will need to be handled and contained in a proper manner so as to not harm someone in contact with the device, but in the case of Freon it will be to not contribute to ozone depletion, a result that would be counter-productive in creating a device that has a positive impact on the environment. If any hazardous substance or chemical comes in contact with one's skin then that area of the skin needs to be treated immediately, the same applies if any come in contact with the eye, then their eye must be washed with water, ideally at the nearest eye-wash station, immediately.

Electrical components and other items deemed necessary that could create a potential hazard will be secured and neutralized. Any exposed leads or wires will be wrapped in rubber electrical tape and all wires will be secured to the frame to minimize the chance of a wire being exposed to the open and becoming frayed. The power should be turned off while modifications are being made to the device, otherwise wires should be tested to see if they have current running through them before being manipulated. Proper grounding of the electrical components will need to be conducted to prevent harm to the user or technician as well as the other elements built into the circuit. Electrical components will also need to be contained in waterproof compartments in order to prevent shorting of the electronics and electric shock upon coming in contact with the electrified water. This feature will also take care of the "weather-proof" objective established for this project. Wearing rubber gloves as well as the use of tools with rubber handles for situations like these would help reduce the chance of electric shock. Elements of the device that are sharp, such as sharp edges and corners will have a rubber or foam layer taped over it to eliminate the chance of injury. The safety of all parties involved with the device is paramount.

A multitude of hazards could also be encountered in the fabrication of the device and result in serious injury. For instance, the frame of prototype device will likely need to be custom built and modified using power tools and construction machines. These could include lathes, table saws, band-saws, power drills, drill presses, or any other machine that will make the specified task of the moment easier to perform. These types of machines are very sharp and powerful cutting and piercing tools that could result in small cuts to severed fingers if the person involved in the construction is not careful. Therefore an experienced user of any of these machines will be required when the use of any specific machine is called upon. This experienced user will supervise the proceedings of any group member in the construction of this device with these machines, or they will use the machine themselves for that particular. If wood is being cut for the frame then safety goggles will need to be worn in order to keep sawdust from contaminating one's eye. If welding is to be performed then a safety visor and gloves will need to be used, ideally this would be in conjunction with a fire retardant shirt or apron. The flame will need to be kept away from the welder at all times and away from flammable materials. An experienced supervisor should definitely be present when conducting any form of welding and ideally this supervisor will have been certified in welding by some official organization.

This project involves taking energy from the sun, so measures must be taken in order to protect the operator from the sun's hazards. For instance, looking directly at the sun could damage one's eyes beyond repair, therefore it is recommended that users and technicians wear polarized sunglasses when outside and avoid looking to the sun to find its location, this will be the device's job. When testing the prototype is it best that the light source is a flashlight or lamp opposed to the sun, this will ensure safety during the test phases of the project. Ideally, the sun will be outputting a lot of energy and shining brightly on the collector installed on the device; in this case the device will be absorbing a lot of heat and is another aspect to consider. Components of the device such as the mirrors and possibly the panels will be very hot, up to 140 degrees Fahrenheit, and should not be touched. Rubber gloves can be worn to eliminate the possibility of experiencing this hazard. There have been instances discovered through research for this project where the light from the sun becomes so focused that it can light a stick on fire. The frame for the device prototype may also be made of wood, so this could be an issue for concern. In the event that a fire does occur, due to solar intensity or welding, one should already know where the nearest fire extinguisher is located and use it to hastily put out the flames. If the fire continues to burn then the appropriate emergency exit needs to be taken and the fire department needs to be contacted immediately. The use of a fire blanket or water to douse the flames could be another measure taken in the unfortunate case that there is a fire.

On the final prototype of the solar tracking device there will be a safety sticker summarizing all of the hazards that may be encountered in the operation of this device. This sticker will be placed at an obvious location on the device. Figure 4.7 is an example of how the sticker will look.

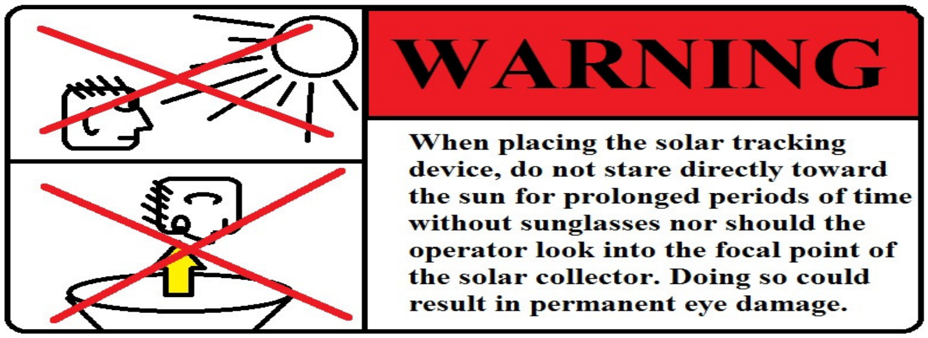

Figure 4.7 Safety Sticker

4.5 Testing

In order to have an effective device, rigorous testing must be conducted before and after the prototype is built. This testing will ensure that goals and specification criteria for the solar tracking device have been achieved. If the tracking device does not meet this criterion, then modifications will need to be made to the system's design or individual components. Since this project is highly dependent on optimization of the device, testing will be a very important phase to make this project of the highest quality and the most beneficial.

Once the solar tracker is built, it must be tested in different environments to determine whether it has complies with the proposed goals and objectives that were defined during the initial design process. Since the solar tracker is an outdoor device, it needs to be tested in various and extreme weather conditions to see how the energy collector, the mechanics, and the structure perform. There are several test cases that will be performed on the solar tracker including: measuring its efficiency, checking to see if it's fully autonomous, user-friendly, durable, and portable. The first thing do is to make sure that the solar tracker is fully functional, that's every component is working like it is supposed to. The collector must be absorbing energy; the motors can adjust the collector as the sun shifts; the battery can charge and discharge; and the LCD module is displaying the correct information. If the solar tracker can demonstrate that it can perform these functions, then the device will be considered a success.

