A Low-Cost Lightweight, Low-Profile Portable Solar Tracker

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Abstract

This paper describes the design and construction of a novel lightweight, low-profile solar tracker. Currently, available solar trackers are very large and rarely mobile. In the majority of cases, these machines require not only foundations, but increased structural support as well. These systems are expensive to install and are fixed to one location. Our device developed in the course of the junior-level Electromechanical Design course in Spring 2009 at Wentworth Institute of Technology, is designed to be portable and inexpensive. Four light sensors are positioned to measure light intensity at the four cardinal directions. By using a light-to-frequency IC, differences between incoming light intensity are detected and processed by a simple algorithm. Two motors then adjust the panel accordingly. The resulting prototype is light enough to transport, stable in wind, and was constructed for less than $120. The prototype will be demonstrated.

Introduction

The demand for alternative energy technologies is the greatest it has ever been [1] [2]. Solar energy represents one of the best clean power options currently available. Unfortunately, solar panels generate only a very small percentage of the power required by the average household [3]. Therefore, it is of great importance to optimize the power collected by each individual cell.

A solar tracker is a device which allows the solar cell freedom of motion to follow the sun throughout the course of the day, focusing the highest possible amount of light energy directly onto the panel surface. By doing this, the efficiency of the cell can be increased by as much as 30-40%.

Solar tracking systems can be either passive or active. Passive systems rely on a purely mechanical means to operate the device. This means they require no additional power to operate.

These devices consist of tanks filled with liquid with low vaporization temperature. When the sun rises in the morning, the heat causes the liquid to vaporize and move up into another tank, adding weight and causing the panel to tilt. However, these systems provide poor accuracy, limited loading options, unnecessary weight and dangerous and environmentally hazardous chemicals such as ammonia. The active solar tracker makes use of electronic sensors and motors to automatically control the orientation of the panel aligning it to the best possible exposure angle.

The aim of this project is to build a lightweight and low-profile solar tracker. This paper outlines the electrical, mechanical and software design elements that went into producing the tracker prototype. This project is part of an Engineering Design course taken by Junior-level Electromechanical Engineering students at Wentworth Institute of Technology. The following is the college catalog course description:

> *Students work in teams to design and construct an interdisciplinary project. Teams, with clearly defined individual responsibilities, are required. During the course of the semester, each team undertakes the necessary activities to bring about a successful design project that is well understood, documented, and presented in both oral and written form. Emphasis is placed on research, innovation, project management, decision-making, prototyping, design for manufacturing, design for testability, environmental and ethical issues in design, depth and breadth of analysis, quality of hardware, documentation, and communications. Prerequisites: Junior Status; ELMC160 Electromechanical Design I; MECH302 Mechanics of Materials; ELEC244 Digital Systems; ELEC443 Analog Circuit Design*

Design Process

The objectives are to design and construct a sensor-based, lightweight, and cost-effective solar tracker versatile enough to be used in a wide range of environments. For optimal sun tracking, the system will have two axis of freedom. The system will also be weather proof since the unit will need to be mounted outside. For this purpose all electrical devices must be enclosed in a water-tight container. The base of the unit must be versatile to be able to mount anywhere and on any surface.

A specifically designed light-sensing unit will communicate with two high-torque DC motors to aim the solar panel towards the brightest part of the sky. The entire system will be controlled by a low-power microcontroller system. All of the electronic systems will be powered directly from the power collected by the panels. The ultimate priority of the electric system will be minimal power consumption. Figure 1 shows a system overview of the propose design.

