1. Introduction
   Objective:
   We aim to build a solar panel that follows the sun as it moves throughout the day in order to maximize the amount of energy converted. We would like to do this by joining the panel onto a mechanical mount. The mount will be moved by two motors that are controlled through a microcontroller. The microcontroller gets feedback for the current position of the panel, the current intensity of light from the sun, and the current state of charge for the battery. There will be a battery that is used to store the converted energy, as well as powering the movement of the panel.

   Background:
   Our client, Professor Karl Reinhardt, has proposed the problem to us. He would like our group, in coordination with another group, to develop a solar streetlight for his property in Minnesota. He would like the streetlight to be comparable in application to a traditional streetlight while remaining completely independent of the grid. Our project comes into play by allowing movement for the panel. This movement will allow the panel to follow the sun as it moves, increasing the stored capacity. Research has been done to verify the feasibility of this and it has shown that movement, in the long run, does increase the stored potential[1]. There are no comparable products to this one. That being said there are large scale sun tracking solar panels that can be integrated into homes and the biggest difference between our project and this product, other than size, is the ability for movement along two degrees of freedom. We believe that this difference is key for DIY use or for large construction projects because the installation time would be greatly reduced. To expand on the complete idea, it is very possible that this project could be used in the future to eliminate traditional streetlights. Progress is already being made to cut down on the cost from streetlights by introducing new high efficiency LED bulbs[2]. Our project could even be modified to introduce a hybrid that uses the solar panel and sun tracking to feed power directly to the grid.

   High-level requirements list:
   ● Using the Spherical coordinate system, the axis will have the positive y-axis directed south. This is because our panel will be mounted in the northern hemisphere, therefore the sun will always be south of directly overhead. The solar panel mount will rotate from 165 degrees to 15 degrees along the azimuthal angle to follow the sun as it moves from east to west through the day. It will also rotate from -65 degrees to -20 degrees along the polar angle to follow the sun as it moves north to south throughout the year.
Figure 1. Spherical coordinates \((r, \theta, \varphi)\) as used in physics: radial distance \(r\), polar angle \(\theta\), and azimuthal angle \(\varphi\).

Figure: Picture with physical angles
• The 4 photosensors will be oriented to track the sun both east to west and north to south. These photo sensors monitor the irradiance of the sun. Irradiance is the power received by a surface per unit area, typically measured in watts per square meter (W/m²). To track the sun east to west, two photosensors will be mounted horizontally at the top center of the mount facing each other about 3 centimeters apart. As the sun moves across the sky, these two sensors will read different values because one should receive more direct power than the other. Depending on which sensor reads a larger value we will adjust our mount to make sure both sensors are reading the same value. This location will be the location of the sun from east to west because the light is landing directly between the two sensors. A similar system will be implemented to track the sun from north to south. The only difference is that these two photosensors will be mounted vertically on the left side of the mount. This will allow us to track the sun from north to south and south to north throughout the year. These 4 sensors will also provide us with information to reset at the end of the day. The irradiance at night is 0 W/m² because there is no sun. So once our sensors drop down to 0 volts we will reset because the solar panel is no longer receiving power. The mount will then rotate to face east to start receiving sunlight at sunrise the next day.

• The panel will provide an average of 400Wh per day of charge. Depending on the scope, we can power our circuit safely with this much energy for three days of no charge and in the integrated system this should power the entire project for two full days without a charge. The battery should be 10Ah to power our project and about 60Ah for the whole project.

• Motors and encoders must give us 1 degree resolution on both axis. They are required to have a minimum torque of 6 Nm. The feedback from the motors must provide an accurate location of the solar panel of +/- 3 degrees.

2. **Design**

   **Block Diagram:**

   We require three units for operation of the Sun Tracking Solar Panel: a power unit, control unit, and a positioning unit in Fig 2.

   The power unit ensures that the system can power the control unit, positioning unit, and streetlight for two full days with an average voltage of twelve volts. It consists of a solar panel used for generation, a li-ion battery used for energy storage, and a li-ion charger used to protect the battery.
The control unit contains four photo sensors, a microcontroller, and two motor drivers. The photosensors will be oriented on the solar panel mounting to find the relative position of the sun on two axis. The microcontroller will process the information from the sensors and will send information to the positioning unit to adjust the panel accordingly. The motor drivers will control the speed and activity of the motors used in the positioning unit.

