Novel Solar Tracking Charge Device

Course:  ECE 4890 Senior Seminar

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Overview

The main focus of this project is to develop a sun tracking system and physical mount for a flat panel photovoltaic collector, commonly known as a solar panel. The solar panel will be used to charge a storage battery as well as provide the necessary power for the sun tracking components. The total system will be completely autonomous and could be put into service on any hard surface on earth.

Solar power is made by collecting the sun’s energy rays and converting them to electrical current. This conversion is done by photovoltaic crystals found in today’s solar panels [1, 2]. Modern solar panels have efficiency ranges from 15 to 20%, with some advanced silicon designs approaching 40% efficiency. Since the efficiency ratings are well below 50%, it is extremely important to have the solar panel perform at its maximum output during times of sunlight collection. The two main ways to facilitate this maximum output are to enhance the sun’s visible light collection process with the addition of solar concentrators or to keep the solar panel at the optimum elevation angle and exactly perpendicular to the sun during collection times [3]. The latter approach is the main emphasis of this design project.

Statement of Problem

Most solar panels are placed on fixed mounts that face the southern sky, usually set to an elevation angle that is given by the pitch of a roof or one based on an average optimum angle for the geographical location. This common method reduces the amount of sunlight energy conversion and increases the number of solar panels needed to fulfill the power requirements.

Placing a solar panel on a mount that will track the sun with high accuracy, as well as maintaining the optimum angle of elevation throughout the calendar year will provide the maximum electrical output of the panel [4]. On a small scale, this will allow for a smaller panel to be used, which will reduce the equipment costs to charge the storage battery. On a large scale, namely utility replacement grid-tied systems, this system will reduce the number of panels needed. This decrease in required devices will reduce costs as well as square footage needed to mount the panels.

The common type of solar panel sun tracking system uses photo-resistive sensors as the main elements to keep the panel aligned with the sun [5, 6]. This type of tracking system is susceptible to changes in light intensity due to environmental factors. These factors include: clouds, trees, shadows caused by fixed objects, snow and dirt collecting on the sensors, as well as insects crawling on them. The changes in light cause the tracker to reposition the panel when not necessary or most commonly position the panel to an incorrect azimuth setting. This will reduce the output of the panel and defray the added costs of a sun tracking mount versus a fixed mount.

This project will develop a sun tracking system that will offer very high accuracy while eliminating the negative effects seen by the photo-resistive sensor designs.
Operational Description

The design will use GPS data to determine the latitude, longitude, and orientation of the solar panel. This data will be analyzed to determine the position of the sun in the sky, while azimuth/elevation motors will be configured to position the panel to point at the sun. These concepts are depicted in

**Figure 1 - Proposed Project Illustrational Overview**

**Figure 2 - Top Level Block Diagram**
Figures 1 and 2. Figure 1 illustrates the components involved in the complete project. It can be seen that the microcontroller is the central control component, as it receives input from the GPS receiver and magnetometer sensor. The microcontroller analyzes the input data to output information to the electro-mechanical devices, which in turn move the solar panel. Figure 2 shows a block diagram representing the data flow of the design.

This design can be broken into 6 sub-systems. The electrical systems will be monitored and controlled by a microcontroller. These sub-systems will be designed independently and then integrated to create the final project.

1. **Global Positioning System Data Acquisition**

![Diagram of GPS Data Acquisition Subsystem]

The proposed design will incorporate a microcontroller based system that will receive Global Positioning System (GPS) data to obtain current geographical location, as seen in Figure 3. The received data will include other factors that will aid in obtaining the optimal position of the solar panel. The critical data obtained from the GPS receiver will be the latitude, longitude, date and time.
2. Optimal Angle Calculation Design

There are two angles of operation that need to be analyzed and calculated to achieve optimal performance of the solar panel. The first is the elevation angle, which is the angle of the solar panel relative to horizontal. There are various ways of determining the optimal elevation angle of the solar panel. The first is to design a look up table with pre-calculated values depending on the latitude, longitude, and date. This table could be implemented in a non-volatile memory device, and accessed by the microcontroller to determine the correct elevation angle.

Another approach would be to develop a microprocessor based mathematical algorithm that will instantaneously calculate the optimal elevation angle based on the data received from the GPS receiver. Figure 4 depicts a generic outline of the input data, and the microcontroller determining the optimal angles. All possible options will be considered for determining optimal angles, and a decision will be made later to determine the most effective way of handling this angle derivation.

