AC 2012-3454: EMBEDDED SYSTEM DESIGN FOR SUN-TRACKING SOLAR PANELS: A CLASS PROJECT TEMPLATE

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EMBEDDED SYSTEM DESIGN FOR SUN-TRACKING SOLAR PANEL – A CLASS PROJECT

Abstract
This paper presents a class project in which students design a controller for a sun tracking solar panel system using microcontroller PIC-16F887. This is a class project in the "Introduction to Microcontrollers" course in the undergraduate program of studies in Engineering Technology. The students are given a previously designed solar panel with built-in true sun-alignment mechanism and are required to write program to control it. The control system is required to align the solar panel to a plane normal to the Sun rays by detecting the actual position of the Sun in the sky over a span of 180 and 90 degrees in the azimuth and incidence planes. The program should detect the sky condition (clear, dark or cloudy), and override the alignment mechanism to send the panel to a home position. The alignment mechanism should have a programmable delayed response to any misalignment incident. The system design should employ C programming on the microcontroller PIC 16F887 from the Microchip Inc. either CCS or Hi-tech Compilers. Students work in teams of twos and test their program on a single panel. Students are encouraged to add special features of their choice. All teams compete and demonstrate their programs in the final lab class.

I. INTRODUCTION

Solar energy is the radiant light and heat from sun that has been harnessed since ages. Only a miniscule of the solar power received by the Earth (174 petawatts) is enough to meet the present-day energy demand. At the same time, the usage of solar energy today is only a very tiny fraction of the total energy demand.

The sun energy is available in the form of radiation over visible light and infrared region albeit at a very low intensity. Most commonly used ways of harvesting the radiant solar energy is using photovoltaic panels which basically are interconnected assemblies of photovoltaic cells. The photovoltaic systems receive solar energy mainly in the visible light and near infrared regions of the spectrum. The light power is converted directly into dc electric current. Photovoltaic energy conversion efficiency in most systems, however, is only in teens.

Amount of the harvested solar energy is critically dependent on the orientation of the solar panel. The solar energy collection is very inefficient in stationary panels. The efficiency of solar energy collection in photovoltaic solar panels at any location can be optimized when the panel a) faces the sun and b) continuously tracks the sun during the day in one or two axis. This tracking can be controlled in a feed forward or feedback controlled manner. The later has obvious advantages. Liping Guo et. Al, [1] have used a feedback controlled one-axis mechanism that compares voltages from two small solar cells mounted on a big solar panel assembly and activates a stepper motor to adjust the east-west alignment. J. Beltran, et.Al [3] uses an open-loop embedded control system for the solar tracker. This paper describes a two-axis feedback controlled tracking system which directly uses sun rays as the feedback signals.

II. SYSTEM DESCRIPTION

Figures 1 and 2 show the solar tracker assembly, named Sunflower. Students are required to design the controller for this solar panel using Microchip PIC-16F887 microcontroller.

The solar panel uses the feedback controlled tracking system that employs actual sun rays as the control signals. The system is comprised of two dc servo motors and four opto-transistors to determine the location of sun in the sky; two for the azimuth and two for the incidence angle, see Fig. 2. The azimuth (horizontal axis on the solar panel) transistors are placed on a straight horizontal line. When the solar panel is aligned with the azimuth angle of the Sun, both transistors receive the sunlight and are turned on. The azimuth (horizontal axis on the solar panel) transistors are placed on a straight horizontal line. When the panel is not correctly aligned in one axis, one or both of the transistors do not receive rays from the sun, the microcontroller turns on the associated motor to begin alignment. When the panel is correctly aligned with sun in that axis, both the associated opto-transistors receive sun rays. The microcontroller stops the dc servo motor and maintains the dc servo motor in that axis. Similar process is used to align the panel in the other axis. Alignment process occurs in both axes simultaneously for speedy alignment. An additional opto-transistor is used to determine the sky condition (clear, dark or cloudy), that overrides signals to stop the alignment process and park the panel in a default (home) state, horizontal facing upwards. This is also the resting position of the solar panel during the night time. The horizontal and vertical angle span 180 and 90 degrees respectively. Limit switches are used to restrict horizontal rotation to 180 degrees and vertical rotation to 90 degrees. Figure 4 shows the picture of the enclosure containing electronic circuitry for driving dc motors and the associated relays.

