EXPERIMENTAL STUDY ON THE OPTIMUM HARVESTING OF SUNLIGHT FOR AN EFFICIENT SOLAR ENERGY SYSTEM

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Abstract

Renewable energy plays an important role in the support and growth of the world economy, especially in periods of fluctuating prices of fossil fuels. Among the renewable energy sources, solar energy provides specific advantages in space utilization, versatility, relatively-low maintenance, and quick payback. The awareness of, and exposure to, solar energy projects on the part of engineering technology students is vital for the development of a highly-skilled workforce in this rapidly-growing field. This paper presents the design and development, to be completed by an engineering technology student, of an efficient solar energy system using an automated solar tracker for the optimum harvesting of sunlight. This project also exemplifies the integration of various aspects of the engineering technology curriculum, such as automation, product and process design, design for manufacturability, and continuous improvement, with the senior design project.

Introduction

A senior design project is a vital part of a four-year undergraduate engineering technology program. The students majoring in this program are required to complete a two-semester long (4 credit hour) senior design project. The students are expected to demonstrate the application of product and process design principles with their projects. One of the engineering technology students, focusing on manufacturing, chose a senior design project in the area of solar energy. The objective of the project is to design and fabricate a solar energy harvesting system with an automated tracker for the optimum harvesting of sunlight. The student was able to demonstrate a working system and its potential improvements.

The solar tracker is used to maximize the absorption of solar power by adjusting the panel automatically to be perpendicular to the sun's rays. This is done by using photo-sensors to measure the radiance of the sun and provide a feedback signal on the current position of the panel. The position of the solar panel is automatically aligned to the direction of the sun's rays by calculating both the seasonal movement and current position of the sun. The panel orientation is processed by the use of two linear actuators; the first one controls the azimuth (season) adjustment and the second one the zenith (day) adjustment.

The solar tracker system is divided into two components: the hardware and the control. The base of the hardware component is designed and fabricated to mount the solar panel and the microcontroller. The control programming was developed using the C++ language. The system is designed to be robust and lightweight for enhanced durability and mobility.

Background

In order for the fixed solar collector to collect maximum solar energy, the panel surface must be oriented toward the equator and optimally inclined to face the perpendicular rays of the sun at the local settings [1-6]. Another potential method, proposed in the literature to increase the flat plate solar system performance, is to integrate the tracker systems with the solar panels. The use of a tracking system enables the flat panel to constantly track the sun, hence collecting solar irradiance during the entire day. The benefits of using a sun-tracking system in solar energy conversion applications have been extensively researched and reported [7-16]. The main purpose of a solar tracker is to minimize the angle of incidence between the incoming light and a photovoltaic panel. This increases the amount of energy produced compared to a fixed-angle panel. Today, only about 20 percent of commercial solar trackers continue to use fixed-angle trackers.

Scientific research comparing the efficiency of fixed vs. tracked panels has shown that the tracked panel annually outperforms the fixed one. Indeed, the fixed array maintains the maximum accumulation of power—at noon—for only a short time (Figure 1); whereas the tracked array is maximized every few hours. Depending on the location and the solar resource, it was proven that 29 to 42% more solar energy can be collected with the tracked system[10-16].

Trackers with single-axis control can track the sun in either horizontal (azimuth) or vertical (altitude) directions. Some of the more effective solar panel trackers reported in the literature are capable of tracking the sun in both directions (along dual axes) [17-19]. These systems are shown in Figures 1 & 2.

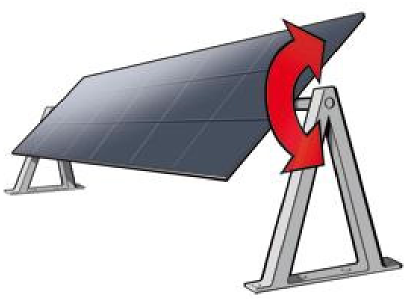

Figure 1. Single-axis tracking

Figure 2. Double-axis tracking

The goal of this paper is to discuss the results of the senior design project covering the design aspects of a one-axis (azimuth) solar panel tracking system and the subsequent improvements to satisfy the requirements for this senior design project.