4.5.1 Efficiency Testing

The most important test will be the measure of the solar tracker's efficiency. The grand scheme is to have an efficiency of at least 20%. The experiment will be conduct on a sunny day during noon, where the collector receives maximum sunlight and heat. Using a voltmeter, it will be use to measure the outputs of two solar panels, one is the collector's panel, and the other one is a stationary panel with no modifications has been done to it. Both panels are identical, with the same specification and from the same manufacture. The stationary panel is use as a reference to how much voltage again can be achieved using a modified solar panel. If there's a 20% or more increase in voltage, then the design and construction of the collector is considered successful and minor tweaks will be needed to perfect it. If the collector's solar panel voltage is the same the unmodified panel or its efficiency is below 20%, then some trouble shootings is needed to indentify why to collector not performing like it's expected. The building process will take place in the summer, and it's a perfect opportunity to observe the effect of heat on the solar tracker, especially the collector. Keeping the solar cells cooled not only produces more voltage, but also helps prevent the cell from aging. The goal is to have the collector operates at a constant temperature below 90 degrees Fahrenheit all time. A surface thermometer or an infrared thermometer can be used to measure the solar panel's temperature. If it's founds that the panel gets hot as the time usage increase and cannot maintain the specified temperature, a cooling system may be added to the design.

4.5.2 Autonomous Testing

To make sure the tracker is fully autonomous, the testing procedure calls for a 24 hours operation of the device. This will be performed on four continuous days without any interventions or instructions from the user. The only human interface allows is when the LCD needs to be turn on to display information. Each team member will take turn monitoring the solar tracker from 6 AM to 9 PM, and at every 15 minutes, the information from the LCD will be recorded. The data can be use to analyze for any abnormal performance from the tracker. The tracker is considered to be self-sufficient when it can be operational for four days with the collector maintaining a consistency in aiming at the sun and the battery always at more than 50% capacity. Since no external devices are connected to the tracker during the testing, the battery should not be depleting but gaining more energy.

4.5.3 Photoresistors Experiment

To verify that the photoresistor is capable and sensitive enough to track the sun, two photoresistors were bought and experiment with. They are: the VT83N1 from PerkinElmer and the P9203 from Advance Photonix. On a cloudless day, the two photoresistors were placed in a fixed position on the breadboard facing directly upwards into the sky. There was precaution to make sure that there's no obstruction that could block the sun from the resistors. Beginning at 7 AM, when the sun started to rise, the first measurements of the resistors were taken with a multimeter and their values were recorded into a table with the corresponding time. This process is then repeated every 15 minutes till 7 PM. Figure 4.8 shows how the P203 and VT83N1's resistance changes from morning to noon and then noon the evening. And from figure, it can be concluded that the resistance's rate of change is higher (meaning more sensitive) when there's little amount light than where there's abundant of sunlight. During sunrise and sunset the photoresistors had a large change, about 20Ω every 15 minutes, whereas during moon the resistance is relatively unchanged, only one or two ohms difference. Comparing the two resistors, the VT83N1 is more responsive than the P203. It has a steep parabolic curve that ranges from 200Ω to 800Ω, whereas the P203 is basically flat with a narrow margin of resistance from under 100Ω to 250Ω. Further testing is needed on the day when there's an overcast to see if the photoresistors are sensitive enough to detect any change even if sky is equally illuminated.

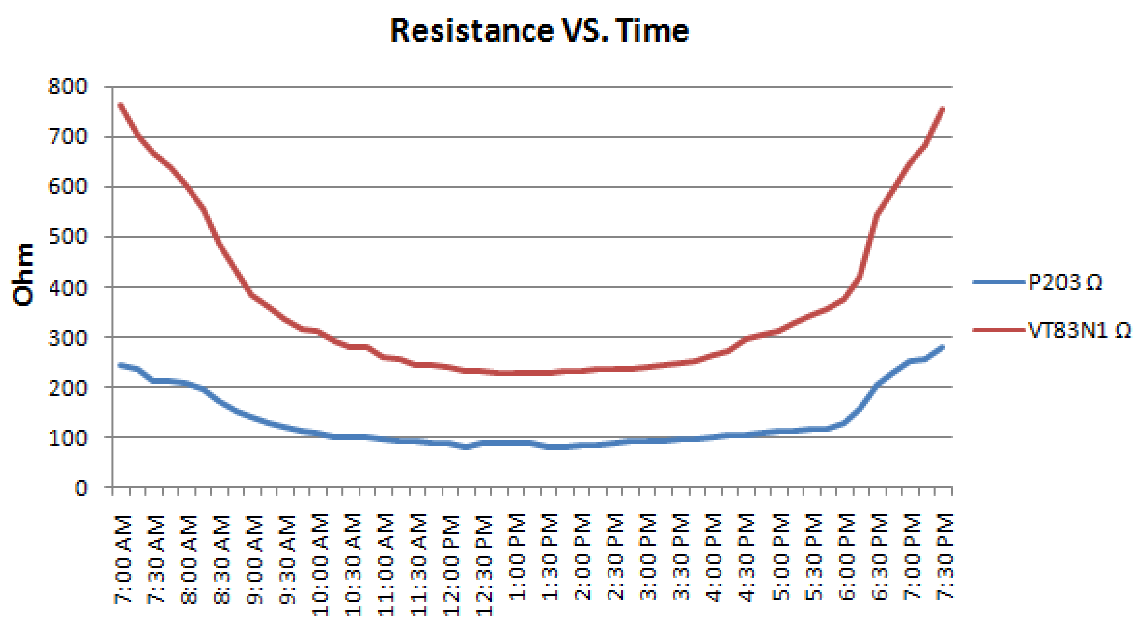

Figure 4.8   P203 and VT83N1's resistance with respect to time of day.

4.5.4 Optical Optimization

The parabolic mirror has been selected as the optical collector of choice, and rigorous testing will be conducted to ensure that it is the most efficient. The focal point is the target in that it will be the area of the highest light concentration. In order to test this and ensure the focal point has been found, the materials necessary will include:

- Parabolic Mirror
- Plane Mirror
- Photovoltaic Panel
- Halogen Flashlight

- Digital Multi-meter
- Vertical Supports (Poles, stools, other available makeshift items)

For this experiment, the parabolic mirror will be fixed with its base along a vertical support such that the mirror is focusing the light in a horizontal direction as shown in figure 4.9. The halogen flashlight will be placed 4 meters away on a surface with even height to the center of the parabolic mirror. A plane mirror will be attached to a thin vertical support such as a pole or stick that has a sturdy base to keep it standing on its own, this pole will be adjusted in its distance until a “sweet spot” is found. A solar square or panel will be at the center of the parabolic dish attached to the digital multi-meter that will be resting on the floor. The “sweet spot” that was referred to earlier will be the focal point, and it will be represented by having a higher voltage read on the multi-meter than having the mirror at any other position. Once the focal point has been found the plane mirror can be securely fixed in that position and attached to the parabolic mirror or the framework of the device.

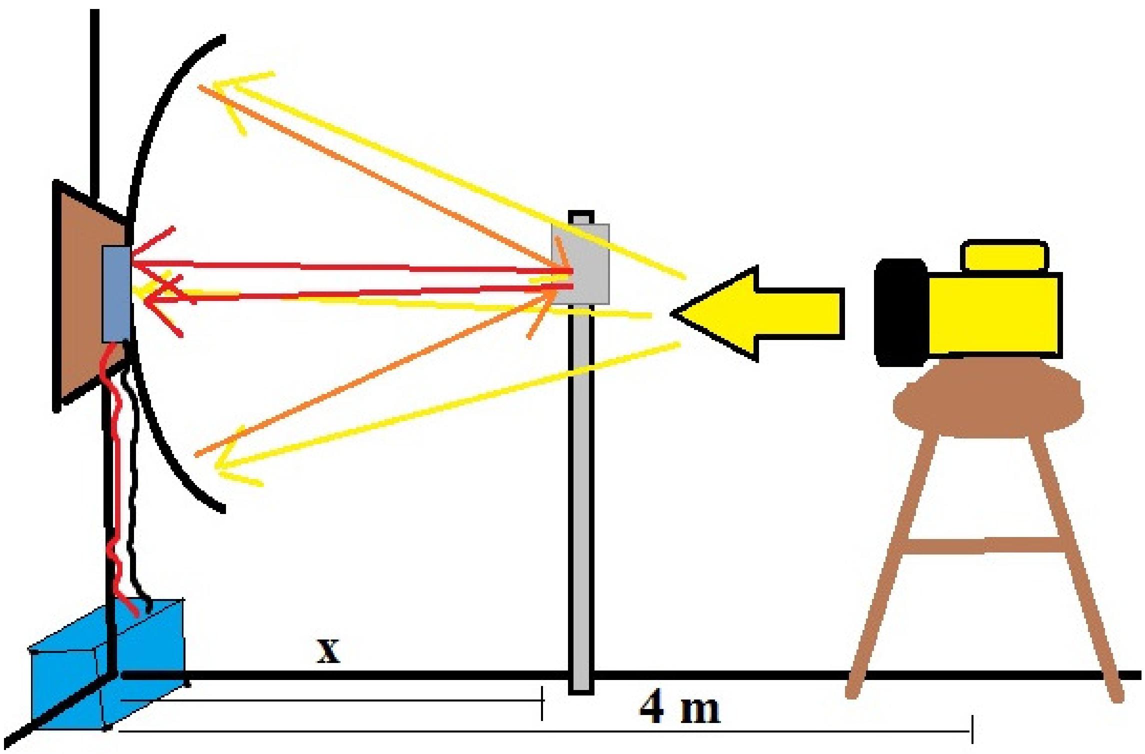

Figure 4.9 Focal Point Test

Complications may arise in this test, namely the mirror blocking the path of the light rays may disallow a direct stream of light to come in contact with the photovoltaic cell. To compensate and test for this possible issue, a control situation will be established where the flashlight remains 4 meters away and the mirror is removed, This voltage reading of the photovoltaic cell in this state will serve as the basis for all other comparisons and will determine the optimization of the energy collection system.

4.5.5 Energy Storage Testing

The power supply for the solar tracking device needs to be tested in order to make sure that it will satisfy the goal of reliable usage as well as supply enough power to the components as well as the output in order to have a successful device. The power supply has to power the microcontroller by supplying the necessary 5 volts, as well as the servo motors, and other components, not to mention the power that will be output to charge an external electronic device. This power also needs to be maintained long enough to last through cloud cover, the dark of night, while external devices are charging, etc. so the capabilities of the energy storage and distribution system are of great interest. The equipment needed to test this portion of the project will include:

- Battery
- Multi-meter
- Variable Load
- Timer
- Miscellaneous wires and components to connect power

First, the battery will be charged for 12 hours to ensure that it is at maximum capacity. Then the battery will be removed and tested on its own. A control will be established by attaching the multi-meter leads to the positive and negative terminals of the battery and determining the voltage. Then, the load will be attached and the voltage and current will be measured, this load will represent the external electronic devices that may be attached as outputs. Conclusions based on this variable load will be made when this data has been collected. All of the individual components will also be tested to make sure that enough power is received for all of them. All components must receive power and be powered on while there is enough power left over to charge an external device; this would be the maximum load since the design will incorporate a system that shuts these elements off during charging to conserve power. This remaining power will be gauged by using the digital multi-meter at the port, after the DC converter, where the load is supposed to be located.

Next, the longevity of the battery will be tested using a timer and same load that will represent the external electronic device. The battery is rated to be capable of discharging for 30+ hours. The insatiable load will be attached to the battery to test this specification. A timer will be used and initiated upon the device being plugged in. The battery will be fully charged. The terminals will remain connected overnight, and will be checked at half-hour intervals throughout the next day, what the timer reads when the battery has been depleted will be the result needed. This experiment will also test the accuracy to which the battery monitoring IC has in coordination with the actual amount of energy stored in the battery. It will also be important to recognize at what point the voltage drops off to where the system, microcontrollers and servos, can no longer function because this point may still read as 15% battery life remaining from the IC. This percentage would then need to be offset in the microcontroller programming so that it will display 0% remaining when the devices are not capable of functioning.