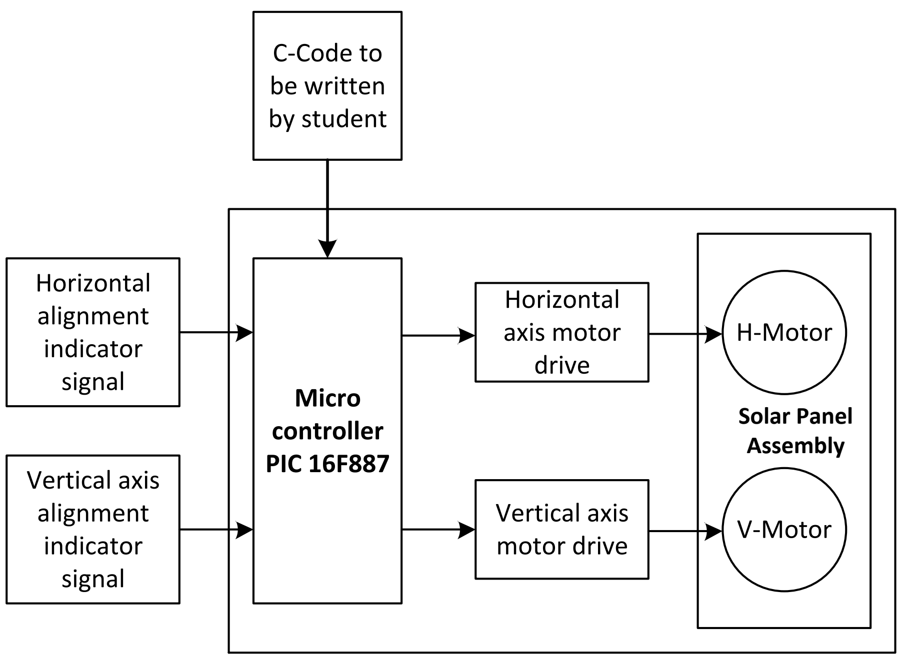

Fig. 1 System Diagram

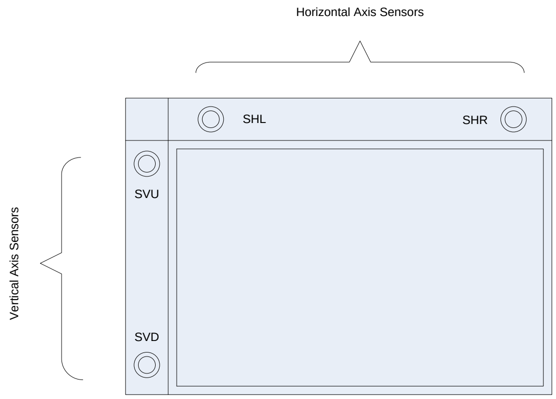

Fig. 2: Solar panel with solar ray sensors

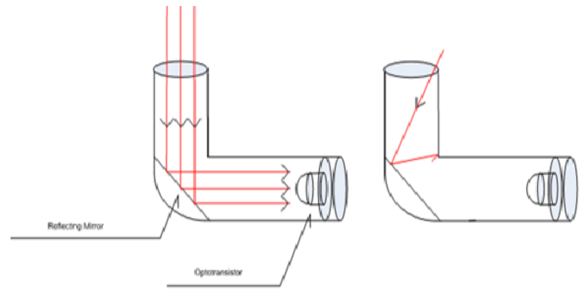

Fig. 3: Solar alignment devices

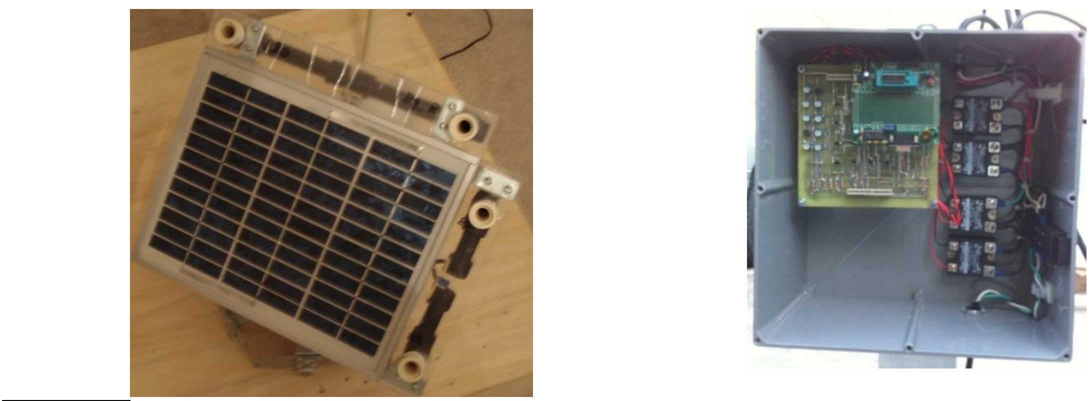

Fig. 4: Solar assembly

Microchip's 8-bit microcontroller PIC16F887 is utilized to control and align the solar panel to sun based on the signals from the five opto-transistors, which are mounted on the sides of the solar panel, see Fig. 2. The PIC16F887 has five 8-bit ports for input output operations. It has three timers, two analog comparators, capture-compare-PWM modules and 14-input Analog to digital converter module. The microcontroller is programmed using C in the MPLAB IDE environment using Hi-Tech Lite Compiler.

III. STUDENT LEARNING OUTCOMES

The class project of designing the microcontroller based controller for solar panel is the corner stone of the class of ECET 20900. The class is offered in every semester of the ECET program of undergraduate study. The class of Spring 2011 had twenty two students. In the first part of 3four weeks, the students are introduced to the architecture of the 8-bit microcontroller Microchip PIC 16F887 and the basics of embedded C programming. In the next eight weeks the students work on the pre-designed laboratory exercises to acquaint them on using input and output ports, interrupt facilities, the timers, comparators and analog to digital converter modules of the microcontroller. In the final three weeks, they are assigned a project in which the students use most of the tools learned in the class.

Description of course ECET 20900 – Introduction to Microcontroller :