Lastly, the positioning unit takes the information from the control unit and moves two motors to adjust the physical position of the solar panel mount to point at the brightest point in the sky. The positioning unit also uses encoders to provide the microcontroller with feedback of the current position of the panel. This will provide the control unit with important information required to implement our tracking algorithm.

Figure 2. Block Diagram of data and power flow among components
Physical Design:

Figure: Picture with motor action and angle movement
The physical design will move along two axis. We plan to use one of our motors to turn a belt that will then turn the mount and panel about a polar degree of freedom. The other motor will turn a worm gear that will tilt the panel about the azimuth angle. At the bottom of the mount all of the equipment will be stored except for the solar sensors and the motor turning the worm gear.
**Block Design:**

**Solar Panel:**

We plan to use a Renogy 100Watt 12 Volt Monocrystalline Solar panel [3]. This solar panel will provide all of the power for our project, Sun Tracking Solar Panel, as well as the integrated project, Solar Streetlight. In our project the solar panel will connect directly a Li-Ion charger which will control how and when the power from the panel gets passed along to charge the battery.

Our sponsor asked for input on this panel and we decided that it would be a good choice because it exceeded our technical recommendations, it has received an average of 5 stars from over a hundred reviews, the company provides free shipping within the continental US at a 4-7 day processing and delivery time, it provides up to 25 years of warranty, and is designed to withstand the weather conditions we are expecting to see in Minnesota (waterproof junction box, waterproof connectors, withstands 2400 Pa from high winds, 5400 Pa from snow loads, corrosion resistant aluminum frame, and low iron tempered glass for increased impact resistance).

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Verifications</th>
</tr>
</thead>
</table>
| Voltage: 10-20V    | ● Connect panel to Multimeter  
                     ● Make room as dark as possible  
                     ● Set-up a photo sensor to detect luminosity of the room  
                     ● Record the voltage and current via the multimeter and the luminosity detected from the photosensor  
                     ● Increase the light in the room  
                     ● Repeat the record and increase step  
                     ● Continue until room is as bright as it can be  
                     ● If possible, repeat this process directly with the sun. |
| Current: 5-5.5A    | We will deliver a plot for luminosity versus the voltage.  
                     We will deliver a plot for luminosity versus the current.  
                     We will deliver an IV curve. |
| Power: 80-100W     | Using the results from the multimeter testing we can detect the output power at various light intensities and currents.  
                     We will deliver a plot for luminosity versus the output power. |
| Temp: 0-45 deg C   | We will get this from the specifications of the panel. (No verifying) |
| Waterproof        | We will get this from the specifications of the panel. (No verifying) |
3. Cost and Schedule
   Cost Analysis:
   i. LABOR:
      Based on the average salary for an Electrical Engineer ($68,000 USD/year) and Computer Engineer ($82,741 USD/year)[4] from the University of Illinois at Urbana-Champaign [cite the source] the total cost for labor for our group is $18313.50 USD, based off of the total times given on the schedule.
      When we spoke to the machine shop they said that there labor costs would be $1000.00 USD for the recycled mounting unit, installation of new sensors, weatherproofing, and modifications to the mounting unit.

   ii. PARTS:
### Description | Manufacturer | Part Number | Cost | Quantity | Total  | Covering |
--- | --- | --- | --- | --- | --- | --- |
Solar Panel | Renogy | RNG-100D | $129.99 | 1 | $129.99 | Leo |
Li-Ion Battery (10Ah) | DC House | DCHOUSE09 | $60.00 | 1 | $60.00 | Leo |
Sensors | Adafruit | PDV-P8001 | $0.95 | 4 | $3.80 | Soumitri |
13V - Voltage Regulator | Linear Technology | LT1084CT-5#P | $8.04 | 2 | $16.08 | Bryce |
Microcontroller | Atmel | AT-MEGA 328P | $2.01 | 2 | $4.02 | Soumitri |
12V - Voltage Regulator | Linear Technology | LT1529CT-5#0 | $6.53 | 2 | $13.06 | Bryce |

| Tentative Total | $226.95 |

iii. **GRAND TOTAL = LABOR + PARTS**

The grand total cost is expected to be $20313.50 USD.