The second angle to consider is the azimuth angle, which is the angle of the solar panel relative to vertical. This determines how the solar panel will sweep horizontally throughout the day to remain totally perpendicular to the sun. Deriving this angle will be likely be determined by finding an initial reference angle as the sun is rising, and incrementally sweeping the solar panel throughout the day.

Again, there are numerous ways to handle determining the optimal azimuth angle, and all options will be considered before deciding on a final process.
3. **Electro-Mechanical Device Integration and Control**

![Figure 5 - Electro-Mechanical Integration Block Diagram](image)

Figure 5 is a continuation of Figure 4, depicting the addition of the implementation of some type of motor or servo control algorithm internal to the microcontroller.

The desired elevation and azimuth angles will be analyzed by the microcontroller, which will control the aforementioned electro-mechanical devices, such as stepper motors or servos. These devices will be attached to the physical mounting structure of the solar panel, and will mechanically move the solar panel to the desired position.

4. **Optimal Position Verification**

![Figure 6 - Position Verification Block Diagram](image)

The position of the solar panel must be verified in some way to determine that the design is working properly. Therefore, a sensor such as a magnetometer will be integrated into the design to compare the actual position of the panel to the desired position, as shown in Figure 6. This will not only act as
feedback to verify the accuracy, but will allow the actual angle to be fine-tuned to obtain maximum efficiency and performance.

5. **On-Board Power Supply Control System**

![](image)

The project will be a stand-alone design, with the power supply being an on-board rechargeable battery, which will eliminate any need for external power. The solar panel will charge the supply battery through a battery control module, as seen in Figure 7. The on-board battery will only consume a minimal amount of the power produced. The result will be a fully functional solar panel, producing maximum efficiency while secondarily powering its own controlling systems.

6. **Mechanical Platform Design**

A mechanical platform must be designed that will support the project design. The platform must include a mounting system that will provide the support for the solar panel. The mount must incorporate rotational aspects, since it will have to pivot on two axes. The electro-mechanical devices must be incorporated onto the platform, with physical components that will attach the solar panel mount to the electro-mechanical devices. The microcontroller, GPS receiver, data table memory device, breadboard/circuit board, and feedback sensors must also be housed on this platform.

To summarize, there are numerous independent design aspects involved in the overall project. First, the solar panel must provide minimal power to maintain the on-board power supply. Second, the integration of a GPS receiver must be integrated to obtain data regarding the geographical location of the solar panel. Next, this information must reference a data table that will produce optimal elevation and azimuth angles corresponding to the location. Following the table referencing, electro-mechanical
devices must physically move the solar panel to the desired position. The actual position of the solar panel must be compared to the desired position using magnetometer sensors, which will verify the accuracy of the design. An on-board battery must be charged by the solar panel to provide external power independence, and finally the physical platform and mounting devices must be constructed to contain the entire design.

Requirements and Specifications

Requirements

The requirements for this project are as follows:

1. Shall track the sun throughout the entire daylight period for every calendar day
2. Shall employ a flat panel photovoltaic collector to power a commercially available charge controller and rechargeable storage battery
3. Solution must be microcontroller based running compact algorithms
4. Solution must power all necessary system electronics from photovoltaic collector and storage battery
5. The final design must position the panel based on calculated position of the sun, making the system impervious to changes in ambient light or other shading obstructions
6. Must have “accelerated day” demo mode

Specifications

The specifications for this project are as follows:

1. Shall maintain < 5° absolute error in azimuth angle with the sun throughout the day
2. Shall maintain < 5° absolute error in elevation angle based on geographical location
3. Must have sufficient battery storage to run system for a minimum of 36 hours without sunlight
4. Must have rotational freedom of 180 degrees on the horizontal axis and 90 degrees on the vertical axis

Design Deliverables

The primary deliverable for this project will be a fully functioning, autonomous sun-tracking solar panel. As previously stated, when the sun is at the proper elevation angle, and completely perpendicular with the sun’s rays, it will produce the maximum amount of power possible.