4.5.6 Cooling System Testing

The cooling system and its overall effect on the voltage output will need to be studied and tested in order to further optimize the solar tracking device. The goal of the cooling system is to optimize the output voltage of the device since it has been discovered through research that solar panels operate more effectively when they are kept relatively cool, which is a difficult feat to achieve when it will baking under the hot Florida sun all day. Therefore a test procedure must be conducted to determine the best way to cool the solar tracker's panels. Different methods of cooling will be attempted and analyzed for this test; they will be tested individually then simultaneously. Here are some of the materials that can be used for this experiment:

- Digital Thermometer
- Solar Square or Panel
- Digital Multi-meter
- Heat sink (Fins)
- Water
- Transparent Container (e.g. Ziploc® Bag)

When water is involved it will be necessary to waterproof all components it may come in contact with it. Apparently the solar panel's internal electrical configuration is completely sealed and waterproof, but the positive and negative terminals are not, so this must be taken into consideration as the experiment is prepared. The procedure is fairly simple; the panel will be placed in a transparent container filled with water out in the sun for half an hour. This amount of time will allow the panel to be impacted by the ambient temperature. A second panel will also be placed out in the sun for half an hour with the same orientation, except it will not be in a container of any sort. The digital multi-meter will have its leads connected to the positive and negative terminals of each device and determine the effect of the cooling system on the voltage output. After the half hour has passed the data will be collected from the multi-meter, and conclusions will be drawn as to whether the method of cooling was beneficial enough. Liquid substances other than water such as mineral oils may also be tested in the place of the water but with the same procedure to observe different results. Longer term testing will need to be conducted in order to determine the true benefit of these various materials. It is also required that this experiment be conducted on a clear day, because any cloud cover could skew the results. The ambient temperature at the time of testing should also be recorded and considered in the analysis of the results.

The second element of the cooling system will also need to be tested, the heat sink fins. These heat sinks will be attached to the rear of one of the two solar panels that are being tested. This time, neither solar panel will be enveloped by water or some substance to provide temperature dissipation; they will both be left out in the sun, in the middle of a clear day (2pm), at the same orientation. Once again, the multi-meter will be attached to the positive and negative terminals of the solar panels and the voltage outputs will be measured and conclusions will be drawn from the data that is obtained. The final test will be to combine this panel with the heat sink attached except in the transparent container filled with the coolant. This should theoretically provide the highest level of optimization. The same procedure that was prescribed before for the collection of data will be undertaken and conclusions will be drawn from these results.

4.5.7 Water Resistance Test

A specification of the solar tracking device is to be weather-resistant; because the device will be left outdoors in order to perform its function it must prove that it can withstand the elements of nature. All of the components will need to be secured and waterproofed as much as possible before this test can be conducted. The test will be put forth to show that none of the electric or electro-mechanical components short out due to contact with the water, but it is highly undesirable that this happens as a result of this test. The group does not want to have to purchase all of the components again and reattach them, so a negative outcome of this experiment could prove disastrous and detrimental to the project’s timely (and cost effective) completion.

This test will take place outdoors, either on a grass or concrete surface. A garden hose with a “spray” or “shower” setting will be used to continuously sprinkle water at a gentle pressure. This “showering” will continue for 5 minutes. 2 ½ minutes into this process the device will be tested while the water is still going (so one of the experiment’s pieces of equipment should be a swimsuit) and the LCD must display its values. After the 5 minutes have elapsed a second test will be conducted to ensure that the device is still functional. All of the information should be accurately displayed. The solar tracking device should continue to function normally after it has dried and further hours have passed.

4.5.8 Wind/Structural Integrity Test

Another specification set forth for this project was to have a device that was durable as well as weather resistant. Unfortunately, the group does not have an abundance of funds and budgeting for a second device, so performing a drop-test to find the breaking point of the object would be a ridiculous aspiration. The group cannot compensate for the abuse incurred by the user (it will void the warranty), however the device does need to perform in a variety of reasonable weather conditions, like wind for instance. The device needs to have enough structural integrity to withstand strong wind gusts and the best way to test this in a controlled environment (with the resources available to the group) is to use a leaf blower. Leaf blowers can generate wind speeds of 150 mph which is the equivalent of a category four hurricane, the most the solar tracker is likely to experience in a region like Florida; this will make this an ideal machine to test how robust the frame and components are. In order to conduct this test an experimenter with leaf blower will hold the nozzle about half a meter away from the device and retain that radius as he or she gradually makes their way around the prototype device. If the structure is maintained and the device remains functional after this test, then it can be considered a success.

4.6 Troubleshooting Procedures

During the initial operating of the solar tracker, it is guaranteed that there will be one or more components that fail to operate, or even if they are working the result is not what is expected. To find which one or more components are not performing like they suppose to, the problem is categorized into three types: mechanical, collector, and power supply. If the tracker fails to follow the sun, then it's part of the mechanical problem. And in the problem, there three components that needed to be fix, they are: the motors, microcontroller, or the photoresistors. If the battery is not charging, then it might be due to the energy collector fault, mainly the solar panels. The panels will be carefully examined using a multimeter to check for the proper voltage output. If there's no power deliver the MCU, the motors, or the circuit board, then the problem might due to battery. A multimeter will use to measure the battery to see if it's supplying the correct voltage. Then a measurement at the converter's output to make sure that it's producing the correct voltage and amperage to the selected components.

4.6.1 Circuit Broad Troubleshooting

One of the problems that is bounded to occur during the building process is the failure when the components on the circuit board or the board itself is defected. Once the PCB is acquired from the vendor, intricate steps will be taken to solder the resistors, transistors, ICs and any other necessary devices onto the circuit board. But even if extra measure is taken to make everything is done correctly there will be some faults in the circuit board. Here are some of the typical problems that might cause the board to not work properly:

- Bad solder joints
- Oscillation/Distortion
- Incorrect terminal connections.
- Incorrect components
- Design errors
- Schematic errors
- Defected PCB

To identify the problem, the circuit of be closely examine for any sign of cracks, discolor or burn mark, corrosion, and unintentional soldering that might cause a short circuit. If none of the problem can be visibly indentified, then an oscilloscope and a multi-meter will be use to trace very resistor and ICs to verify that they are inputting and outputting the correct voltage and signal. The continuity function on the multi-meter can be use to determine if the soldering is well connected between the PCB trace and the components pins. It also can be use to detect whether the PCB tracing or a wire is broken even if they can't be seen. Once a defected component is identified, it will be de-soldered, remove from the board and replace with a new one.

4.7 Vendors

Lists of vendors or possible vendors:

- Sparkfun.com
  - For compass
- Ebay.com
  - For solar panel
  - For LCD panel
- Onlybatteries.com
  - For the lithium-ion battery
- Pololu.com
  - For the gyroscope
- amainhobbies.com
  - For the servo motors
- 411techsystems.com
  - For LCD panel

4.7.1 Pricing

Table 4.1 is a listing of the products and its availability. So far the entire product goes, it is in stock and is ready to order.

Product	Product Pricing	Availability
Lithium-Ion Battery	Varies with type of capacity	• In stock • Onlybatteries.com
Solar panel Polycrystalline PV Cell	$36.65	• In stock • Ebay.com
HD44780 LCD panel	$7.49	• In stock • 411techsystems.com
HMC6352 Compass	$34.95	• In stock, backorder allowed • Sparkfun.com
Hitec HS-322HD Servo Motor	$9.99	• In stock • Amainhobbies.com
Gyroscope	$19.95	• In stock • Pololu.com

Table 4.1 Parts and pricing

5 Design Summary

The design of the project is currently tentative due to the process of optimization that will occur and the interchanging of components to achieve the most efficient device possible, however a set of primary components will be experimented with first. These primary components have been selected because research has shown that they have the best features and specifications for what this device is trying to achieve. A parabolic mirror has been chosen as the optical collector. This will be arranged in a manner similar to what is shown in figure 3.1, reprinted here:

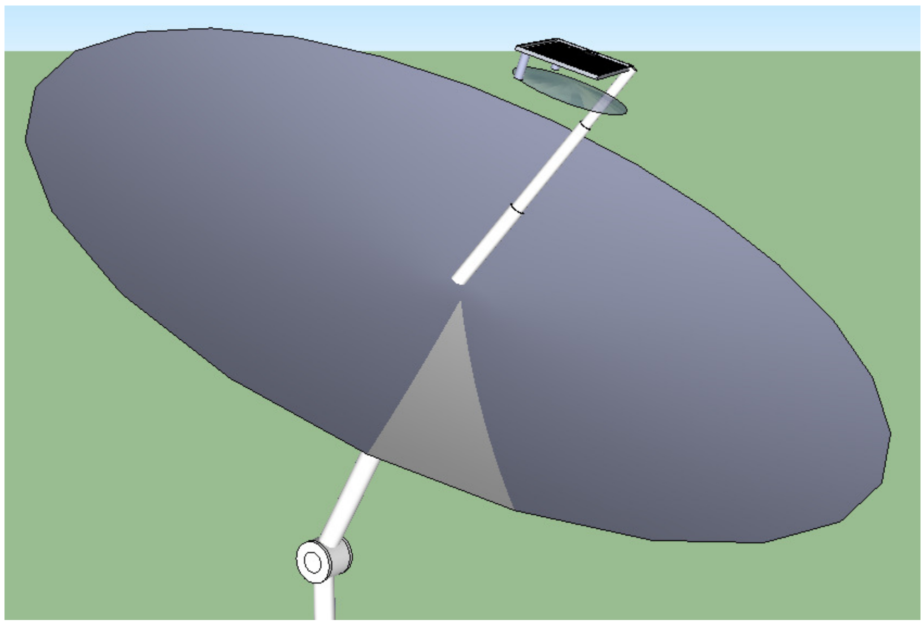

Figure 3.1 Optical Configuration

The sunlight will be focused on a series of photovoltaic panels that will be capable of providing 12 Volts to be stored in a Lithium-ion battery. The collector will follow the path of the sun in the sky using photoresistors. Information from the photoresistors will be analyzed by an Arduino Duemilanove microcontroller. The Arduino will also be powered by the energy stored in the battery and it will also power the servo motors that move the collector. The Arduino will analyze information from IC's like the DS248 that monitor the state of the battery and output the information in a user-friendly visual representation on an LCD screen. Other features may also be added including a compass IC, thermometer IC, and a gyroscope. The interfacing of these components is shown in figure 4.3, but is also reprinted here:

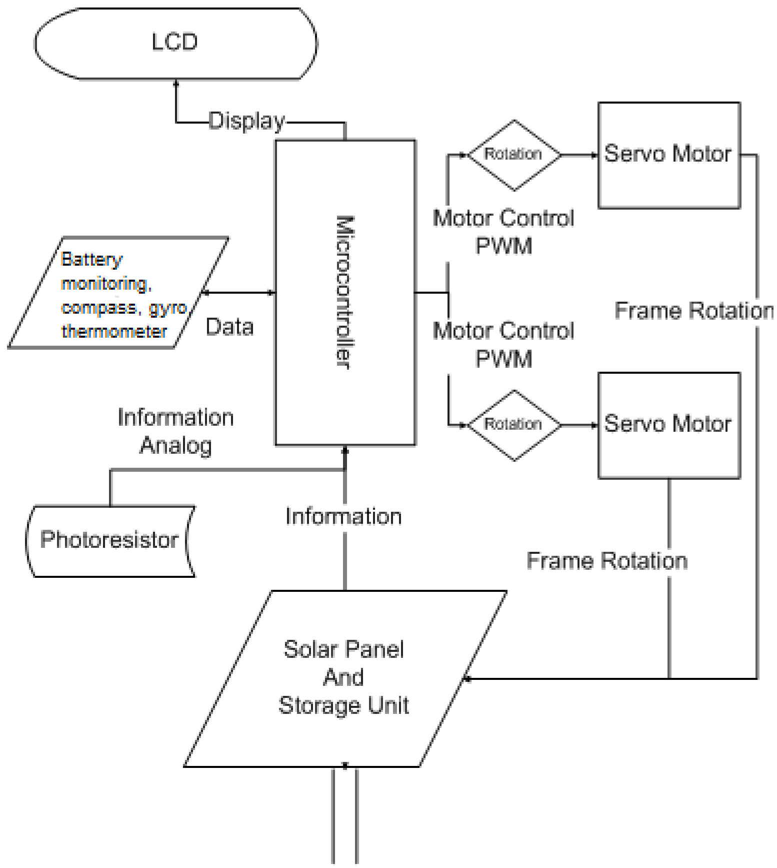

Figure 4.3 Interface of components

The device will also output power through a 5 Volt USB port. A DC/AC inverter may be used to achieve the method necessary to plug the device in through an adapter. Switches and other logic devices in the circuitry will also be necessary in order to conserve power in the device when sunlight is not available. Proper management and attention to detail in all of these areas should assist in achieving the goal of a reliable and effective solar tracking and energy storage device.