### Schedule:

<table>
<thead>
<tr>
<th>Week of</th>
<th>Overall Task/Sequence</th>
<th>Individual</th>
<th>Task</th>
<th>Hours</th>
<th>Notes</th>
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</thead>
<tbody>
<tr>
<td>10/9/17</td>
<td>Design Review. Get feedback and make modifications. Start preliminary testing of solar sensing configurations.</td>
<td>All</td>
<td>Feedback and modification from design review and design document. Soumitri - testing configurations for photosensors</td>
<td>F&amp;M- Varies. 4 hours max Tests - 2 hours Total- 6 hours</td>
<td>Purchase the photo sensors, microcontroller, motor drivers, motor/encoders, solar panel, Li-lon components in the week of 10/2/17</td>
</tr>
<tr>
<td>10/16/17</td>
<td>Li-Ion charger, Under voltage protection, Microcontroller</td>
<td>Leo</td>
<td>Start building the Li-Ion charger, testing to make sure overcharging protection works.</td>
<td>Li-Ion Charger - 5 hours</td>
<td>Meet once or twice a week to bring each other up to speed with our progress, clarify any questions, ask for help, present on results. Meet with each other when we need to discuss and test interconnection modules.</td>
</tr>
<tr>
<td>Date</td>
<td>Group</td>
<td>Task</td>
<td>Time</td>
<td>Notes</td>
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<tr>
<td>10/23/17</td>
<td>Bryce, Leo, Soumitri</td>
<td>Construct and test under voltage protection IC. Verify that it cuts off power to the motors when the battery voltage drops below the threshold voltage.</td>
<td>Under Voltage protection - 5 hours</td>
<td>Meet once or twice a week to bring each other up to speed with our progress, clarify any questions, ask for help, present on results. Meet with each other when we need to discuss and test interconnection modules.</td>
<td></td>
</tr>
<tr>
<td>10/23/17</td>
<td>Soumitri</td>
<td>Testing the solar panel will include getting a PIV characteristics, integrating to the the charger.</td>
<td>Solar Panel - 5 hours</td>
<td>Meet once or twice a week to bring each other up to speed with our progress, clarify any questions, ask for help, present on results. Meet with each other when we need to discuss and test interconnection modules.</td>
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<tr>
<td>10/23/17</td>
<td>Soumitri</td>
<td>Work on testing configs for motor driver.</td>
<td>Motor driver - 7 hours</td>
<td>Meet once or twice a week to bring each other up to speed with our progress, clarify any questions, ask for help, present on results. Meet with each other when we need to discuss and test interconnection modules.</td>
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<tr>
<td>10/30/17</td>
<td>Bryce</td>
<td>Verify that the output voltage is within the range for the microcontroller and motor driver. Make sure there is no noise on the output voltage by adding filtering capacitors.</td>
<td>Voltage Regulators - 2 hours</td>
<td>Meet once or twice a week to bring each other up to speed with our progress, clarify any questions, ask for help, present on results. Meet with each other when we need to discuss and test interconnection modules.</td>
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<tr>
<td>10/30/17</td>
<td>Leo</td>
<td>Testing the output of the battery, connecting it to the charger and making sure that the two can interact together.</td>
<td>Li-Ion Battery - 5 hours</td>
<td>Meet once or twice a week to bring each other up to speed with our progress, clarify any questions, ask for help, present on results. Meet with each other when we need to discuss and test interconnection modules.</td>
<td></td>
</tr>
<tr>
<td>10/30/17</td>
<td>Soumitri</td>
<td>Additional time for the microcontroller design and testing or to integrate the circuit with the parts that Leo and Bryce are doing.</td>
<td>Mic.Controller extra time - 3 hours</td>
<td>Meet once or twice a week to bring each other up to speed with our progress, clarify any questions, ask for help, present on results. Meet with each other when we need to discuss and test interconnection modules.</td>
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</tr>
<tr>
<td>10/30/17</td>
<td>Bryce</td>
<td>Test the feedback outputs and generate code to convert outputs to the physical angles</td>
<td>Motors/Encoders - 3 hours</td>
<td>Meet once or twice a week to bring each other up to speed with our progress, clarify any questions, ask for help, present on results. Meet with each other when we need to discuss and test interconnection modules.</td>
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</tr>
<tr>
<td>Date</td>
<td>Task Description</td>
<td>Participants</td>
<td>Activity Details</td>
<td>Notes</td>
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<tr>
<td>11/6/17</td>
<td>Finalize any needed PCB's, Start building the final product to the mechanical build, test interconnecting components when applicable</td>
<td>All</td>
<td>All-Start attaching to the build, testing larger interconnecting modules, finalize PCB design. We will use a breadboard in place of the PCB during testing.</td>
<td>Bryce has three midterms, Soumitri has a couple</td>
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</tr>
<tr>
<td>11/13</td>
<td>Start Final Report</td>
<td>All</td>
<td>Individually add our work into the document.</td>
<td>Submit to Yuchen for initial review</td>
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<tr>
<td>11/20/17</td>
<td>Thanksgiving Break, Finish rough draft of Final report</td>
<td>All</td>
<td>Individually finish report rough draft, review, make modifications Meetup on Sunday to prepare for mock demo</td>
<td>Submit to Yuchen for secondary review</td>
<td></td>
</tr>
<tr>
<td>11/27/17</td>
<td>Mock Demo Week, complete second review of the final report, soldering, prepare for demo</td>
<td>All</td>
<td>Continue work towards the second draft of the final report, prepare for final demonstration, solder everything onto the PCB</td>
<td>Mock Demo is on the first day we get back.</td>
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<tr>
<td>12/4/17</td>
<td>Demonstration, Prepare for presentation, work on final paper</td>
<td>All</td>
<td>Prepare for Demo by testing the product operation, integrating all components, recording operation, prepare for presentation, work on final paper.</td>
<td>Prepare Demo-3 hours</td>
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<td>Prepare for Presentation - 4 hours</td>
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<td>Final paper - 3 hours</td>
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<td>Total - 30 hours</td>
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<tr>
<td>12/11/17</td>
<td>Presentation, Final Paper due, Lab Notebook Due</td>
<td>All</td>
<td>Practice for the presentation and ensure that the final product is working. Ask for final review from Yuchen of the</td>
<td>Presentation - 5 hours</td>
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<td>Final Paper - 4 hours</td>
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<td>Total - 27 hours</td>
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4. Discussion of Ethics and Safety:

Originaly we discussed three major concerns in regards to ethics and safety. The concerns relate to communication with the other teams as well as with the client, operating and use of the lithium-ion battery, and acts of nature. Since then we have discussed motor protection to ensure they are only used when they can be.

In regards with the concerns about communication, we want to make sure that the other teams that we will be working with will be made aware of what we are doing and the safety concerns that we have with our part of the larger product. On top of that we need to make sure that the client is aware of the concerns that we have and the limitations that we have proposed. One of this concerns that we discussed with a couple of the other teams and the client is the ideal operating temperature of the batteries, chips, and motors. The original problem statement includes the operation of the product outdoors in Minnesota and the conditions are not ideal for the operation of most electrical components because of climate. Specifically, the batteries, microcontroller, sensors, and additional chips must not be used in sub freezing temperatures. We made sure to acknowledge this concern with the client and spread the word to other teams.

The discussion of the battery is probably the largest cause for concern for our project. The reason is that the batteries have the ability to catch fire and the potential to cause more serious damage. This problem occurs when the charging of the batteries is not managed properly, specifically overcharging. This is a concern that we have discussed and we believe that the issue is not of great concern so long as we manage the charge properly. Another issue is the operating range of the batteries[5]. Since they are planned to be used outside we need to make sure that we account for nominal temperature range of the location as well as the operating range. This information will be made aware to the client.

Acts of nature are unforeseen natural challenges that we can not predict. In the proposal we mention birds, squirrels, or other animals interacting and damaging the product. Other situations include weather conditions like snow, rain, or hail, as well as dust, dirt, and grime. We plan to mitigate the potential for damage as much as possible but these are still uncontrollable scenarios.

A concern that we have only recently thought about was the motors. The motors are used to turn the panel but they also need protection to ensure that they are not strained or damaged. Unnecessary strain can damage the motors and faulty
motor operation could cause sparking. This is mitigated because of feedback directly for the motors but the concern for safety is still present.

From the IEEE code of ethics[6] we plan to follow item 7 by communicating with the client and other teams, items 1 and 10 for safety concerns, and item 2 for concerns from client.

We plan to protect from acts of nature by consolidating most of our components into the mount of the panel. The mount will be located at the base of the product for stability and will include the polar angle controlling motor, the PCB board that contains most chip level equipment, and the li-ion charger and batteries. This procedure will allow us to protect from acts of nature by enclosing the components and weatherproofing the storage compartment. Our concerns for the battery are mitigated by including a charging block that protects from overcharging. The temperature issue is not as damaging of a concern, and if time allows we want to include a thermal sensor to discontinue use in extreme temperatures.

We plan to have multiple levels of protection protocol for the motors. We will have a voltage regulator to cut off power if it is not enough to power the motors. This concern should eliminate that potential strain. The motors will also provide feedback on their position through an encoder. We plan to use that encoder to ensure that the motors are not strained from torque restrictions.

5. Citations:


