Solar Panel Tracker

By Andrew Hsing

Project Advisor: Dale Dolan

Senior Project
ELECTRICAL ENGINEERING DEPARTMENT
California Polytechnic State University
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Acknowledgements

I would like to thank Professor Dolan for all the guidance and ideas he provided me throughout this project. I would also like to thank Daniel Chang for the use of his fabrication lab so I was able to create PCBs for the tracking circuit.

Abstract

This project will be a design and implementation of a polar single axis solar panel tracker. It will have a fixed vertical axis and an adjustable horizontal motor controlled axis. This setup is similar to an office swivel chair. The tracker will actively track the sun and change its position accordingly to maximize the energy output. To prevent wasting power by running the motor continuously, the tracker will correct it's position after 2 to 3 degrees of misalignment. The sensors will compare the light intensities of each side and move the panels until the tracker detects equal light on both sides. Additionally, it will prevent rapid changes in direction that might be caused by reflections, such as cars passing by. A rear sensor circuit is also incorporated to aid in repositioning the solar panels for the next sunrise. The gear motor will have overturn triggers to prevent the panel from rotating 360° and entangling wires. The motor control and sensing circuitry will run on batteries charged by the solar panel. This project will use three small 10W solar panels of approximately 15 inches by 10 inches to model larger panels used in industry.

I. Introduction

A solar tracker is a device for orienting a solar photovoltaic panel, day lighting reflector or concentrating solar reflector or lens toward the sun. Solar power generation works best when pointed directly at the sun, so a solar tracker can increase the effectiveness of such equipment over any fixed position. The solar panels must be perpendicular to the sun's rays for maximum energy generation. Deviating from this optimum angle will decrease the efficiency of energy generation from the panels. A few degrees of misalignment will only cause 1% to 5% of energy loss, while larger angles of 10° to 20° will significantly decrease the energy generation of up to 35% [4]. Although, this loss is also dependent on the material and pattern of the protective glass that covers the solar panel.

An active tracker uses motors to direct the panel toward the sun by relying on a sensing circuit to detect light intensity. There are two main ways to mount a solar panel for tracking; single axis and dual axis. Single axis trackers usually use a polar mount for maximum solar efficiency. Polar trackers have one axis aligned to be roughly parallel to the axis of rotation of the earth around the north and south poles. When compared to a fixed mount, a single axis tracker increases the output by approximately 30% [1].The second way is a two axis mount where one axis is a vertical pivot and the second axis is the horizontal. By using a combination of the two axes, the panel can always be pointed directly at the sun. This method increases the output by approximately 36% compared to stationary panels [1]. As the gain from a dual axis tracking system is not a significant improvement over a single axis tracker, this project will focus on a single axis horizontal angle tracking with a manually adjusted vertical angle.

III. Background

The purpose of solar panels is to meet the growing demand for renewable energy resources. In the modern world, the demand for electricity has grown at alarming rates to meet the needs of society. Many other benefits to solar energy include the lack of pollution directly created by these systems and their inexpensive and practical nature in the long term. As the demand for solar panels grow, so will the need for ways to optimize their energy collection. Tracking systems are designed to orient solar panels toward the sun. By adding a tracking system, the energy a solar panel can output could be increased by up to 50% during the summer months [2]. This project is very practical and feasible as there are many types solar tracker designs in industry today. In addition, a similar senior project was done in 1994 on the "Sun Luis solar racer 101" electric car by a physics major, David Babbitt. However, the 1994 project dealt with manual panel adjustments given sensor data.

IV. Requirements / Project Specifications

1. Polar single axis tracking

2. Self powered by rechargeable batteries

3. Sensor and motor unit controlled by comparing light intensities on either side

4. Overturn sensor to limit rotation to 270 degrees (prevent wire entanglement)

5. Rear light detector for resetting position on the next day

6. Saves power by turning off the main tracking circuit or the rear sensor when not needed

V. Design

There will be four main parts to this project. The first part is constructing a simple polar mount where the panel can swivel by connecting a low RPM motor. The horizontal axis will be controlled by a motor while the vertical angle can be manually adjusted. An example of this type of mount is depicted in Figure 1. The second part is designing the front detector, main tracker sensor, and rear sensor. A general overview of the interconnections between the various tracking circuits is provided in Figure 2. These circuits will use light emitting diodes to detect light intensity at various points on the solar tracker. There are several other better alternatives to LEDs such as photodiodes and phototransistors. These are much more precise and have a higher responsivity for light. However, this design will use LEDs as they are readily available and have sufficient sensitivity for use as light sensors in a small scale solar tracker. Although, a major disadvantage in using LEDs is the lack of ultra violet light detection. UV light detection is useful for tracking the sun under partially cloudy conditions and in most cases LEDs do not detect light in the UV range.

Figure 1: Example of a polar mounted solar panel

The next part will be designing the motor control circuit. This circuit will take the signals from the sensors and control the motor accordingly. The last part will be interfacing the sensor and motor control and powering everything through energy stored from the solar panel. The solar panel will charge a lead acid 12V battery trough a battery charge controller. The motor and control circuitry will draw power from the battery.

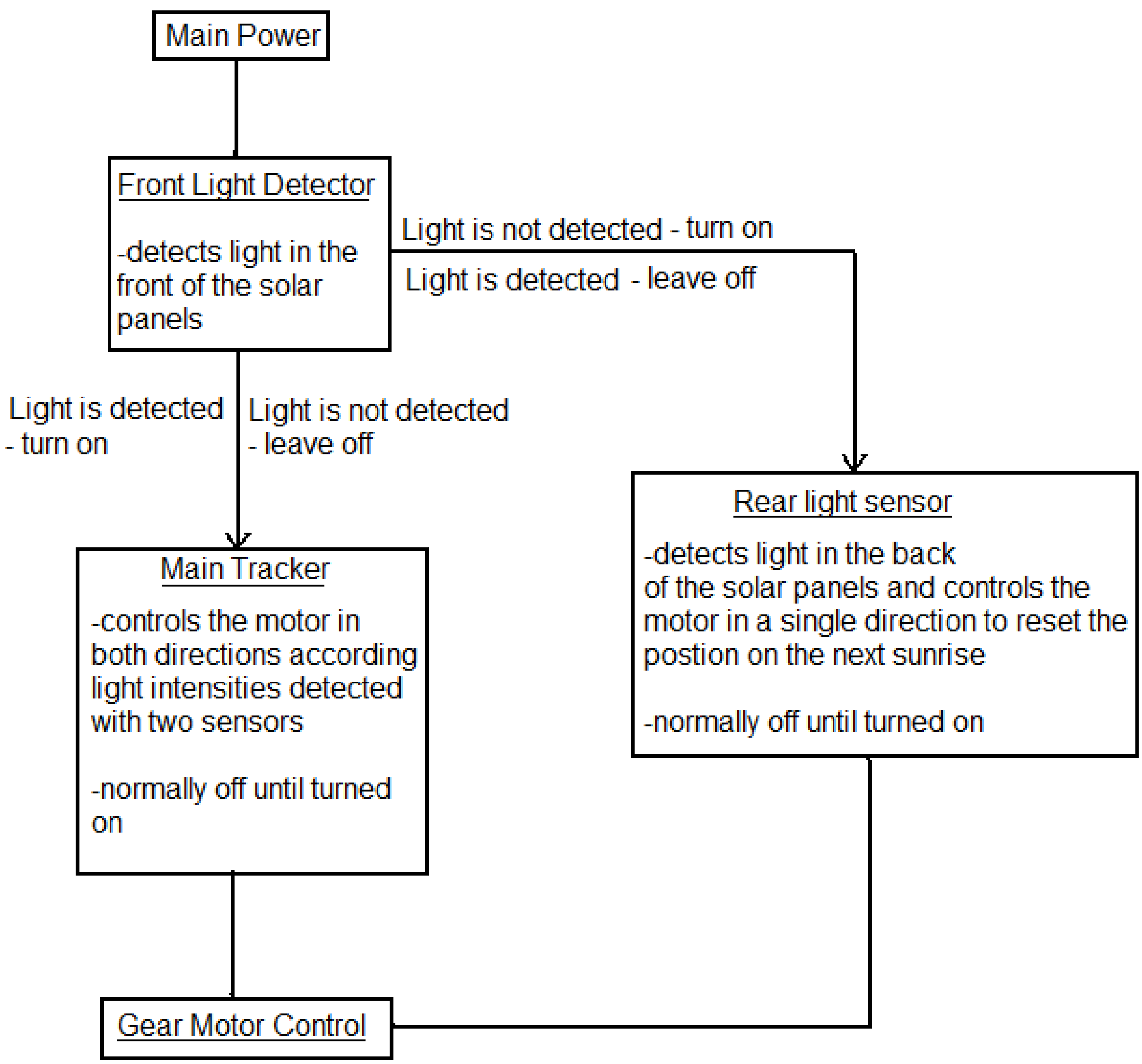

Figure 2: Overview of Solar Panel Tracking Connections

Figure 3 goes through the tracking operation that the tracker will follow. The main tracker is able to control the motor in both directions according to the signals sent from the LEDs. When light intensity is higher in the east side the panels will rotate in the counter clock wise direction. Alternatively, the panels will rotate in the clock wise direction when light is more intense on the west side. The rear light sensor is designed to correct the position of the solar panel on the next sunrise and will rotate the panels in the counter clock wise direction when it detects light.