6 Project Summary

Ultimately, the task of designing and creating a solar tracking and energy storage/discharge device will be a challenge. The major difficulties will lie in the optimization of collection as well as the power management and conservation of the device. Experimentation of different methods of collecting energy will be necessary to provide confidence that the final design is indeed the optimal design. Theoretical schematics and circuit analysis will need to be scrupulously considered and conducted in order to ensure that upon implementation of the device no problems will occur. Testing will be an important phase to guarantee a strong overall project.

The device will essentially consist of a few major components, such as the solar panel, microcontroller, motors, screen, and a battery, that will be interfaced with minor components, such as battery monitoring IC's, photoresistors, wires, and other miscellaneous electrical circuit elements, in order to develop a fully functioning prototype. Residual issues such as the quantity and arrangement of the solar panels would be irrelevant so long as the power requirements for the device are achieved. The battery power supply will also only need to have enough capacity to power the components and an external electronic device, any extraneous capacity will be unnecessary.

Achieving the initial specifications that were established for this device while providing the highest efficiency possible, is a primary goal for this project. Reducing the overall cost of the device by eliminating minimally enhancing components will also be undertaken. The challenges posed by this project are indeed formidable, but enough planning, research, and design has taken place to prove that the construction of this device can be accomplished.

Appendix A: Works Cited

1. http://www.instructables.com/id/How-to-build-a-Solar-Power-Station/step4/Pre-Wiring/
2. www.youtube.com/watch?v=Gi0Mf3cl1E
3. http://www.youtube.com/watch?v=-anuxcdBDPw
4. www.youtube.com/watch?v=tI8Xfw1bLms
5. http://www.youtube.com/watch?v=-yh1q59a1h0&NR=1. 4/10/10.
6. http://www.greenpowerscience.com/index.html. 4/11/10.
7. http://www.stirlingenergy.com/how-it-works.htm
8. http://www.stirlingengines.org.uk/sun/sola3.html
9. http://www.windows.ucar.edu/tour/link=/earth/climate/sun_radiation_at_earth.html. 3/31/10.
10. http://science.nasa.gov/science-news/science-at-nasa/2002/solarcells/. 4/6/10.
11. http://www.pvresources.com/en/home.php. 3/21/10.
12. Mark Z. Jacobson (2009). Review of Solutions to Global Warming, Air Pollution, and Energy Security p. 4. 3/21/10.
13. http://en.wikipedia.org/wiki/Solar_cell. 3/30/10.
14. http://www.solarbuzz.com/technologies.htm. 3/26/10.
15. http://www.solarpowerfast.com/build-solar-panel/monocrystalline-solar-panels/. 4/6/10.
16. http://www.solarpowerfast.com/build-solar-panel/polycrystalline-solar-panels/. 3/30/10.
17. http://sustainability.claremont.edu/solar/chapter2.pdf. 4/5/10.
18. http://arduino.cc/en/Main/ArduinoBoardDuemilanove. 4/2/10.
19. http://xenophilius.wordpress.com/2010/02/16/dirt-cheap-solar-cells-from-copper-zinc-tin-selenium-and-sulfur/. 3/30/10.
20. http://www.sciencedaily.com/releases/2009/04/090409151444.htm. 4/5/10.
21. http://yylab.seas.ucla.edu/papers/YY-PV-12-Vishal-Measurement-AFM-06.pdf. 4/5/10.
22. "IMEC's Poortmans: Organic PC more than "niche"." PhotoVoltaics World. November, December 2009 issue. 8-9.
23. http://www.reuk.co.uk/Effect-of-Temperature-on-Solar-Panels.htm. 3/27/10.
24. http://solarwall.com/en/products/solarwall-pvt.php. 3/29/10.
25. Rechargeable Batteries Applications Handbook, Gates Technical Marketing Staff of Gates Energy Products, Inc. Printed in Boston, Copyright 1998 by Newns, Butterworth-Heinemann
26. SBS Pocket Plate Ni-Cd Batteries: Flooded Nickel Cadmium Cells 8AH-1580AH www.sbsbattery.com/subpage_index.php?_subp_=131
27. Ni-Cd Specs and characteristics by SBS company at www.sbsbattery.com
28. David Linden, Thomas B. Reddy (ed). Handbook Of Batteries 3rd Edition. McGraw-Hill, New York, 2002 ISBN 0-07-135978-8 page 23, 28-18
29. Cowlishaw, M. F., *Trans. British Cave Research Association*, Vol 1, No. 4, pp199-214, December 1974
30. Lithium-ion batteries: Science and technologies by Masaki Yoshio, Ralph J. Brodd, Akiya Kozawa. Printed in New York by Springer Publishing, Copyright 2009.