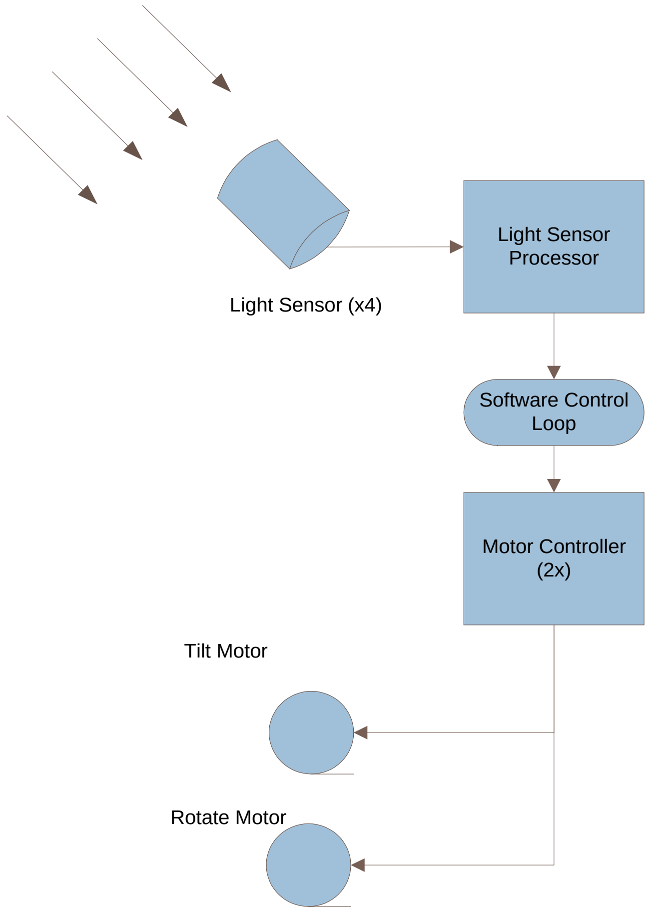

Figure 1 ~ System Diagram of Tracker

Electronic Design

The electronic system consists of four main components: light sensors, a microcontroller, two DC motors and a battery for power storage. Each subsystem is outlined below. To locate and track the sunlight four Texas Advanced Optics and Sensors (TAOS) TSL230R light-to-frequency converters where chosen. This device is an integrated circuit specifically designed for optic detection applications. The device outputs a square wave whose frequency is proportional to the intensity of the light. This signal can be input directly into the microcontroller's digital input without need for additional conditioning circuitry. This sensor data is then fed into the software control loop which makes the decision of where the sun is relative to the four light sensors. Figure 2 shows the arrangement of the sensors on the front of the panel.

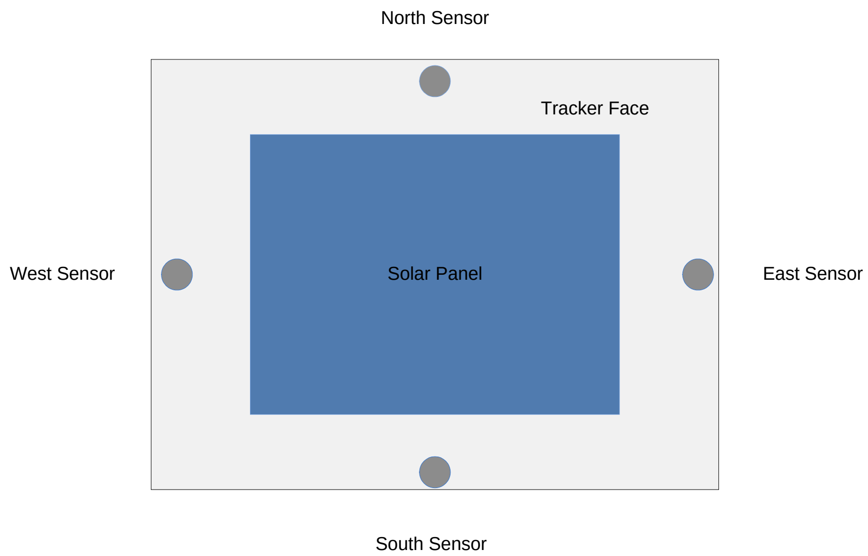

Figure 2 ~ Sensor location on front of panel

Based on the sensor information, the control program commands the motor to adjust the solar panel's heading and tilt angle. The Parallax Basic Stamp II microcontroller was chosen due to its simplicity, versatility, and its number of input/output channels. The board on which the microcontroller is being programmed is a *USB Parallax Board of Education* which has a built in breadboard as well as four pins designed for servomotor control.

In addition to having a large number of I/O pins, the controller offers memory space for up to 500 lines of code. Since the device will spend much of its time in a sleep state its 50µA sleep current draw means it will not be a significant burden on the system's power source.

The BASIC Stamp is programmed in the PBasic programming language which is proprietary derivative of the BASIC programming language [4]. This software offers 42 prewritten commands used for a wide variety of purposes including counting functions, pulse width modulation and serial communication. PBasic also allows for a semi-modular approach to program design allowing the definition of subroutines. This approach to programming simplifies program design and system debugging by breaking a program into specific components. The software is outlined in more detail in the Software Design section.

Two high torque DC motor were chosen to drive the rotation and tilt action of the solar tracker [5]. These motors were attached to a 500:1 ratio gearbox. This decreased the speed of the motors to 6 revolutions per minute and increased the torque to 7.34 N-m at stall torque. The motors operated on a voltage between 3 and 12V. The controller communicates with the motors through two motor controllers which translate the digital control signal into a high power signal which drives the motors. Each DC motor has its own dedicated motor controller.

One of the main objectives of this design was to maintain an extremely low power tracking system. The combination of low power electronic and a carefully designed mechanical system means the system requires very little power to operate. The prototype system runs easily on a two 9V batteries: one for the BASIC Stamp and sensor electronics and one for the motors.

Since the Stamp is requires only 5V the power requirements of the tracker could be reduced to a single 9V battery.

Testing has shown that during the motors draw only 12.5 milliamps for rotation, 155 milliamps for tilting up and 25 milliamps for lowering. These current requirements are easily satisfied by a 9V battery.