An introduction to microcontroller hardware and software focusing on embedded control applications. The architecture, programming, and interfacing of Microchip PIC16F88 microcontroller is studied. Interconnection of components, peripheral devices, C language programming, debugging, input/output techniques, and use of PC-based software development tools are studied.
Class 3, Lab 3, Credit 4
It is a Required Course in the ECET program.

Course Goals/Objectives
Demonstrate a working knowledge of microcontroller busses and the flow of data within a microcontroller system.

Instruction Outcomes
1. Develop and demonstrate a C language program to accomplish a given task using a microcontroller.
2. Demonstrate a working knowledge of the necessary steps and methods used to interface a microcontroller system to devices such as motors, sensors, etc.
3. Demonstrate the use of interrupts and other advanced concepts related to microcontrollers.
4. Complete the design, development, programming, and testing of a PIC microcontroller-based embedded system.

Class Project Expectations:
Students are required to design a system with PIC16F887 at its center, integrating discrete hardware into a cohesive functioning system. The system's software will perform the functions of monitoring, controlling, displaying and recording of data.

Project Definition: Start with defining a two-member team and write an abstract defining the project. Please get instructor's approval of the topic by the 10^{th} week. The project definition should meet the following provisos:
1. Project has to be more comprehensive than a typical laboratory exercise.
2. Project should integrate material learned during the semester. Extra points will be awarded to the project that covers material not covered in class.
3. Add features to impart smartness and intelligence to your controller.
4. Extra points will be awarded to integrate and control hardware from outside spheres.