Design Process

Morphology of design proposed by Morris Asimov [20] was used in the engineering design process to achieve the desired outcome for this project. The following sections present the project's phases of design process: conceptual design, embodiment design, and detail.

Design objectives and constraints of the project agreed upon by the student and faculty advisor are as follows:

Design Objectives: Design a prototype that will use a tracking system with a solar panel to track the sun for optimum harvesting of sunlight. The solar tracker panel will adjust itself automatically to face the changing direction of the sun.

Design constraints:

- The device should be sturdy and lightweight as possible for increased durability and mobility.
- The device should be adjusted for different solar panels available.
- It is expected that the finished product will include three units: the solar panel, base with all actuators and sensors, and the control unit.
- The device should be easy to use and set up.
- The actuation unit should provide enough push force to easily move the solar panel.
- The actuation mechanism should be adjustable/compatible to fit other solar panels.

Multiple Constraints

- Environmental: The actuator should operate in both wet and dry environments at temperatures between 0 ^{0} C and 55 ^{0} C.
- Environmental: The control unit should operate in a dry environment at temperatures between 15 ^{0} C and 40 ^{0} C.
- Economics: Budget for prototype is $300.
- Time: Two semesters.

Conceptual Design

Conceptual design is the process by which the design is initiated, carried to the point of creating a number of possible solutions, and narrowed down to a single best concept [21]. Tracker movement will be determined by the differential output power of two photocells placed on a platform and separated by a vertical wall. The tracker device is attached to the flat solar panel in the same plane. The orientation of the tracker with respect to the position of the sun causes a shadow over one of the photo sensors. As a result, an electrical output difference is detected, causing the tracker to move until the light is on both sensors as shown in Figure 3.

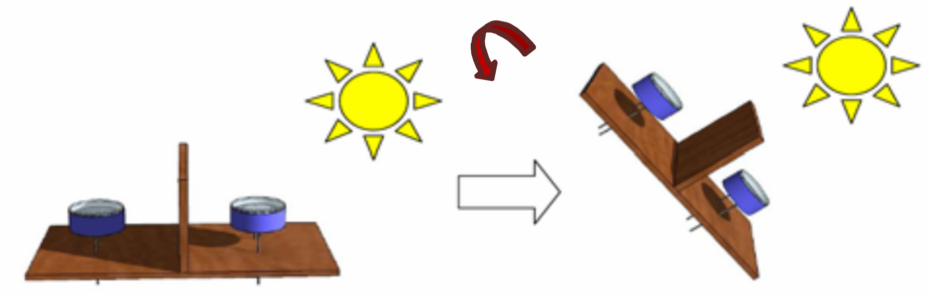

Figure 3. Sensor response when a shadow falls

The conceptual design of the solar tracker is shown in Figure 4.

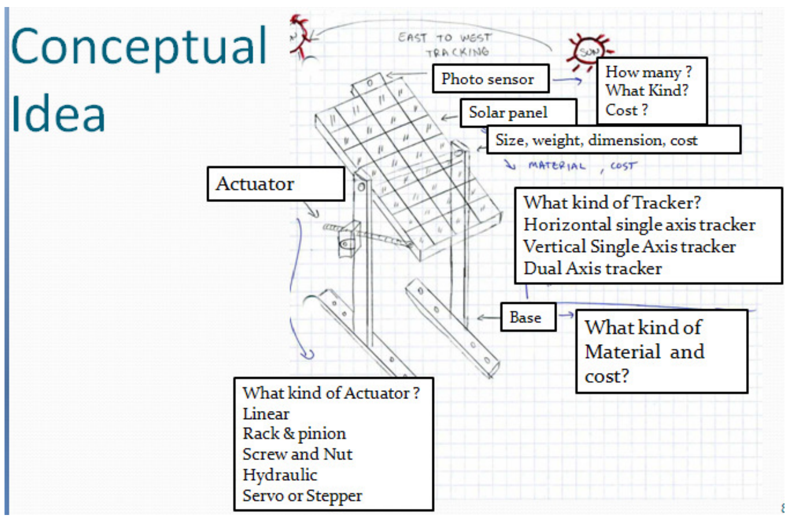

Figure 4. Conceptual Design

The flow chart shown in Figure 5 provides the sequence of control signals required for the operation of the solar tracker. The chart shows how the photocell will detect sunlight and convert it into an electrical signal that triggers the input module. The output signal is sent either in DC or AC and cause the actuator motor to move.