Each sub-system of the project must be designed and verified incrementally. The microcontroller must properly interface with the GPS receiver to receive the critical information. The optimal elevation and azimuth angles must be determined, and the alteration of the solar panel’s position must be implemented and verified. The verification for this includes the implementation of sensors, which will provide data back to the microcontroller to determine what the actual azimuth and elevation angles are.
The solar panel must charge an on-board battery which will provide all of the power for the control system. Lastly, the physical platform must be constructed to support the entire design, with provisions for axial rotation. The platform shall be lightweight, aesthetically appealing, and weather-resistant.

**Preliminary System Test Plan**

The test plan for this project will be to test each sub-system individually. Only after each sub-system is functioning as desired will all of the components become combined to create the overall design. The preliminary test plans for each sub-system are as follows:

1. **GPS Implementation Test Plan**

   Testing the data received from the GPS receiver will be a predominantly visual verification. The microcontroller will have to initiate communication with the GPS receiver, and then receive and possibly store the data. This received data will be compared to the actual data (latitude, longitude, time, date, etc.).

2. **Optimal Angle Calculation Test Plan**

   Simulating numerous different random locations, dates and times will verify that the correct azimuth and elevation angles are obtained. These angles will be compared to a known good reference table. This will likely be implemented using simulation software like MATLAB.

3. **Electro-Mechanical Integration Test Plan**

   The test plan for the electro-mechanical devices will be to input numerous different desired elevation angles and azimuth angles, and tracking the precision of the movement. It is imperative that the electro-mechanical devices will move the solar panel with fine precision, since a minimum of 1 degree of accuracy is required.

4. **Feedback Sensor Test Plan**

   The feedback from the sensors will be compared to measured values to determine their accuracy.

5. **On-Board Battery Control System Test Plan**

   This sub-system will likely be implemented using off-the-shelf components, since it is not a primary design aspect of this project. General voltage and current measurements will be obtained to verify the performance of the charging system.

6. **Mechanical Platform Test Plan**

   The mechanical platform must be sturdy and allow for rotation on both the horizontal and vertical planes. Testing this will include verifying the rotational capabilities of the design. It is difficult to specify a thorough test plan for the physical platform without components mounted to it, so the majority of the quality of its functionality will be tested during the complete project verification.
## 7. Complete System Test Plan

After all of the individual sub-systems are performing as desired, they will be combined to implement the final project design. The test plan for this includes verifying that the requirements of the project have been met. This test plan can therefore be divided into various steps which are stated as follows

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Test Plan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shall track the sun throughout the entire daylight period for every calendar day</td>
<td>Due to time constraints, this cannot be fully verified for every calendar day in a year. Therefore, it will be tested every day that the device is fully functional by performing numerous checks on the solar panel's location throughout the day.</td>
</tr>
<tr>
<td>Shall maintain $&lt; 5^\circ$ absolute error in elevation angle based on geographical location</td>
<td>Measurements will be taken throughout the day to verify the actual azimuth angle of the solar panel. These measurements will be compared to the astronomical information obtained.</td>
</tr>
<tr>
<td>Shall be within 5 degrees of the optimal elevation angle based on geographical location</td>
<td>The test plan for this is similar to verifying the azimuth angle, whereas measurements will be taken and compared to expected results.</td>
</tr>
<tr>
<td>Must have sufficient battery storage to run system for a minimum of 36 hours without sunlight</td>
<td>The completed system will be run for intervals exceeding 36 hours without charging the battery to verify performance.</td>
</tr>
<tr>
<td>Must have rotational freedom of 180 degrees on the horizontal axis and 90 degrees on the vertical axis</td>
<td>The mechanical rotation will be physically verified before and after complete system integration.</td>
</tr>
<tr>
<td>The final design must position the panel based on calculated position of the sun, making the system impervious to changes in ambient light or other shading obstructions</td>
<td>The output power of the solar panel will be measured incrementally throughout the day to check its performance. External factors will be simulated to verify that the autonomous tracking features are not affected.</td>
</tr>
</tbody>
</table>
Reference List


Revision History

<table>
<thead>
<tr>
<th>Revision</th>
<th>Date</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>v1.0</td>
<td>4/16/2010</td>
<td>Initial Draft</td>
</tr>
<tr>
<td>v1.1</td>
<td>5/6/2010</td>
<td>Updated based on reviews of pre-proposal presentation</td>
</tr>
</tbody>
</table>