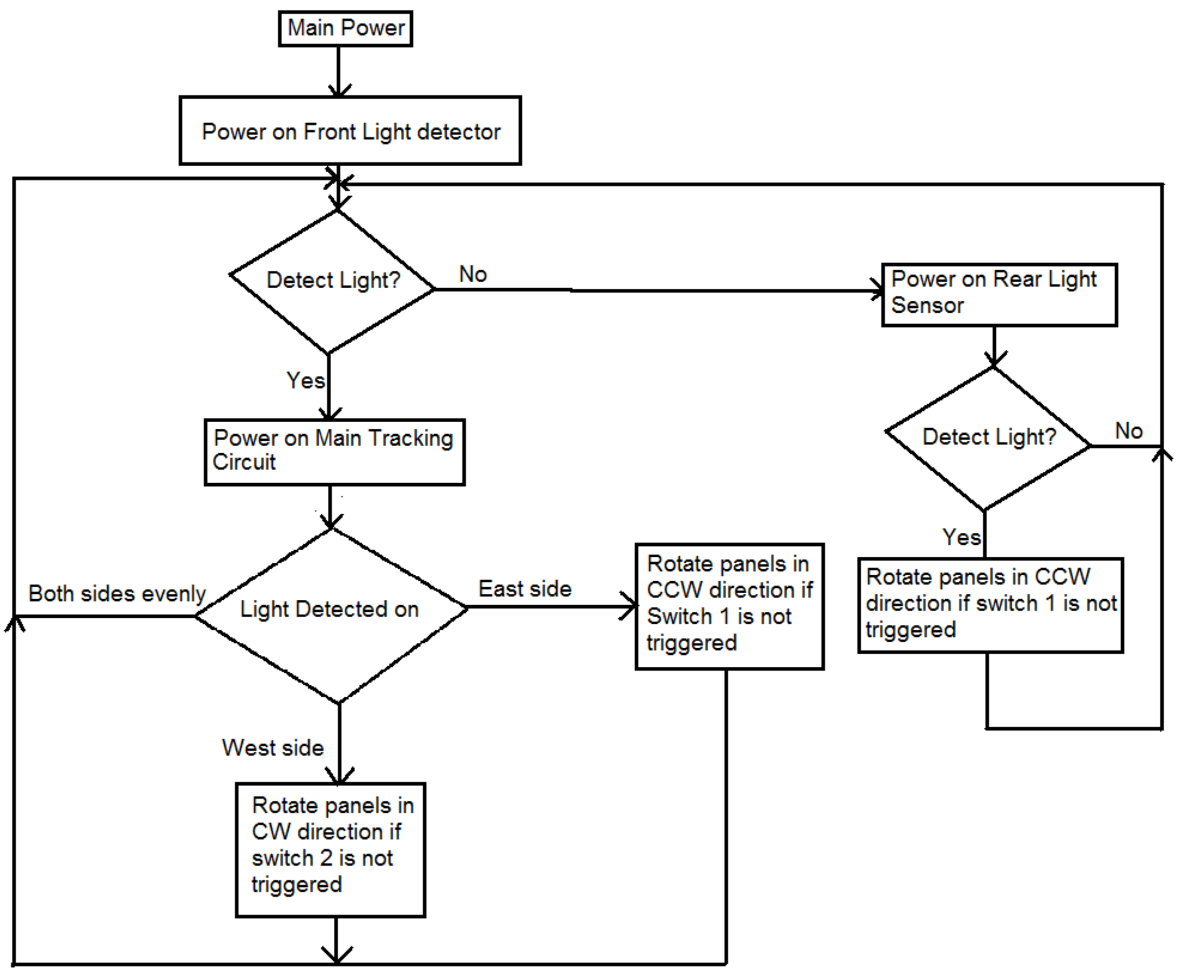

Figure 3: Flow Chart Tracking Operation

A. Front Light Detector

The front light detector powers on the main tracking circuit if it detects light or it powers on the rear light sensor if it does not detect light. With this set up, energy is conserved by being able to turn off the main tracking circuit when not in use. Initially, a large 10mm red LED acted as the sensor by generating a voltage when light is detected. The LED chosen has a 50° light detection angle and has high sensitivity. It detects light in a conical direction. However, after testing, the front detector LED was replaced by a smaller 5mm LED with a decreased detection angle of 30°and decreased sensitivity. This was done to allow the rear sensor to turn on correctly as ambient light was able to trigger the front detector.

The schematic design for the front light detector is shown in Figure 4. The voltage generated by the LED triggers the transistors and allows current flow to trigger the relay. With the relay triggered, the relay switch will be in the normally open position (NO) and the main tracking circuit is powered on. When there is no current the relay switch is in the normally closed position (NC) and the rear light sensor is powered on. The front light detector supplies power to the other sensor circuits.

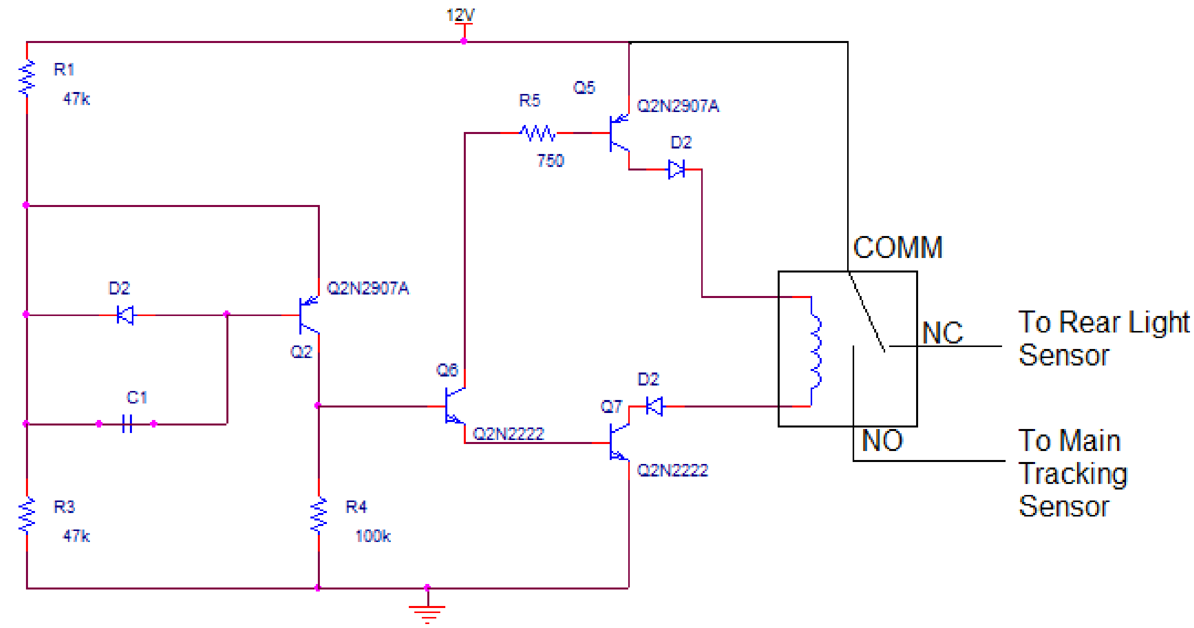

Figure 4: Front Light Detector Schematic

B. Main Tracking Sensor

The main tracking circuit uses two clear 10mm wide 50° angle LEDs which are very sensitive. The high sensitivity is required to get the optimum angle for maximum power in the solar panel. The configuration of the main tracking circuit went through several modifications from the original design.