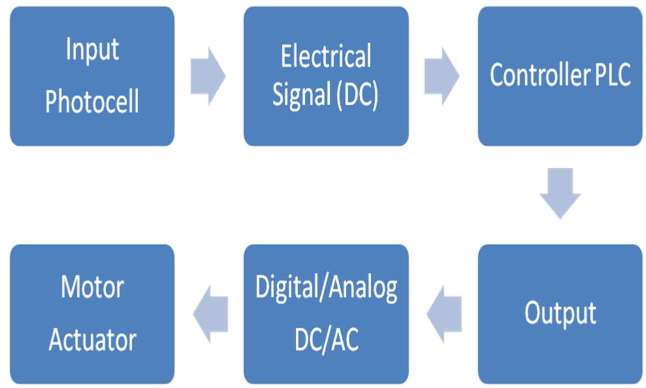

Figure 5. Sequence of signal flow for tracker control

Embodiment Design

In this stage of design, all of the main functions that must be performed by the solar tracker are incorporated. The embodiment design of the solar tracker is shown in Figure 6.

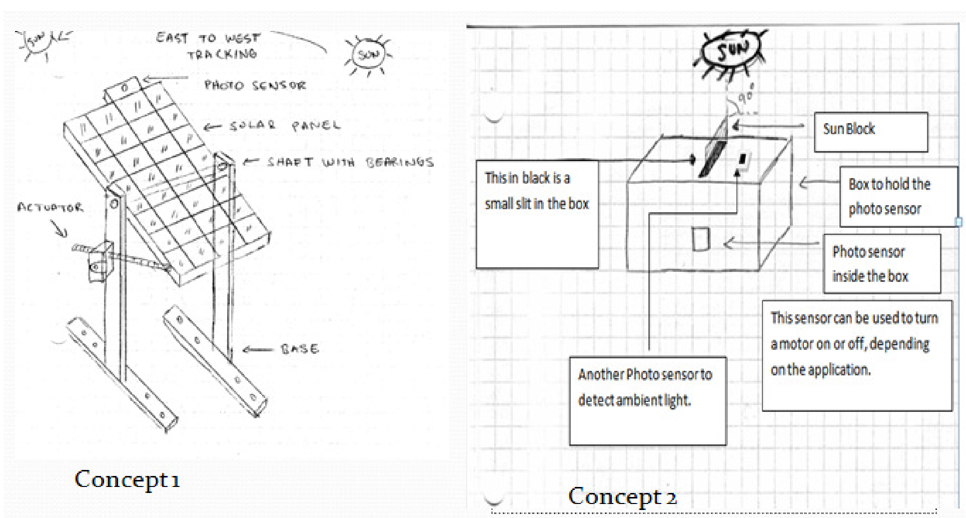

Figure 6. Embodiment Design of the Solar Tracker System

Detail Design

The detail design involves the complete engineering description of a tested and producible product. Figure 7 shows the final fabrication and assembly of the automated solar tracker, including the base stand and actuators that control the movement of the panel to track the sun.

Figure 7. Finished Solar Panel

Control System

An Arduino microcontroller serves as the brain of the control system. The Arduino software is an open source software similar to C++, with which it is easy to write code and upload it to the I/O board. The Arduino can sense its environment by receiving inputs; and thus affect its surroundings by controlling lights, motors, and actuators. It can operate as a standalone system or communicate with software running on a computer.

The solar tracker has photocells that measure sun intensity as an analog input into the microcontroller. The microcontroller cannot move the actuator on its own; therefore a motor controller is used to provide the extra power to move the actuator. After the analog signal is received by the microcontroller's software, an output signal goes into the motor control, thus moving the actuator in or out depending on the sensor readings and the program. Soon after the movement of the panel, the sensors will register a different sun intensity reading, thus restarting the cycle. An overview of the control system architecture is shown in Figure 8.

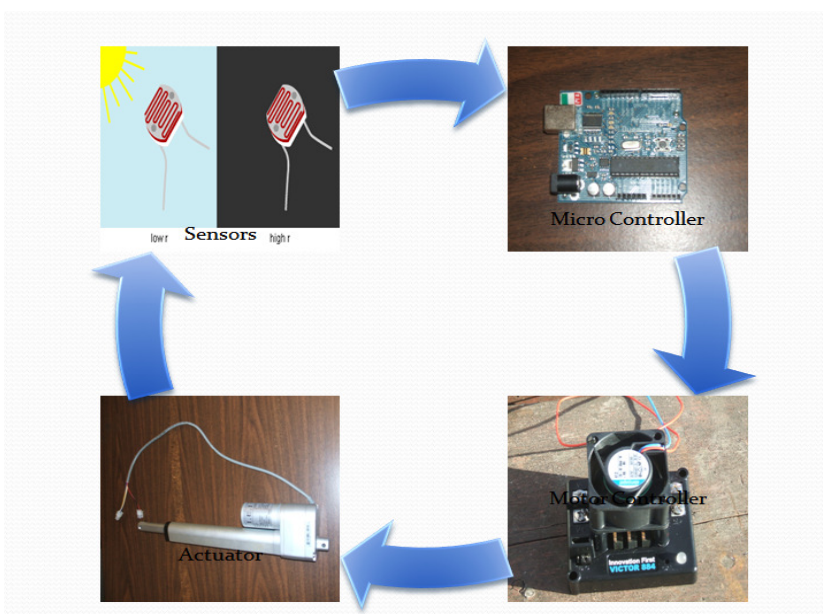

Figure 8. Control System

Control Box

The control box houses the microcontroller and the bread board, where all of the wiring is distributed to the motor controller, actuator, and the photocells. Figure 9 shows the control box mounted to the solar panel and the divider that separates the photocells. The purpose of the divider is to cast a shadow on one of the photocells; this causes a difference of output power between photocell A and photocell B, thus sending signals to the actuator motor to move the solar panel accordingly.

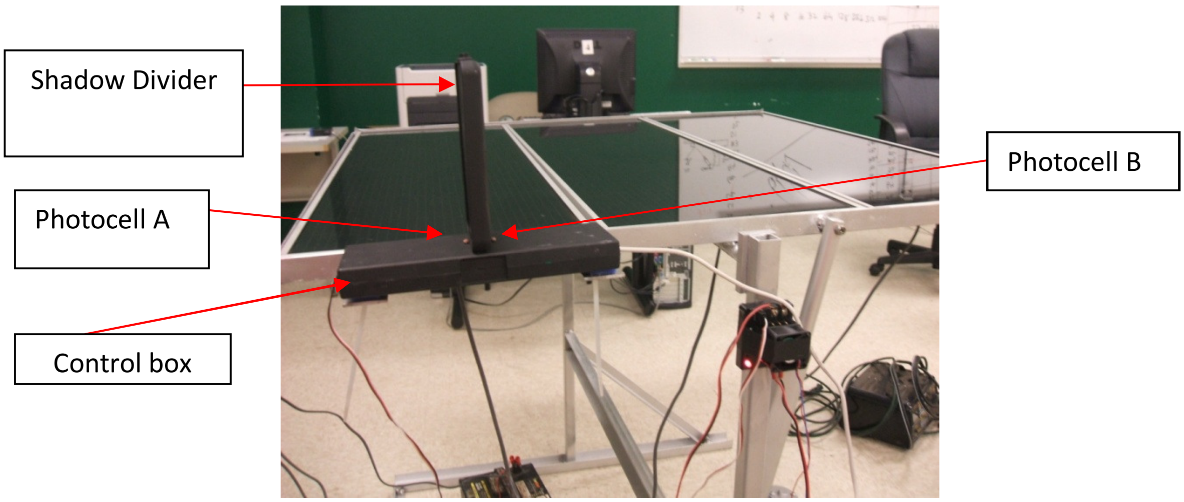

Figure 9. Control Box

The microcontroller and bread board are stored inside the control box to keep them out of the outdoor environment as shown in Fig. 10. The photocells are wired using a voltage divider as shown in Fig. 11. The photocells are wired as analog inputs to pins 2 and 4 on the microcontroller. Pin 9 (output) goes into the motor controller.