Mechanical Design

The frame of the tracker for the prototype was constructed from one inch angle steel. This material was chosen because it is easy to machine and weld. Each piece of the frame was cut and welded together to make the base and tilting frame. Steel provided moderate protection against corrosion. Ideally this frame would be built out of aluminum or plastic to lower the overall weight and decrease corrosion.

A custom adapter was needed to attach the driveshaft of the motor to the rotating base of the tracker. This part was designed using SolidWorks CAD software and then machined out of PVC.

Finally, to overcome the weight of the tilting frame and solar panel, a spring was attached between the base and panel frame. This added force assisted the motor when lifting the solar panel. With the spring attached, the DC motor only needed to overcome friction and the moment of inertia of the panel and frame. A rendering of the prototype is shown in Figure 3.

Figure 3 ~ SolidWorks rendering of prototype

Software Design

A flow chart of the tracking algorithm is shown in Figure 4. The program begins with an initialization and testing procedure. During this test the motors are stopped, the sensors are activated and tested, and the system is put into 1X scaling mode. With the start up sequence complete, the system then takes the first readings from the sensors. If no clear reading is found, the system will enter a scan function which rotates the panel until a satisfying reading is found. After one minute of scanning the system goes into a low-power sleep mode.

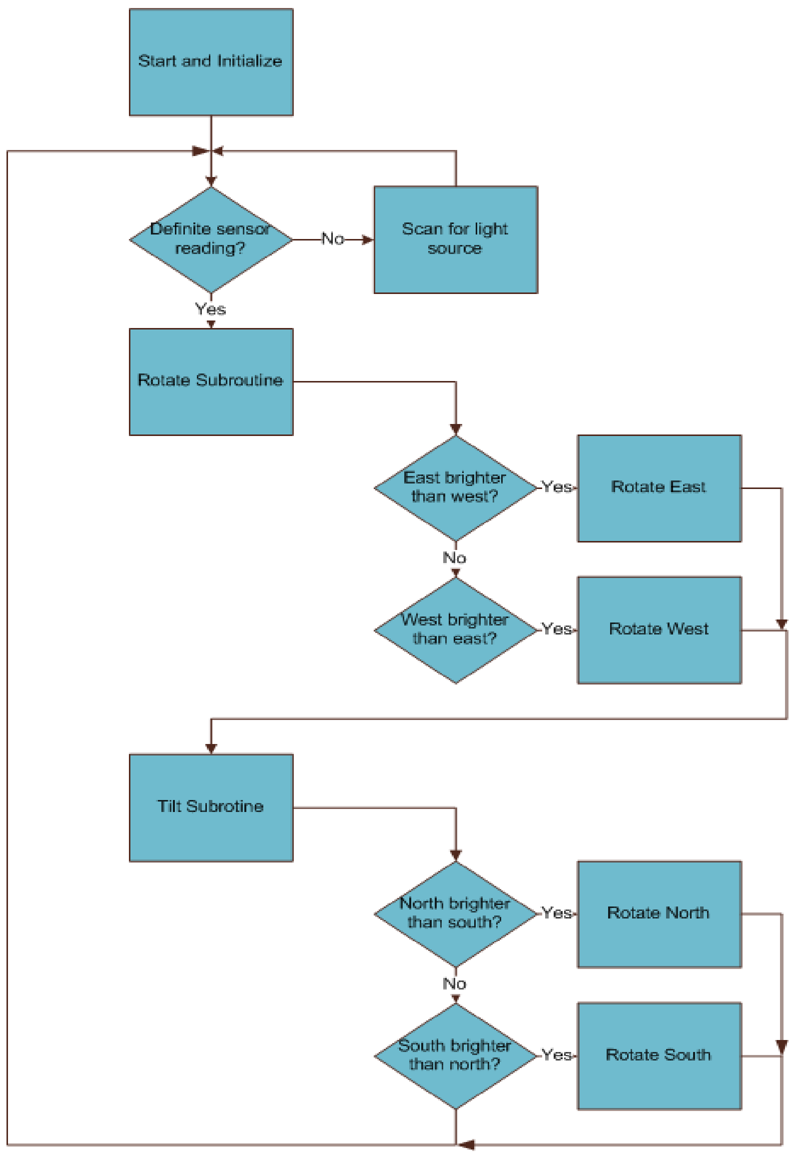

Figure 4 ~Software control flow chart

Conclusions

Through the course of the design and construction of this solar tracker prototype the students gained considerable insight into the engineering process. Additionally, this project also required knowledge of both electronics and mechanics. This makes it well suited to compliment the Electromechanical Engineering program at Wentworth Institute of Technology.

Ultimately the prototype met all original design requirements (see Figure 5). The system was lightweight and portable compared to other trackers currently available. Additionally, it was completed for only $150.

Figure 5 ~ The completed prototype

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