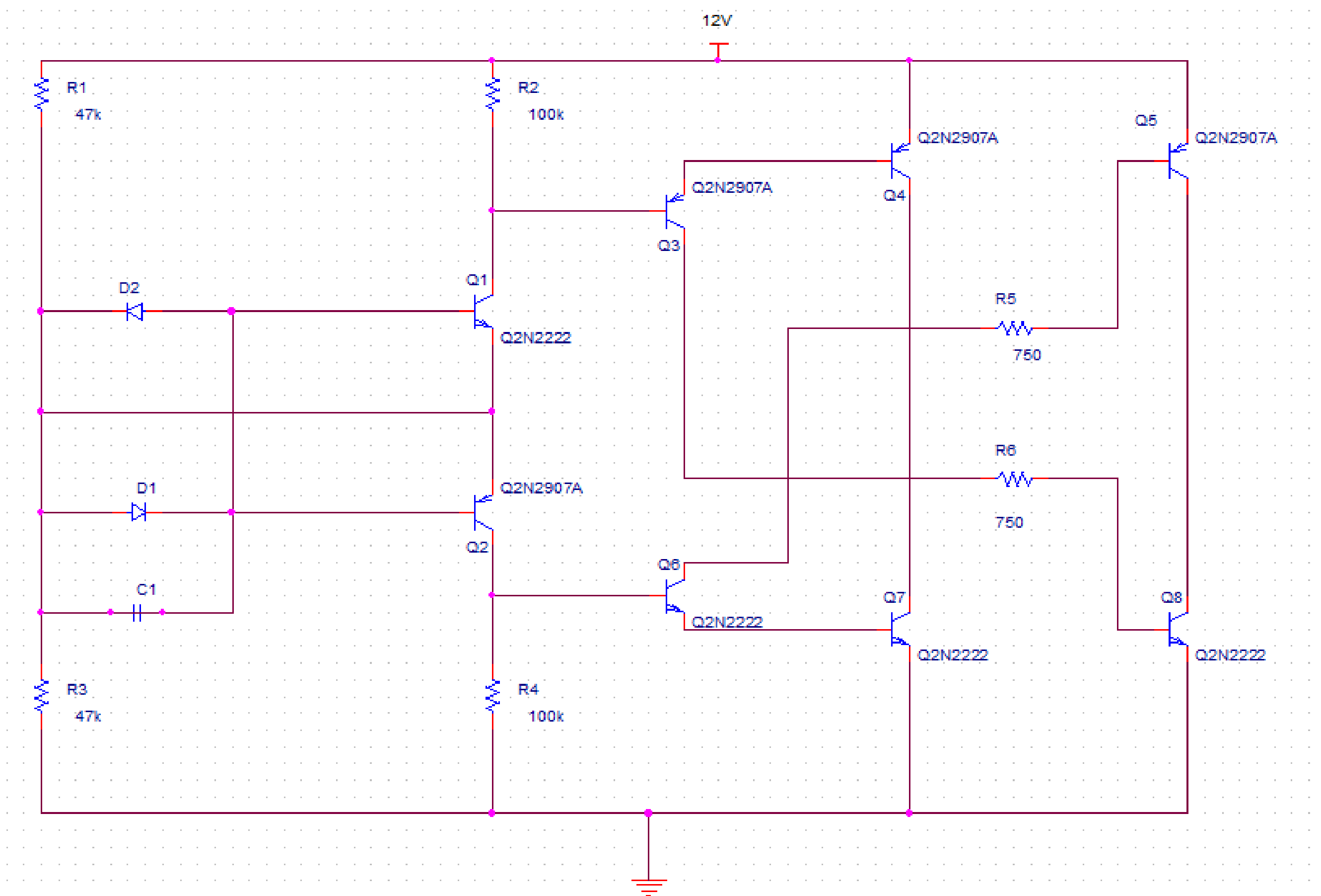

Figure 5: Initial Circuit Diagram of the Main Tracking Circuit

In the initial design, shown in Figure 5, the transistors were directly powering the motor. This caused Q4 and Q7 to overheat and stop working. Although the two transistor pairs,

2N2222 and 2N2907, were rated to sufficiently power, the motor the circuit was not able to function long. This was due to the poor quality of the 2N2222 and the 2N2907 that were purchased, in which over half were defective. To solve this problem the transistor pairs were changed to 2N4401 and 2N4403. The ratings of these transistors are sufficient to drive the motor, however it was noticed that the transistors also ran fairly hot since directly driving the motor required 12V at 200mA. To fix this, two 12V relays were added to drive the motor instead of directly driving the motor with the transistors. So, the transistors are now triggering the relays shown in Figure 6.

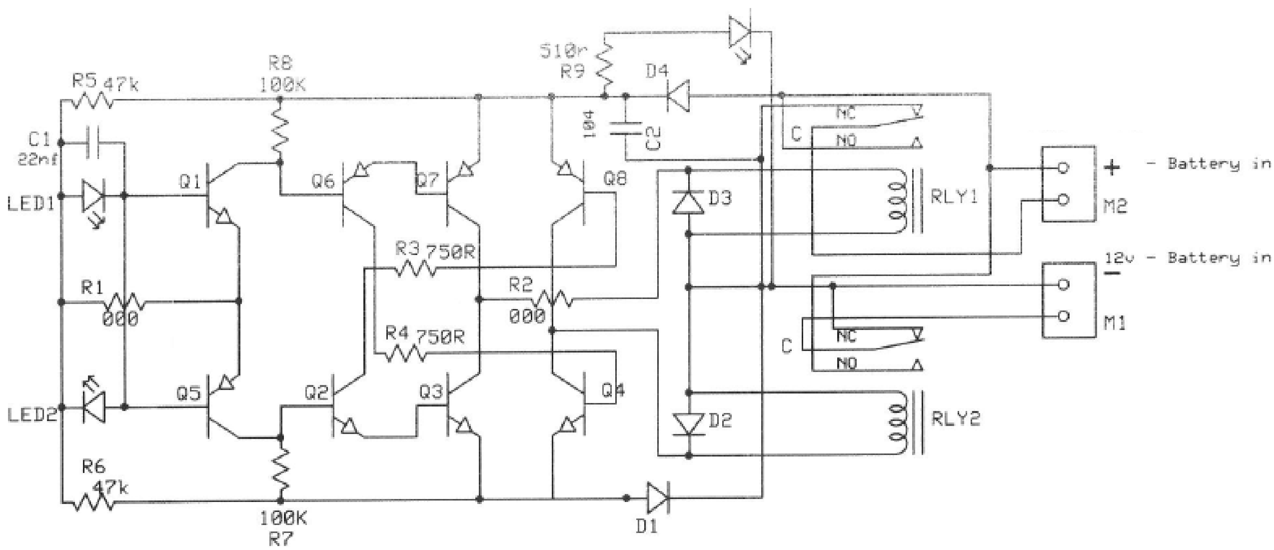

Figure 6: Schematic of Final Main Tracking Circuit

Figure 6 shows the final circuit diagram for the solar tracker. It was created using PCB Express, a free prototyping software by Sunstone Circuits. The development and construction section describe this in more detail. The 0 ohm resistors are just jumpers that needed to be put in so everything can be done on a single layer PCB board. This circuit detects the voltage

generated by the sensor LEDs. The LEDs are placed anti-parallel with each other so that the voltage will be positive or negative when light is more intense one side. This forward biases the transistors Q1 or Q2. These transistors act as switches which shorts a path for the current to travel and forward bias the Q7 and Q4 or Q8 and Q3 pairs respectively. This triggers a single relay as the diodes D3 and D2 only allow current to flow in one direction. When the LEDs detect equal light, both LEDs generate equal and opposite voltage. This occurs when the panels are perpendicular to the sun. The voltage at that node is zero as they are both canceled out. A capacitor is placed in parallel with the LEDs to act as a buffer, this prevents rapid changes in directions that might be caused by reflections such as cars passing by. When this happens none of the transistors will bias and the relays will not trigger.

Figure 7: First Version of Main tracker (red LEDs) and front detector (clear LED) sensors

Figure 7 illustrates the initial placement and LED type used for the main tracker and the rear sensor. It was discovered that using large 10mm LEDs allowed the main tracker to have much higher accuracy. They are placed one inch apart in the top center of the panels and approximately 40° from the perpendicular of the panels. However, it takes the tracker about an hour after the next day sunrise to reposition itself correctly. The solution for this is a rear light sensor.

Figure 8 shows the final version for the sensors. The reason for the size and color change was primarily due to sensitivity problems. This is described in detail at the Solar Tracking Testing section of the Testing and Results.

Figure 8: Final Version of Main tracker (10mm Clear LEDs) and front detector (5mm red LED) sensors

C. Rear Light Sensor

The rear light sensor, shown in Figure 9, is similar in design to the front detector. The voltage generated by the LED triggers the transistors and closes the relay switch. With the relay triggered, power is supplied to the gear motor and the rear light sensor will reposition the solar panels for tracking by the main tracker. This sensor uses a clear 10mm high sensitivity LED to detect light during sunrise. This circuit only operates when there is no light detected in the front of the solar panels. This prevents any problems where the gear motor will be controlled simultaneously by both the main tracker and the rear sensor. The rear sensor can only control the motor in the clock wise direction in order to reposition the panels. This is done so the solar panel will never rotate over 360° and therefore prevent wire entanglement.