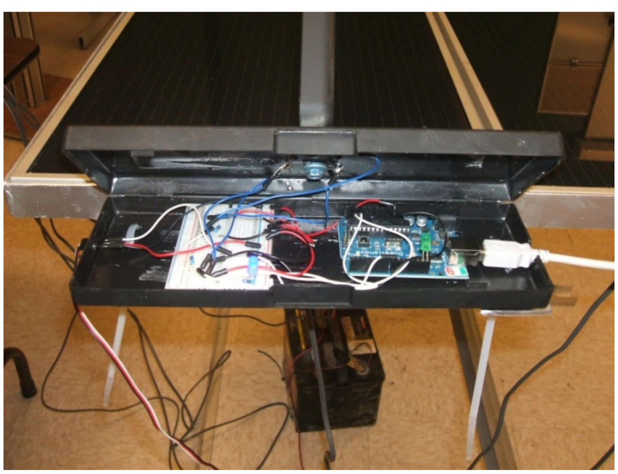

Figure 10. Control Box Internals

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 Photocell A     10K

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Pin 2 o----------
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Figure 11. Photocell Voltage Divider

Control Programming

The program is written using "if" statements. If the statement is "true", the program sends out an output signal. By trial and error, the threshold value above 150 has been determined to be strong sun light. In the program, if both photocells read above 150 then the sun is perpendicular to the solar panel and no movement is triggered. As the sun moves, there will be shadow on one of the photocells, causing the value to drop below 100 and the actuator to move the solar panel accordingly. After the panel moves, both photocells will read above 150, causing the panel to stop. This process will continue until it gets dark outdoors. Once it gets dark, both photocells will read "0"; and the actuator will move to the morning position to wait for the sun to start the cycle again the next day.

Results

PV panels convert solar energy into DC electric current. DC electrical power wattage is the product of voltage and current:

- DC watts = voltage X current. And the Power is measured in units of watts, (W).
- Voltage is measured in units of volts, (V) and the Current is measured in units of amps, (I).

The solar panels used for this project have a rated voltage of 17.5 V and a rated current of 0.86 amps. This gives a maximum power of 15W per panel; there are three panels generating a total of 45 watts. The first experiment was run from sunrise to sunset on a sunny, cloudless day, with the panel fixed (no tracking). Measurements were taken every hour. The experiment was repeated with the solar panel tracking the sun. Both results were graphed to show the difference, in watts per hour, between the fixed panel and the solar tracker (Figure 12).