Students were given freedom to use any 8 or 16-bit Microcontroller, although most of them used Microchip PIC 16F887.

Presentation: The system design must be presented using standard Presentation gear (Slides presentation) to the class as part of the finals along with the system demonstration (15 minutes team presentation).

Design Team: The project is executed by two member teams. A formal Project Report (consisting of Abstract, introduction, Design Description consisting of Schematic(s) and Software Code and Bibliography) will be prepared by each member of the group.

Duration: *Week 13, 14 and 15*
Project Grading: Five points for the design features, 10 points for successful execution and demonstration, 5 points for code quality and organization, total 20 points, which is the 20% of the total class grade.

IV. STUDENT AND FACULTY FEEDBACK

This class is offered in every semester to engineering technology undergraduate students. Several ideas were generated regarding the course content and delivery issues. For those who wish to offer this course, we recommend following questionnaire for students:

1. Did you like the course on the Introduction to Microcontroller as a whole?
2. Did you find the course subject and class project interesting?
3. Was the course difficult to follow?
4. Do you feel your background knowledge was sufficient for the course and the project?
5. How you think this course and the class project would help you in future?
6. Would you have liked more class projects in this class?
7. Did you find student presentations useful (as a presenter and as a listener)?
8. Were the home and lab assignments well designed and helpful in learning the subject?
9. Which part of the course you like the most; the lecture, lab exercises or the class project?
10. Any suggestions making the course more alive and efficient?

The feedback comments are satisfactory, instructive and provided valuable suggestions. Out of responses, five expressed satisfaction on the course contents, organization and assignments. They were also confident that this course has given them the necessary foundation principles and knowledge of the prevailing technology. Four responses told that the Hi-tech compiler is good but is very detailed. They suggested that either we use a higher level compiler or build more user defined functions that will shorten the length of code and thus will make it simpler to apprehend. Two responses expected a visit to an industry/lab where they can see how the design is done in real work environment. A few students complained about the grading system and requested a clearer picture about the weight of each assessed component on the final grade.

The suggestions and review by faculty colleagues was also sought to determine the usability of the course. The faculty was invited to the presentations of the class project. They were also presented the course material and lab exercises. Suggested questionnaire for faculty colleagues are as follows:

1. How do you think this course will help the overall educational objectives of the graduate program in Technology (Engineering if you are an engineering faculty)?
2. What could be improved?
3. Do you think if this class should be followed by an advanced level class on the embedded design in the undergraduate level?

Two of my colleagues in the Engineering Technology faculty at Purdue University Calumet provided the feedback. In summary, both expressed satisfaction that the foundation knowledge is very helpful to the students. One of them suggested to offer another course to teach DSP based microcontroller design and using Ethernet based controls. The second colleague suggested to teach s course on embedded real-time motor control for robotic machines. Obviously all suggestions are very good. We will try to embed as many of them subject to the space available on the tightly controlled plan of study in the undergraduate programs. However, they can be adapted relatively easily in the graduate plan of study.

V. SUMMARY

The paper presents a class project in which students design and implement an embedded controller for a sun tracking solar panel system using microcontroller PIC-16F887. This class project is the culminating project in the “Introduction to Microcontrollers” class in the undergraduate program of studies in Engineering Technology. Students are given a previously designed solar panel with built-in true sun-alignment mechanism and are required to design and write C-program to control it. The control system is required to align the solar panel to a plane normal to the Sun rays by detecting the actual position of the Sun in the sky over a span of 180 and 90 degrees in the azimuth and incidence planes. The program is required to bring the solar panel in the home position in the night time and in the inclement weather (clouds and rainy conditions). The alignment mechanism is also required to provide a programmable delayed response to any misalignment incident. Students work in teams of twos and test their program on a single panel. Students are encouraged to add special features of their choice. All teams compete and demonstrate their programs in the final lab class and present their report to the class using PowerPoint. Students have shown great enthusiasm and the feedback is very encouraging.

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