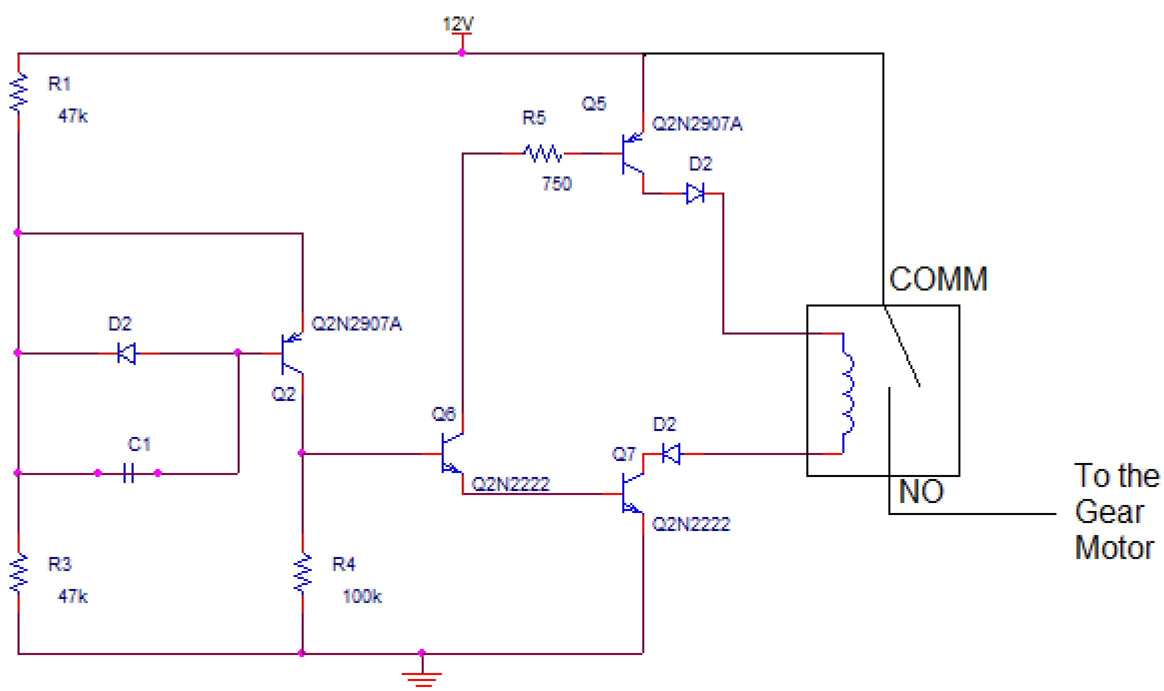

Figure 9: Rear Sensor Schematic

D. Motor Control

The gear motor is rated at 12V and 150mA. However, through measurements, it has been determined that the motor draws approximately 200mA when loaded. The gear motor is powered directly by the battery with relays controlling the rotation direction. Micro switches, shown in Figure 10, were used to act as the overturn triggers. They will be used to open one side of the circuit to prevent the motor from operating in one direction, while allowing operation in the opposite direction. This is done with diodes, see Figure 11. Two triggers are used to prevent wire entanglement, one in the clock wise direction and the other in the counter clock wise direction as per Figure 12. S1 represents switch 1, which is triggered by T1. S2 is switch 2 and is triggered by T2. In this configuration, the base of the solar tracker will need to be placed in the correct East and West direction with approximately 30° of error on either side.

Figure 10: Micro Switch

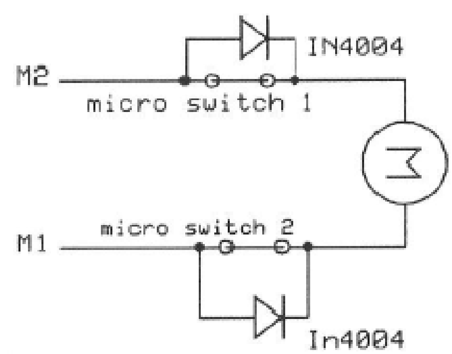

Figure 11: Microswitch configuration

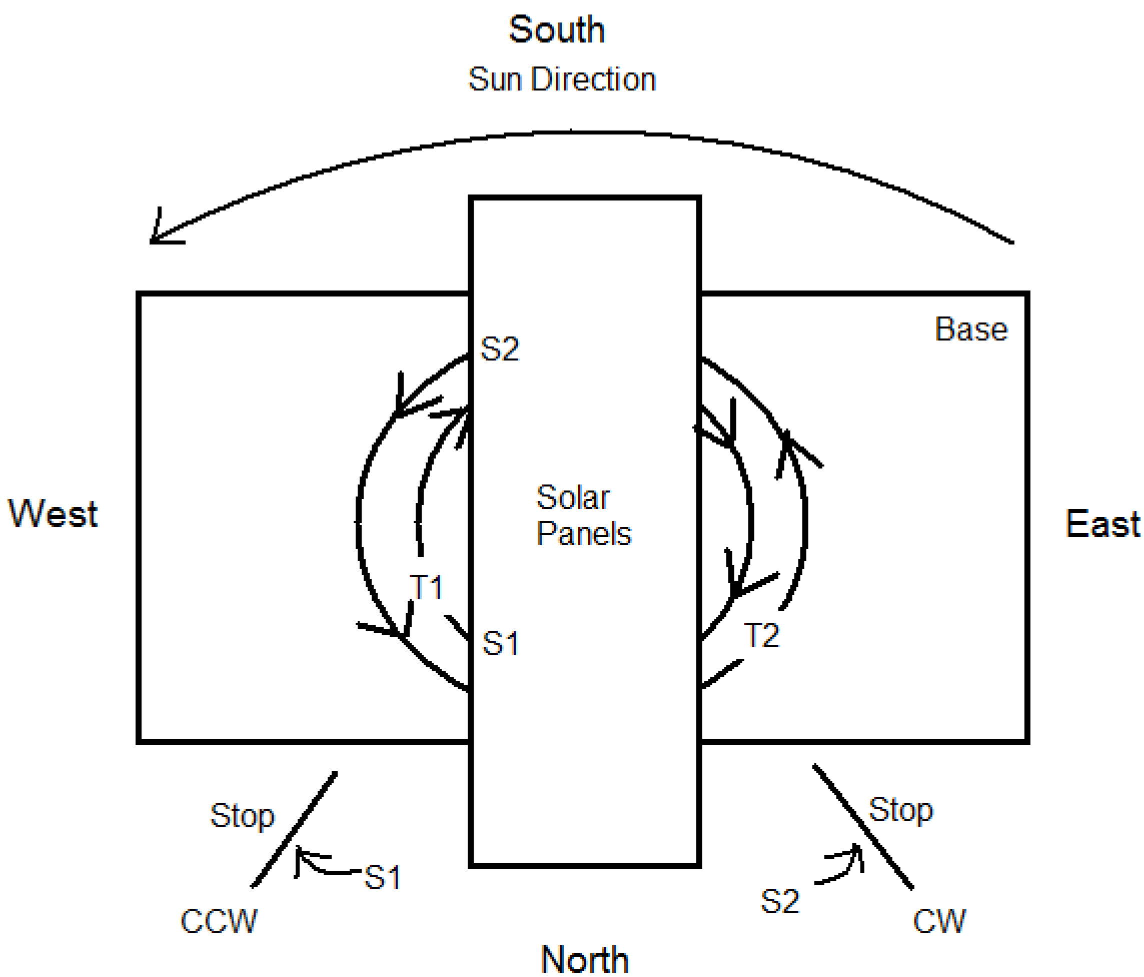

Figure: 12 Microswitch Placement

VI. Development and Construction

The complete solar tracker is depicted in Figure 13 below.