31. http://www.greenbatteries.com/nibafa.html#mAh defined
32. http://www.greenbatteries.com/noname.html
33. http://www.societyofrobots.com/schematics_batterymonitor.shtml
34. http://focus.ti.com/lit/ml/sluc077/sluc077.wmv
35. www.robots.freehostia.com
36. http://www.datasheetcatalog.org/datasheet/maxim/DS2438.pdf
37. http://www.smps.us/power-inverter.html
38. http://www.voltageconverters.com/itemdesc.asp?ic=XR100-12
39. http://www.sss-mag.com/usb.html
40. http://www.instructables.com/id/Portable-USB-Charger-Version-2.0/
41. http://www.instructables.com/id/MintyBoost!---Small-battery-powered-USB-charger/?ALLSTEPS
42. http://datasheets.maxim-ic.com/en/ds/MAX756-MAX757.pdf
43. http://ww1.microchip.com/downloads/en/DeviceDoc/41268D.pdf. 4/6/10.
44. http://ww1.microchip.com/downloads/en/DeviceDoc/41248B.pdf. 4/6/10.
45. http://en.wikipedia.org/wiki/PIC_microcontroller#Performance. 4/6/10.
46. http://www.robotshop.com/PDF/basicatompro24-specifications.pdf. 4/2/10.
47. http://www.atmel.com/dyn/resources/prod_documents/doc2545.pdf. 4/2/10.
48. http://www.robotshop.com/pololu-orangutan-lv168-robot-controller.html. 4/2/10.
49. http://arduino.cc/en/Main/ArduinoBoardDuemilanove. 4/2/10.
50. http://www.parallax.com/dl/docs/prod/datast/SX20AC-SX28AC-Data-v1.6.pdf. 4/5/10.
51. http://www.freescale.com/files/microcontrollers/doc/data_sheet/M68HC11E.pdf
52. MC68HC11: An Introduction Software and Hardware Interfacing
53. http://www.freescale.com/webapp/sps/site/taxonomy.jsp?nodeId=01624684498635]
54. CY8CKIT-003 PSoC 3 FirstTouch Starter Kit Guide, Spec. # 001-49613 Rev. *C
55. http://www.seattlerobotics.org/guide/servos.html
56. http://www.sparkfun.com/datasheets/Robotics/servo-360_e.pdf
57. http://www.springrc.cn/en_index/view_list.asp?id=235&typeid=61
58. http://www.pololu.com/catalog/product/536/specs
59. http://www.parallax.com/dl/docs/prod/motors/crservo.pdf
60. http://www.parallax.com/Portals/0/Downloads/docs/prod/motors/900-00008-CRServo-v2.0.pdf
61. http://www.hitecrcd.com/products/servos/robotics/hsr-1425cr.html
62. http://www.servocity.com/html/hs-322hd_standard_deluxe.html
63. http://www.hitecrcd.com/product_file/file/17/HS322HD.pdf
64. http://www.servocity.com/html/s9405_hi-torque_mg_bb.html
65. http://www.gpdealera.com/cgi-bin/wgainf100p.pgm?I=FUTM0098
66. http://www.gpdealera.com/cgi-bin/wgainf100p.pgm?I=FUTM0029
67. http://www.servocity.com/html/s3001_precision_ball_bearing.html
68. http://electronics.howstuffworks.com/brushless-motor.htm
69. http://www.solarbotics.com/assets/datasheets/motor_data_summary-gm14a.pdf
70. http://www.solarbotics.com/assets/datasheets/motor_data_summary-gm21.pdf
71. http://www.pololu.com/catalog/product/1109/specs
72. http://www.sparkfun.com/datasheets/Robotics/Pololu%20-%20Qik%202s9v1%20User%27s%20G....pdf

73. http://www.pololu.com/file/0J86/TB6612FNG.pdf
74. http://www.pololu.com/catalog/product/713
75. http://www.pololu.com/catalog/product/767/specs
76. http://www.pololu.com/catalog/product/765/specs
77. http://www.pololu.com/file/0J150/LISY300AL-gyroscope.pdf
78. http://www.pololu.com/catalog/product/1271
79. http://www.pololu.com/file/0J240/lpy550al.pdf
80. http://www.sparkfun.com/commerce/product_info.php?products_id=9094
81. http://www.sparkfun.com/datasheets/Components/SMD/Datasheet_IDG500.pdf
82. http://www.sparkfun.com/commerce/product_info.php?products_id=7915
83. http://www.sparkfun.com/datasheets/Components/HMC6352.pdf
84. http://www.parallax.com/StoreSearchResults/tabid/768/txtSearch/HM55B/List/0/SortField/4/ProductID/98/Default.aspx
85. http://www.parallax.com/Portals/0/Downloads/docs/prod/compshop/HM55BDatasheet.pdf
86. http://www.sparkfun.com/commerce/product_info.php?products_id=9371
87. http://www.sparkfun.com/datasheets/Sensors/Magneto/HMC5843.pdf
88. http://www.ladyada.net/learn/sensors/cds.html
89. http://www.datasheetcatalog.org/datasheet/perkinelmer/VT500.pdf
90. http://www.societyofrobots.com/schematics_photoresistor.shtml
91. http://www.advancedphotonix.com/ap_products/pdfs/PDV-P9203.pdf
92. http://www.tstonramp.com/~pddwebacc/technical.htm
93. http://shop-on-line.tvielectronics.com/download/TC51854UM.pdf?osCsid=fbf518aa4e7e76ca8a7a7c4e45f0df14
94. http://en.radzio.dxp.pl/bitmap_converter/
95. http://www.datasheetcatalog.org/datasheets2/16/160893_1.pdf
96. http://www.sparkfun.com/datasheets/LCD/HD44780.pdf
97. http://www.mirrorlink.org/tech/types/index.htm
98. http://www.physicsclassroom.com/class/refln/u13l1d.cfm
99. http://www.physicsclassroom.com/class/refln/U13l3a.cfm
100. http://www.haaretz.com/hasen/spages/890970.html
101. http://www.reuk.co.uk/Effect-of-Temperature-on-Solar-Panels.htm
102. http://www.physicsclassroom.com/class/refrn/U14L5a.cfm
103. http://www.physicsclassroom.com/class/refrn/U14l5b.cfm
104. http://hyperphysics.phy-astr.gsu.edu/Hbase/geoopt/fresnellens.html
105. http://scientificsonline.com/product.asp?pn=3052833&cm_mmc=Mercent-_-Google-_-NULL-_- 3052833&mr:trackingCode=CC6E1735-DB81-DE11-8C0A-000423C27502&mr:referralID=NA
106. http://www.homedepot.com/h_d1/N-5yc1vZ5yed5/R-
107. http://www.delphiglass.com/index.cfm?page=itemView&itemSYSid=130206&source=froogle
108. http://www.amazon.com/Concave-Mirror/dp/B000701BF6
109. http://www.physicalgeography.net/fundamentals/6h.html
110. http://www.radio-electronics.com/info/data/semicond/phototransistor/photo_transistor.php

111. http://www.datasheetcatalog.org/datasheet/panasonic/SHE00003AED.pdf
112. http://pdf1.alldatasheet.com/datasheet-pdf/view/139953/OPTEK/OP800SL.html
113. http://www.video-surveillance-guide.com/how-does-thermal-imaging-work.htm
114. http://letsmakerobots.com/node/7752
115. www.8051projects.net/lcd-interfacing/lcd-4-bits.php
116. Official Journal of the European Union 13.2.2003 issue 37 pg 21 http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:037:0019:0023:EN:PDF

Appendix B: Permission

No higher resolution available.