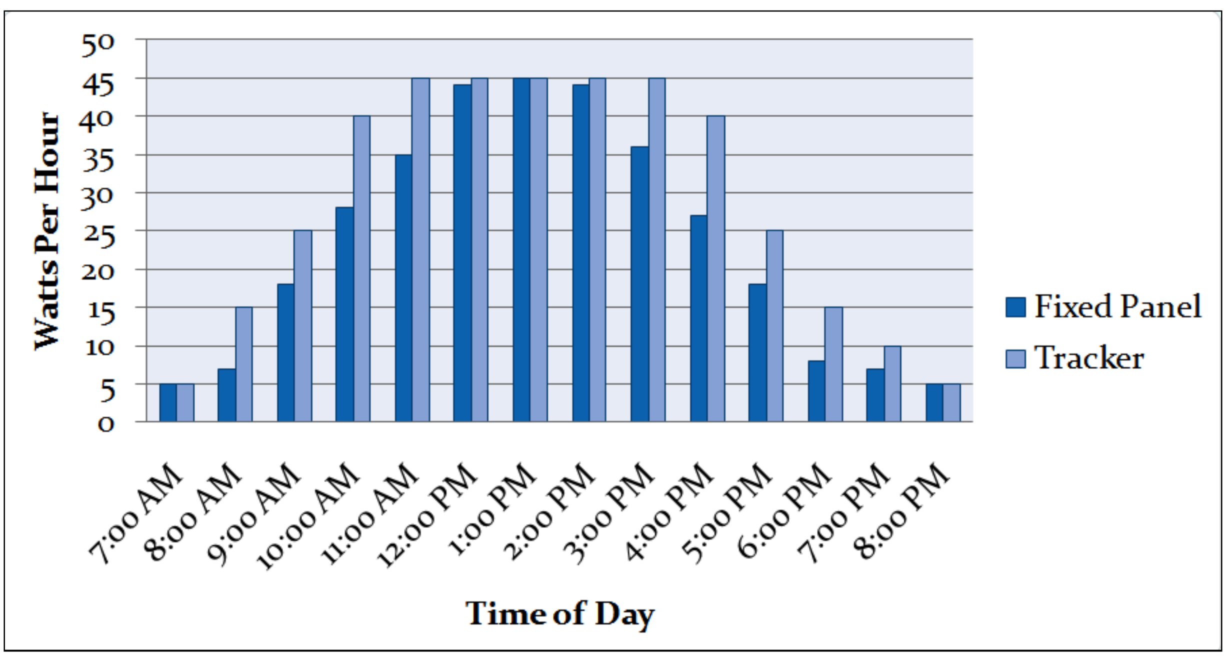

Figure 12. Results of Fixed Panel vs. Solar Tracker

Discussion

The current system uses a single axis to follow the sun in the sky. Also, it loses energy from the accumulated battery storage. This problem comes from the constant need of energy by the sensor system which is always in the activated condition. The system can be improved by changing the mechanical structure: adding movement for the azimuth direction to create a dual-axis tracker. The Arduino code has to be re-wiritten to include the second movement. Also, the sensor has to be limited to activation only once an hour; then the battery can accumulate energy.

The following three structural changes can be made to the original structure to include the second axis movement for the solar tracker:

- Add support for the solar panel and the component for the azimuth moves (seasons).
- Connect structures to also allow the zenith moves (days).
- Add base of the solar tracker.

Each structure is connected by a shaft and a ball bearing. The movements will be activated by two actuators, one per movement. Figure 13 shows the redesigned solar tracker.

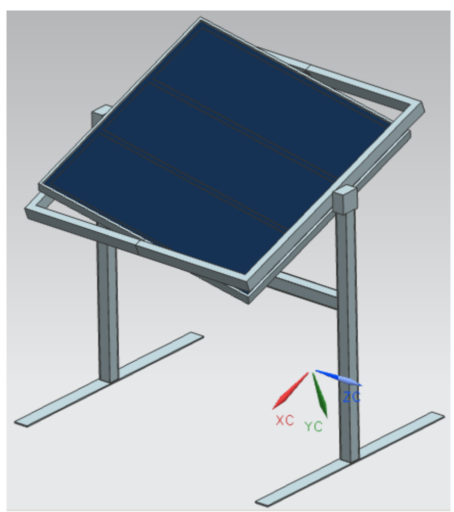

Figure 13. The redesigned solar tracker

Conclusion

The study has provided an excellent educational platform that includes design considerations, hands-on manufacturing, experimentation, data analysis, and consideration of future directions.

The tracking system had a 24% increase in efficiency compared to the fixed solar panel. The efficiency could be greater with a smaller actuator. To improve efficiency, the panel area would have to increase, or actuator power consumption would have to decrease. Also, the current setup can be converted to a dual-axis tracker, making it more efficient and thus generating more power.

This project suited perfectly to the current concerns of society for clean and renewable energy. This new technology represents the future, and it is going to be more and more developed with time. This project constitutes a perfect topic for an engineering technology student that wants to specialize in renewable energy. Indeed, this work has helped the student to develop several abilities and skills in design and manufacturing.

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