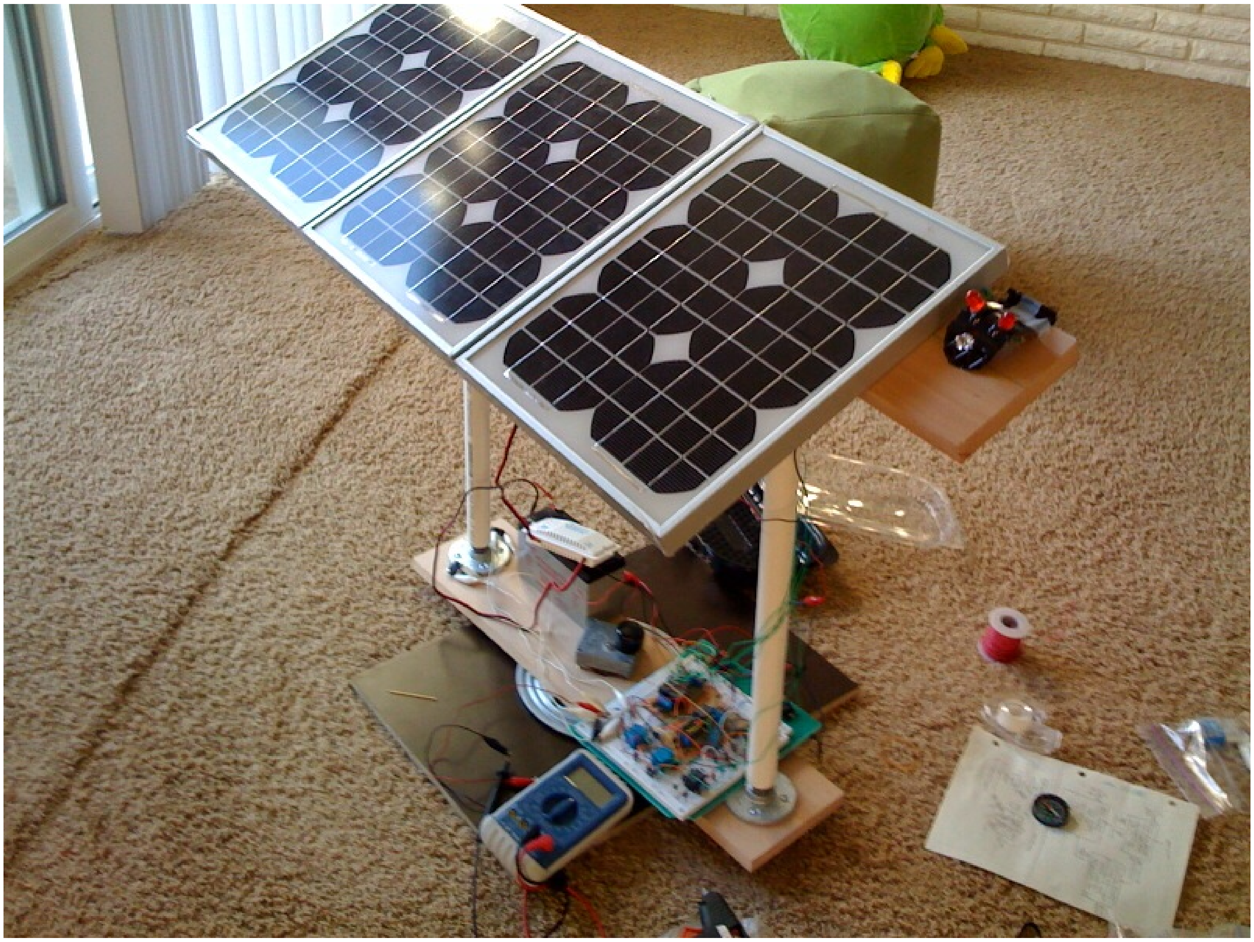

Figure 13: The completed Solar Tracker

A. Mount construction

Figure 14 illustrates preliminary sketches of the front and back of the solar tracker mount.

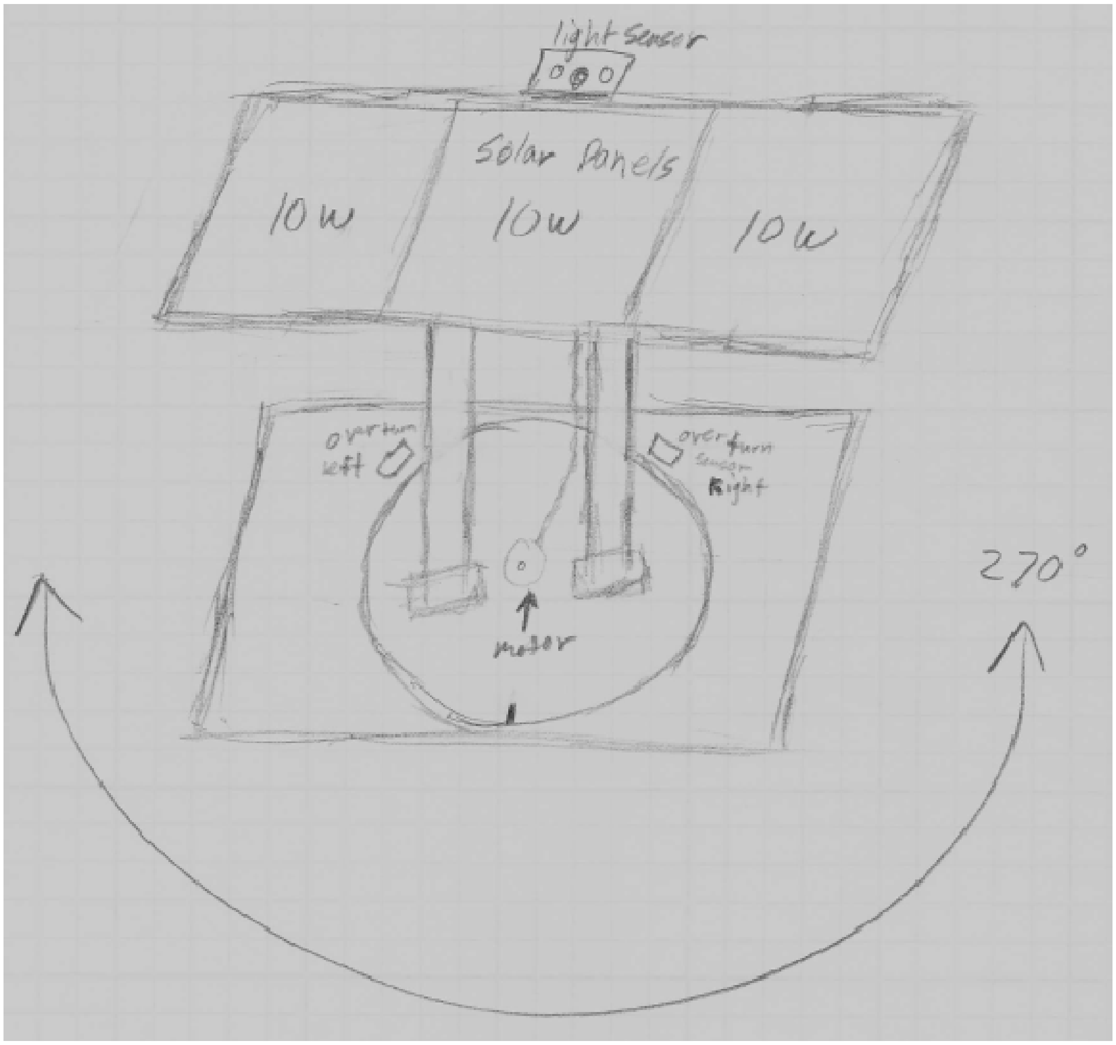

Figure 14: Preliminary sketch of the solar tracker (Front)

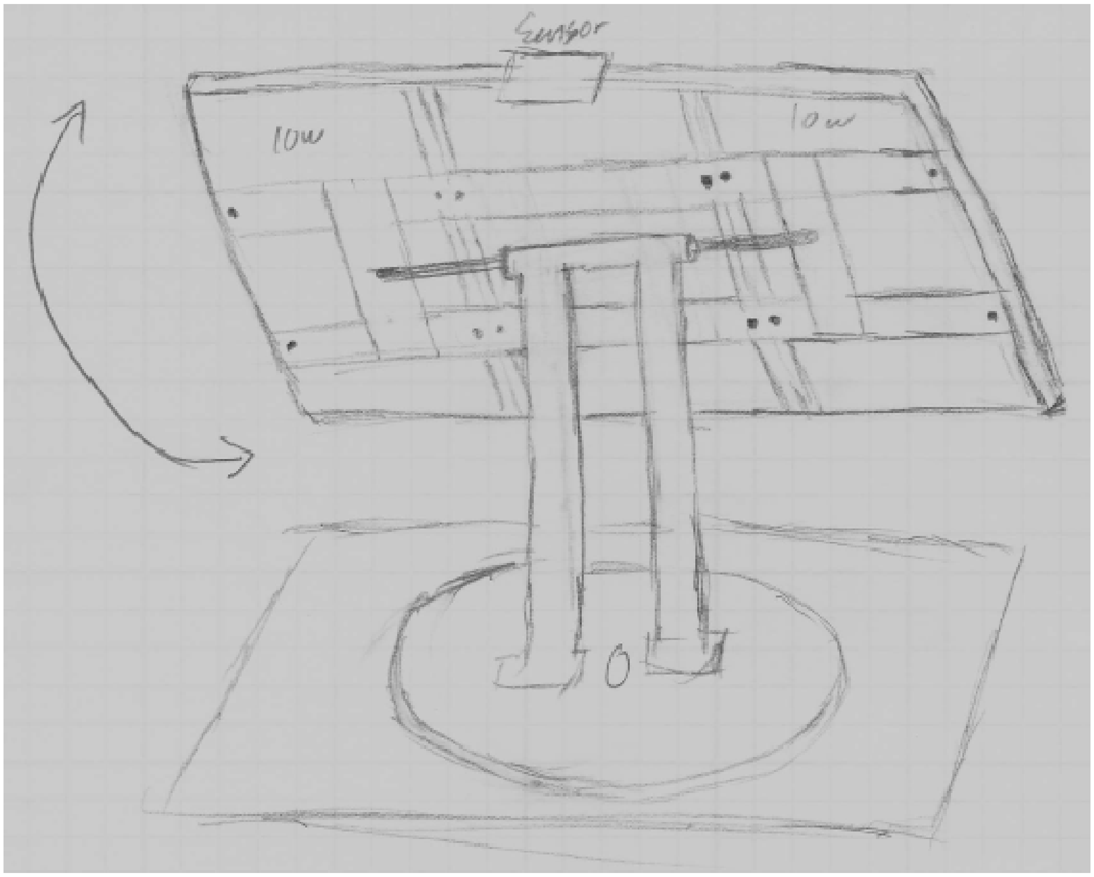

Figure 15: Preliminary sketch of the solar tracker (Back)

Figure 15, illustrates the initial plans for the manual vertical angle adjustment. In the finished mount, the adjustment comes from two PVC pipes inside one another. The outer pipe is secured onto the solar panels while the inner pipe is connected on the bottom of the mount. The angle is adjusted by loosening and tightening the screws on the pipe connectors seen in the yellow circles of Figure 16.