Seasons.too.png (642 × 457 pixels, file size: 6 KB, MIME type: image/png)

Summary [edit]

How directness of sunlight causes warmer weather and how it effects climates.

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	Date/Time	Thumbnail	Dimensions	User	Comment
current	16:42, 23 April 2009		1,501×1,164 (263 KB)	Delphi234	*({{Information |Description={{en|1=Annual PV Solar Radiation (Flat Plate, Facing South, Latitude Tilt)}} |Source=Uploaded to en wiki by en:User:Sillybilly at 18:30, 18 December 2005 from http://www.nrel.gov/gis/il_solar_pv.html |Author=NREL |Date=May)*

Permission for Figure 2.1

http://en.wikipedia.org/wiki/File:PVeff(rev100414).png

Other versions http://commons.wikimedia.org/wiki/File:PVeff%28rev110707%29d.png

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{{subst:Please link images|File:PVeff(rev100414).png}} ~~~~

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Permission for Figure 2.3

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http://solarwebworld.com/blog/2006/04/18/knowing-sun-tracker/

From: **Mridul Kashatria** <mridul@mridkash.com>
Date: Sun, Apr 11, 2010 at 5:13 AM
Subject: Re: Permission to use materials
To: Tuyen Bui <tuyenhbui@gmail.com>

Hi Tuyen Bui,

Sure, you can use it with attribution. I'm glad you asked. I'll be interested in your report also. What is it about?

Regards
Mridul

On Sat, 2010-04-10 at 20:22 -0400, Tuyen Bui wrote:
> Mr. Kashatria, may have the permission use your work along with the
> pictures on
> http://solarwebworld.com/blog/2006/04/18/knowing-sun-tracker/ for my
> report. I reference my source to your site. Thank You

http://www.i4at.org/lib2/inverter.htm

From: **Albert Bates** <albert@thefarm.org>
Date: Fri, Apr 9, 2010 at 11:36 AM
Subject: Re: Permission to reprint picture
To: Tuyen Bui <tuyenhbui@gmail.com>

redirected:

Hi, may I get your permission to use the picture from
http://www.i4at.org/lib2/inverter.htm for my report. Thank You

Yes.

-ab

http://letsmakerobots.com/

From: **Recktenwald Peter** <p.recktenwald@gmail.com>
Date: Fri, Apr 9, 2010 at 4:03 AM
Subject: Re: [Let's Make Robots!] Wii camera image
To: tuyenhbui@gmail.com

Hello tuyen,

All my contents at LMR, Flickr, Youtube, Google Code (pictures, videos, text, sourcecode) is published under the Creative Commons License cc by-nc-sa (Attribution Non-Commercial Share Alike). Feel free to use it under this license.
http://creativecommons.org/licenses/by-nc-sa/3.0
http://creativecommons.org/licenses/by-nc-sa/3.0/legalcode

Regards Peter

http://www.ladyada.net/learn/sensors/cds.html

From: **Adafruit Industries** <support@adafruit.com>
Date: Tue, Mar 23, 2010 at 12:24 PM
Subject: Re: Requesting permission to use
To: Tuyen Bui <tuyenhbui@gmail.com>

please do - thx for the email

On Tuesday, March 23, 2010, Tuyen Bui <tuyenhbui@gmail.com> wrote:
> Hi, I would like to get your permission to use the information and pictures from this page http://www.ladyada.net/learn/sensors/cds.html for my report. I will reference my source to your website. Thank You

www.societyofrobots.com
From: **John Palmisano** <palmisano@gmail.com>
Date: Sun, Mar 21, 2010 at 8:39 AM
Subject: Re: Permission to use pictures and application
To: Tuyen Bui <tuyenhbui@gmail.com>

For reports? Sure! Just make sure you properly reference/credit it.

John Palmisano
Robotics Specialist
www.societyofrobots.com

2010/3/20 Tuyen Bui <tuyenhbui@gmail.com>:

> Hi, I would like to get your permission to use this excel program
> http://www.societyofrobots.com/downloads/photoresistor_maximization.xls
> on my reports.
>

www.8051proejcts.net

From: **Ajay Bhargav** <contact@rickeyworld.info>
Date: Fri, Mar 19, 2010 at 1:34 AM
Subject: Re: Permission to reprint picture
To: Tuyen Bui <tuyenhbui@gmail.com>

Hi Tuyen,

Yes you have full permission to use that picture in your report.

If possible you can mention "www.8051proejcts.net" in Bibliography area or wherever possible.

You can also help us by submitting your project, i will showcase that project on website.

Good luck!

Regards,
Ajay

On Fri, Mar 19, 2010 at 4:28 AM, Tuyen Bui <tuyenhbui@gmail.com> wrote:
Mr. Bhargav, may I have the permission to use this picture http://www.8051projects.net/lcd-interfacing/lcd.png for my project report.

Battery Monitoring Circuit Diagram Permission

I would like to use one of your circuit diagrams Inbox | X

Stephen Holman to talulah — show details Apr 23 (8 days ago) — Reply

Hello, my name is Steve Holman, I am an electrical engineering student working on a senior design project involving battery monitoring. We are currently in the research paper stage of the project. I liked your circuit at http://homepages.which.net/~paul.hills/Circuits/BatteryMonitor/BatteryMonitor.html on battery monitoring and would like to place your circuit diagram in the research paper, it will serve as an example for a way to monitor the battery status of our device, although it may not be the finalized implementation. This is a school project and is not a device that is looking to get marketed, do I have your permission to reprint your diagram?

Reply Forward

Hills, Paul to me — show details Apr 27 (5 days ago) — Reply

Yes, no problem.

Cheers,
paul

Paul Hills

Software Manager

Landis+Gyr UK Ltd

Office: +44 161 919 8960

Paul.Hills@landisgyr.com

www.landisgyr.com

manage energy better