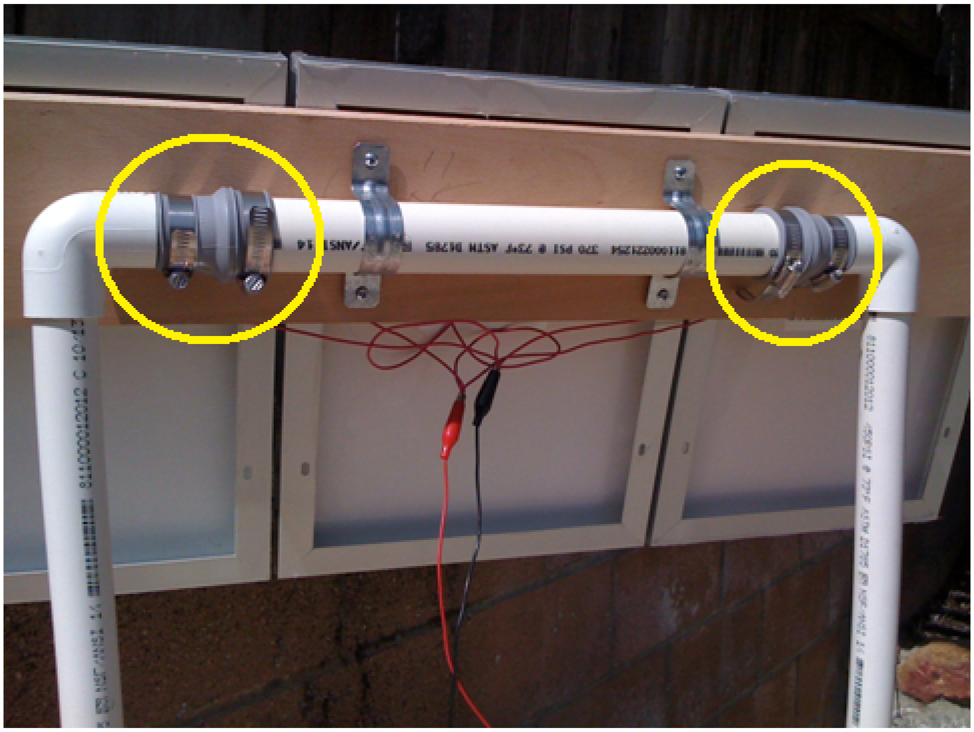

Figure 16: The Back of the Solar Mount

B. Gear Motor Interface

Connecting the motor with the mount was the most problematic part of this project. Initially, the motor was mounted on the bottom with the rotor going through the center of the lazy susan swivel and attaching to the top board. This did not work well, the rotor was not long enough and the wiring to the sensor needed to go through the rotating board and under the base. With several other failed configurations, a working design was developed. See Figures 17 for the interface between the base and motor. The rotor rotates on the fixed wooden center cylinder. This way the motor itself is moving rather than the rotor. The connections are held in place with aquarium silicone sealant. This provides some protection from shock as the silicone is flexible. Figure 18 gives a picture of the rotating mount power directly by the battery.

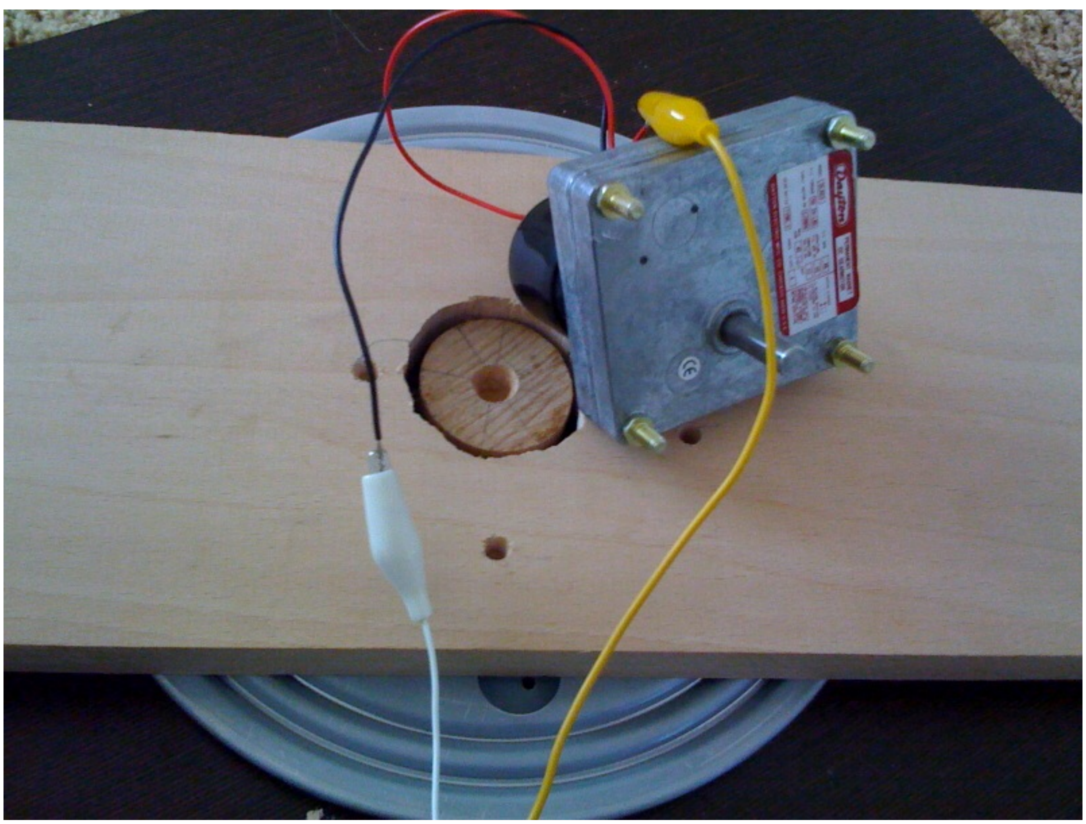

Figure 17: Connection between the motor and the solar panel mount.

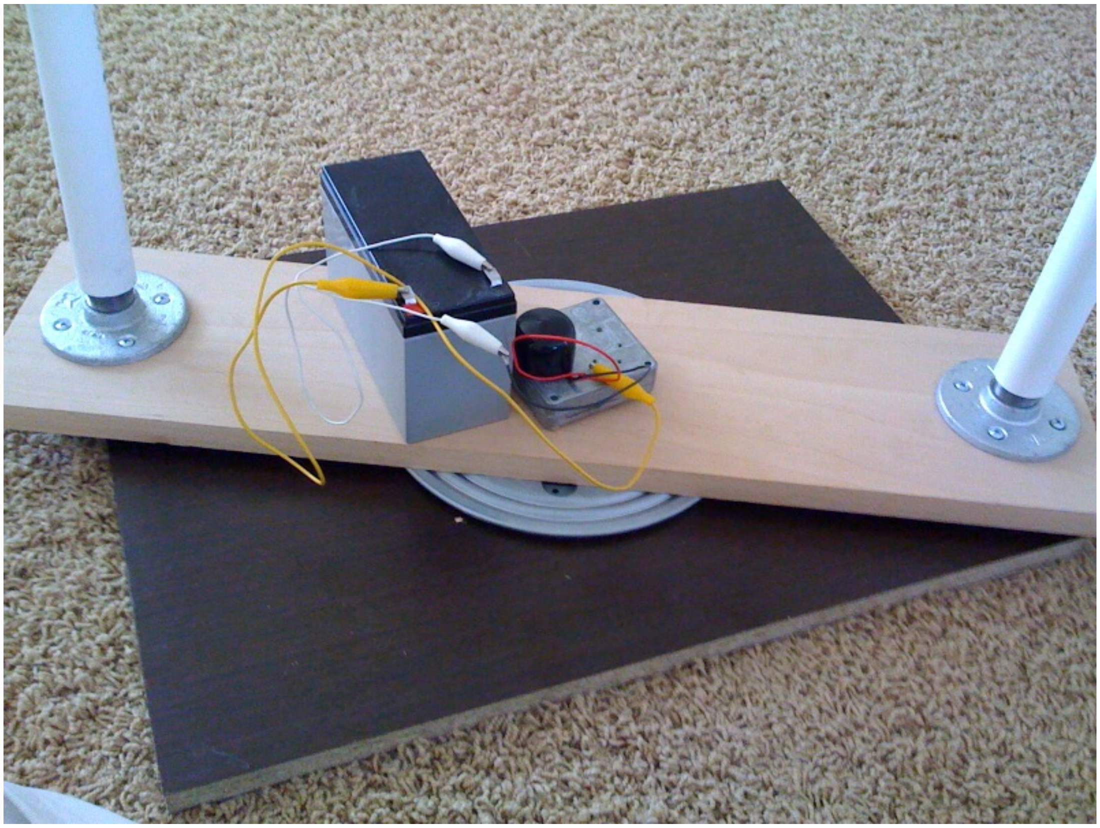

Figure 18: Motor powered directly from the battery, rotating the solar panels.

C. The Solar Panels, battery, and charger

The three 12V, 10 watt solar panels are connected in parallel to generate increased current for the charger. The charge controller, shown in Figure 19, provides an indication of the battery's state with a charging and charged LED indicators. A 12V lead acid battery rated at 7AH was used to store energy from the solar panels and provide power to the tracker.

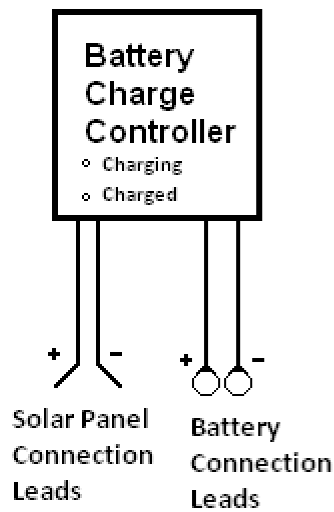

Figure 19: Battery charge controller

D. PCB Fabrication

The PCB was designed and created at a fabrication lab. The schematic in Figure 6 was designed in PCB Express and a photomask was created from it. Through a process called photoengraving, the photomask and chemicals were used to etch away the copper on a blank PCB. This leaves only the desired copper traces. Next, holes were manually drilled in the PCB where the components would be placed, this is indicated by Figure 20. Due to their similarity, PCBs were made for the main tracking circuit and the front detector.

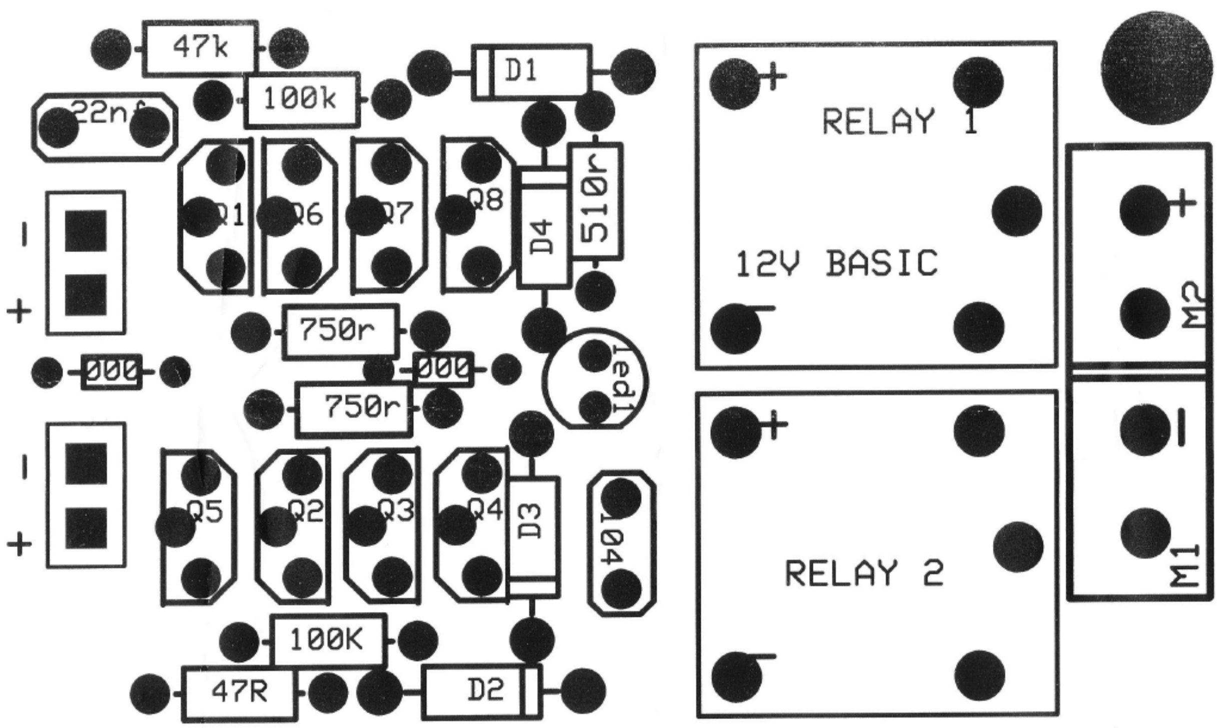

Figure 20: PCB layout of the Main Tracking Circuit

VII. Testing and Results

Initial testing will be done with simulations. Parts of the circuit will then be built and tested for correct operation. The sensor will need to give two signals for the motor to either turn clockwise or counter clockwise. The motor control should also be able to receive the signals and turn CW or CCW accordingly. Once completed, solar tracking will be tested by a moving light source (flashlight) and observing panel movement. The panel should move slowly by comparing the light intensities of each side. Finally, the tracker will be tested for accuracy. The tracker will be place in the sun and turned clock wise and counter clock wise to see if it will return to the original position when correcting itself.

A. Solar Panel Test Results

The output was tested in all three solar panels individually in bright sun, low sun, and a cloudy day. The panels were manually adjusted to get maximum output. Several measurements were taken and averaged. The results are tabulated in tables I, II, and III below. With the panels in parallel, the open circuit voltage was 21.1V and the short circuit current was 1.52A on a clear day shown in Table IV. These results will be compared in Table V, in which the panel position is adjusted by the solar tracker.

10 Watt solar panel specifications:

Peak Power 10.0 W
Maximum Power voltage 17.5 V
Maximum Power Current .571 A
Open Circuit Voltage 22.1 V
Short Circuit Current .617 A

Single panel testing results

Table I: Solar Panel Output in Bright sun

Panel	1	2	3
Open Circuit Voltage	21.8 V	21.8 V	21.6 V
Short Circuit Current	623 mA	610 mA	550 mA

Table II: Solar Panel Output in low sun

Panel	1	2	3
Open Circuit Voltage	18.2 V	18.1 V	17.9 V
Short Circuit Current	280 mA	290 mA	250 mA

*The current dropped off significantly as the light decreased

Table III: Solar Panel Output in Cloudy

Panel	1	2	3
Open Circuit Voltage	14.4 V	14.9 V	14.2 V
Short Circuit Current	150 mA	140 mA	111 mA

Next, multi-panel testing was performed and recorded in Table IV. The output was tested in all three solar panels in parallel in bright sun, low sun, and cloudy conditions. The voltage measurements were tested in the configuration shown in Figure 21. The current was tested by paralleling several 1/4 watt low value resistors illustrated in Figure 22. This was to prevent the resistors from burning out due to high currents during testing.

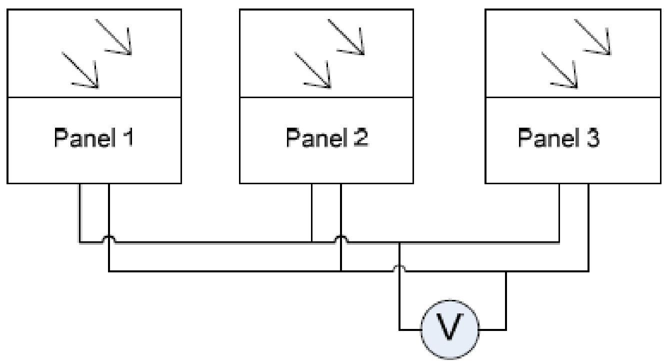

Figure 21: Open circuit voltage test for the panels in parallel

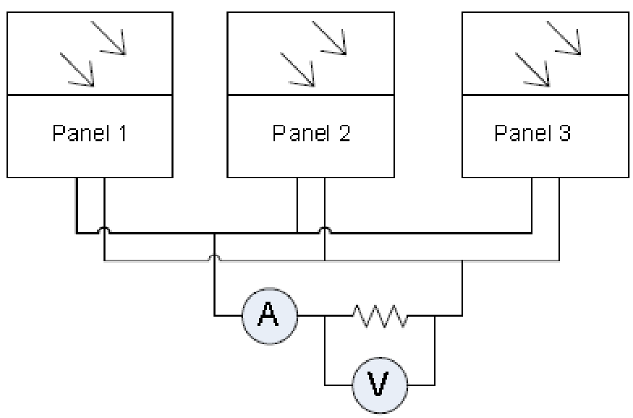

Figure 22: Current testing with a low value resistor

Table IV: Output Values for Manually Adjusted Solar Panels in Parallel

	Bright Sun	Low Sun	Cloudy
Open Circuit Voltage	22.4 V	18.1 V	15.3 V
Short Circuit Current	1.52 A	821 mA	420 mA

By paralleling the solar panels, the voltage remained roughly the same as expected. However, the current was somewhat lower (30mA) than the sum of three panels. This decrease is due to testing at slightly different times.

Table V: Output Values for Automatically Adjusted Solar Panels in Parallel

	Bright Sun	Low Sun	Cloudy
Open Circuit Voltage	22.3 V	20.1 V	14.42 V
Short Circuit Current	1.44 A	981 mA	371 mA

Finally, the output of the panels are measured while the tracker was operating and tabulated in Table V. The results are very close to the manually adjusted values. The tracker had problems operating in low light as seen in the values for cloudy conditions. This problem can be addressed by using photodiodes or LEDs that are sensitive to UV light. UV rays are able to pass through clouds much more easily than other spectrums of light. Overall, the automated tracking values were approximately the same as the manually adjusted values which were taken by fine tuning the panel position until a maximum output was reached.

B. Gear Motor Testing

There were limited specifications for the motor which were "low current 12V Gear motor". Current draw and RPM were tested with a simple load.

For current draw, a clamp was attached on the motor and the rotor was inserted into a hole drilled through the center of a lazy susan. A 25 pound weight was placed on top to approximate the weight of the solar panels and mount. With this set up, the current draw was approximately 200mA. The current was not constant and varied from 150mA to 220mA. This amount of current draw was within the range of the transistors chosen for this circuit.

The RPM was tested by averaging the time it for several full rotations on while operating on 12V and converting to RPM. This came out to approximately 1.2 RPM no load and about 0.9 RPM with the loaded set up above.

C. Sensor and Motor Control Problems:

The sensor section of the circuit worked as expected, producing +1.5V and -1.4V at the output of the sensor LED's. The first two transistors Q1 and Q2, see Figure 6, worked correctly after correcting the problem described below.

With the first design of the tracking circuit in Figure 5, the voltages were tested at each node but the results were too varied in the second half of the circuit (motor control). Every time the transistors were changed for identical ones, different voltage values would be measured at each node. All the transistors were then replaced in the motor section which resulted in only a working single rotation direction. All of the transistors were replaced again and neither direction was working. Some of the transistors would forward bias just by touching them. It was found that touching the top of the transistors would forward bias some of them. After this was discovered, more detailed testing on the transistors was done. In the original test, they all biased correctly when a base voltage was applied, but later a few of them would forward bias on very low voltages (80mV). A strange thing to note was that one of them (Q7) would turn on (forward bias) when a very small positive or negative voltage was applied to the base, but will remain off when no voltage was applied.

The problem in the circuit was found to be the poor quality of the transistors. Using the equipment at the fabrication lab, the transistors were tested and it was found that almost all of them were defective and did not meet the specifications on their datasheets. This and bread board connection problems was the reason the tracking circuit did not function properly in the

first setup. The Q8 transistor, which would frequently burn out, was due to Q7. Q7 caused a short on the right side of the circuit which would burn out Q8 when Q8 turned on.

To solve these problems, the circuit was rebuilt with 2N4401 PNP and 2N4403 NPN transistors. Using this configuration the circuit works correctly, see Figure 6 for the final tracking circuit. However, these are low current transistors which can only operate at up to 130mA. They would not be able to handle the higher current draw of the motor at approximately 200mA. This is opposed to the 2N2222 and the 2N2906 which are rated at 800mA. Two 12v relays were added to drive the motor instead directly driving the motor with the transistors. In this configuration, the transistors are triggering the relays.

D. Solar Tracking Testing

In the initial test, the sensor circuit and motor was used to track the sun for a full day. The sensor was mounted on a box and the motor would rotate the box to face the sun. The box would rotate a few degrees at varying time intervals. The setup rotated about 170^{o} for the full day. It was not able to track the sun the next day due to the sensors facing the opposite direction of the sunrise.

In the first version, using two large red 10mm LEDs for the main tracker, as seen in Figure 7, allowed the panels to find the sun the next day. However, it took the tracker about an hour after the next day sunrise to reposition itself correctly. This was corrected with the addition of a rear sensor. The tracker is now able to reposition itself correctly at sunrise. The front detector used a large 10 mm clear LED, also seen in Figure 7. This was too sensitive and caused the main tracker to be always on, which also resulted in the rear sensor to remain off. With the rear sensor off, the panels were not able to reset its position the next sunrise.

The tracking was further tested in terms of accuracy by having the main tracker find the sun from both directions. The solar panels were rotated further in the CW direction and allowed to return. The position was noted and the panels were rotated in the CCW and allowed to return. The difference of the two return positions were about 20° which demonstrates poor sensitivity and sun tracking.

Both problems described above were corrected by changing the size, sensitivity, and position of the sensors as per Figure 8. The front detector LED was changed to a 5mm red LED. This decreased its sensitivity and reduced its detection angle from 50° to 35°. By doing so the

rear sensor was able to turn on properly. The two main tracker LEDs were changed to 10 mm clear high sensitivity LEDs. The angle between the two were also decreased to 25° from the perpendicular of the solar panels. This greatly improved the accuracy. The same test of allowing the panels to return from the CW and CCW directions was repeated with this new configuration. The differenced was decreased to approximately 3° from 20°. This was a major improvement to the first version.

VIII. Conclusion

Renewable energy solutions are becoming increasingly popular. Photovoltaic or solar systems are one good example of this. In order to maximize power output from the solar panels, one needs to keep the panels aligned with the sun. This is a far more cost effective solution than purchasing additional solar panels when dealing with large panel arrays [3]. A fairly large solar panel tracker would cost several hundred dollars and will increase the energy produced by 30% to 50% depending on the season and location. The solar panels in the large arrays would cost in the thousands of dollars, so the addition of a solar tracker is very cost effective. Another benefit is the space saved rather than adding extra panels.

This project develops an automatic tracking system which will keep the solar panels aligned with the sun in order to maximize efficiency. The use of the PCB drastically reduced the size of circuitry in the project and made it more reliable as there were no more connection problems. This project can be converted to a dual axis tracker fairly easily. The components and circuitry are already present in the finished tracker. The rear sensor can be converted to a tracker for the second axis with some wiring changes. All that is needed is a second gear motor or linear actuator.

To conclude, this project turned out well and met the original requirements and functionality. Although there were many problems and more work on the mechanical side than originally expected, overall it was an enjoyable experience completing this project.

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A. Project Schedule

The project will be divided up into several parts and will be completed over two quarters (20 weeks). The major parts will be the design and construction of the sensing unit, the motor control, and testing. The project should be completed and tested by week 18. The following is a rough schedule, with some parts that will be done at the same time.

---------------------------- EE 464 -----------------------------------

Proposal - week 2 (1 wk)

Research – weeks 3 - 4 (2 wks)

- Research various designs of existing solar panel trackers
- Order parts (solar panel, components for sensor circuit, motor)

Requirements – week 4 (1 wks)

- Refine requirements and make any final changes before design stages

Design sensor and motor control circuit – weeks 5 - 7 (2 wks)

Build and test sensor circuit– weeks 8 - 10 (2 wks)

---------------------------- EE 464 -----------------------------------

Build and test – weeks 11 - 14 (3 wks)

Design and build polar mount – weeks 11 - 14 (3 wks)

Integration – week 15 (1 wks)

- Put all parts together

Testing/Trouble-shooting – weeks 16-18 (2 wks)

Draft of final report – week 18 (1 wks)

Final report – week 19 (1 wks)

Project completion - week 20

Table VI: Allotted Time and Actual Time Spent

	Allotted Time	Actual Time Spent
Proposal	1 week	**1 weeks**
Research	2 weeks	**2 weeks**
Requirements	1 week	**1 week**
Design	5 weeks	**4 weeks**
Build	5 weeks	**6 weeks**
Integration	1 week	**1 weeks**
Testing/Trouble shooting	3 weeks	**3 weeks**
Project Report	2 weeks	**2 week**
Total	**20 weeks**	**20 weeks**

B. Materials and cost

Table VII Parts and Materials Cost

Part Name	Quantity Required	Unit Cost	Total Cost
10 Watt Solar Panel	3	$18	$54
12 volt Gear Motor	1	$70	$70
Wood boards 24" X 18"	2	$12	$24
Lazy Susan swivel	1	$15	$15
package of various Transistors	1	$35	$35
Packaged Resistors	1	$10	$10
Packaged Capacitors	1	$10	$10
Packaged LEDs	1	$14	$14
Bread board	1	$18	$18
12V Relays	5	$3	$15
12V Lead acid battery	1	$12	$12
Charger Unit	1	$10	$10
PVC Pipes	1	$10	$10
Wire	1	$8	$8
Box of screws	1	$5	$5
Silicone sealant	1	$50	$50
Grand Total			**$360**