A Team-based ECET Capstone Project: Design and Implementation of a Solar Insolation Measurement System

Abstract

This paper describes an example of the successful design and implementation of a Portable Self-powered Solar Insolation Measurement System. The project was designed and implemented by a team of three students. Furthermore, the paper explores synthesis of student learning in terms of enhancing their team work, problem-solving and analytical thinking skills. DeVry University's Electronics Engineering Technology/Computer Engineering Technology (ECET) program senior project is a four-session course sequence in which students synthesize knowledge and skills learned in the previous courses. In the first course (ECET-390, Product Development: 8-Week session) students research, plan and develop a project proposal. And in the next three senior project courses (ECET-492, ECET-493 & ECET-494: three 8-Week sessions) students implement a project plan by building and testing a prototype. The format of paper (sections II-XIV) parallels the required written report format of the capstone course at DeVry University.

DeVry University's Senior Project Capstone Course Sequence

DeVry University's Electronics Engineering Technology/Computer Engineering Technology (ECET) program senior project is a four 8-Week sessions course sequence in which students synthesize knowledge and skills learnt in the previous courses. In the first course (ECET-390, Product Development) students from Electronics and Computer programs are asked to form teams, and then required to research, plan and develop a project proposal. And in the next three senior project courses (ECET-492, ECET-493 & ECET-494: 24 Weeks) students implement the project plan by building and testing a prototype. A typical project involves a solution to a software/hardware-based engineering problem. The process of developing and implementing a solution to the problem offers a unique learning opportunity for students to gain new insights and competencies and their team work, problem-solving and analytical thinking skills.

Overview of Solar Insolation Measurement System

Solar insolation is the amount of electromagnetic energy (solar radiation) incident on the surface of the earth, in other words, how much sunlight is shining down on a given area of earth[1]. It is the most important factor when planning to install a solar electric power system. Knowing the solar insolation level of particular regions, system designers can determine which location is the most appropriate for a solar power station and the size of the solar collectors required[2]. Solar insolation values are generally expressed in W/m^2: the amount of solar energy that falls on a square meter of the earth's surface. Wind speed also plays an important role in solar power systems. Since cooling makes solar cells more efficient.

Problem Identification

The problems associated with the majority of solar insolation measurement systems available on the market are their high cost, large size, and lack of portability. In addition, these industrial systems have too many options, which make them difficult to operate. The devices available on the market cannot be used by amateurs, and the need of professionals to operate them is inevitable.

Solar Insolation Systems Presently Available on the Market

The solar insolation measurement systems available on the market are either expensive (ranging from $787 to $7,402), or too bulky and heavy, or too complicated to work with. In addition, all of them are powered by batteries. Table 1 presents a detailed comparison between such systems available on the market.

Project Objective

The main goal of this project was to develop a portable solar insolation system for engineers and non-experts interested in solar system design. Anyone who wants to install a solar panel system can choose the best location by analyzing the solar intensity data acquired by the device.

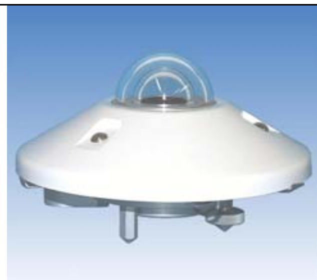
Project Team's Solution

The project team proposed a solution based on a design that is simple, portable, low cost and easy to develop for measuring solar insolation. The system design specifications are that the system should be small enough to be carried to any location and must yield an accuracy of ±5% and give solar insolation measurements covering a range from 0 to 800 W/m^2, in short, design and implement a simplified version of the industrial systems available in the market. Another requirement was that the project solar insolation measurement device should be simple and not require a professional to operate it. The designed system's simple interface makes it easy to operate. The cost of the solar insolation system is lower compared to available products on the market (see Table 1). The system is powered by a small solar panel and a rechargeable battery. Photodiodes estimate the solar insolation level and a wind sensor measures the speed of the wind. A solar tracking system consisting of phototransistors is used for optimal power collection for the battery. The results from the system are displayed on LCD screen and can also be transferred to a computer. The user can choose the data transfer interface: wireless or via USB. Unlike many websites which provide recorded data about solar insolation of major cities only, the DeVry team's portable device can provide live data from any location. Also, the data gathered is updated every minute.

System Block Diagram

Figure 1 depicts the system block diagram for the portable self-powered solar insolation measurement system. The block diagram shows various components required to implement the system. There are four sensors installed to measure different quantities. The first sensor (wind

Table 1: Market availability of Solar Insolation Measuring Systems

System/ Manufacturer	Illustration	Powered by	Measurement	Price
Pyranometer CM22/ Kipp & Zone		Separate power source	Direct solar radiation, solar insolation, sky radiation on the level surface, global-inflected and reflected radiation	$7,402
Radiometer - PMA2100/ Solar Light Co.		Batteries	Solar insolation, humidity, graphic display, complex processing algorithms, Selectable units of measure, and averaging.	$1,768
Solar Radiation Transmitter/ InnoCal		Separate power source	Solar insolation Wind speed Rain fall Barometric pressure Humidity	$787 (power source not included)
Portable Self-powered Solar Insolation Measurement system/ Project designed and implemented by DeVry Students		Self-powered	Solar insolation, wind speed	$445

Sensor) is used to measure the wind speed, which determines the wind effect on the system. The second sensor (photodiode) is used to determine the solar insolation level. The tracking of the solar panel system is controlled by the third sensor (phototransistors). The fourth sensor (light-dependent resistor) is used to detect the light, which is the main factor considered for turning the system ON or OFF. As shown in Figure 1, the signals from these sensors are amplified to match a desired output for the microcontroller. The analog data are then converted into digital data using the HCS12 microcontroller. An LCD display is used to display the wind and solar sensors output. The data are stored in a memory and then are transferred via a USB drive or a wireless interface. The user has the option of choosing either method for easy access to the data.

Figure 1 also shows the implementation of the solar tracking system. Since the device is self-powered, a small solar tracking system is used to collect optimal amount of sun power. A DC motor is used for controlling the solar tracking system's movement and angle. The DC motor is powered directly from the panel, and, in case of insufficient sunlight the motor is powered by a backup source using the 9V battery.

Prototype Development: General Approach

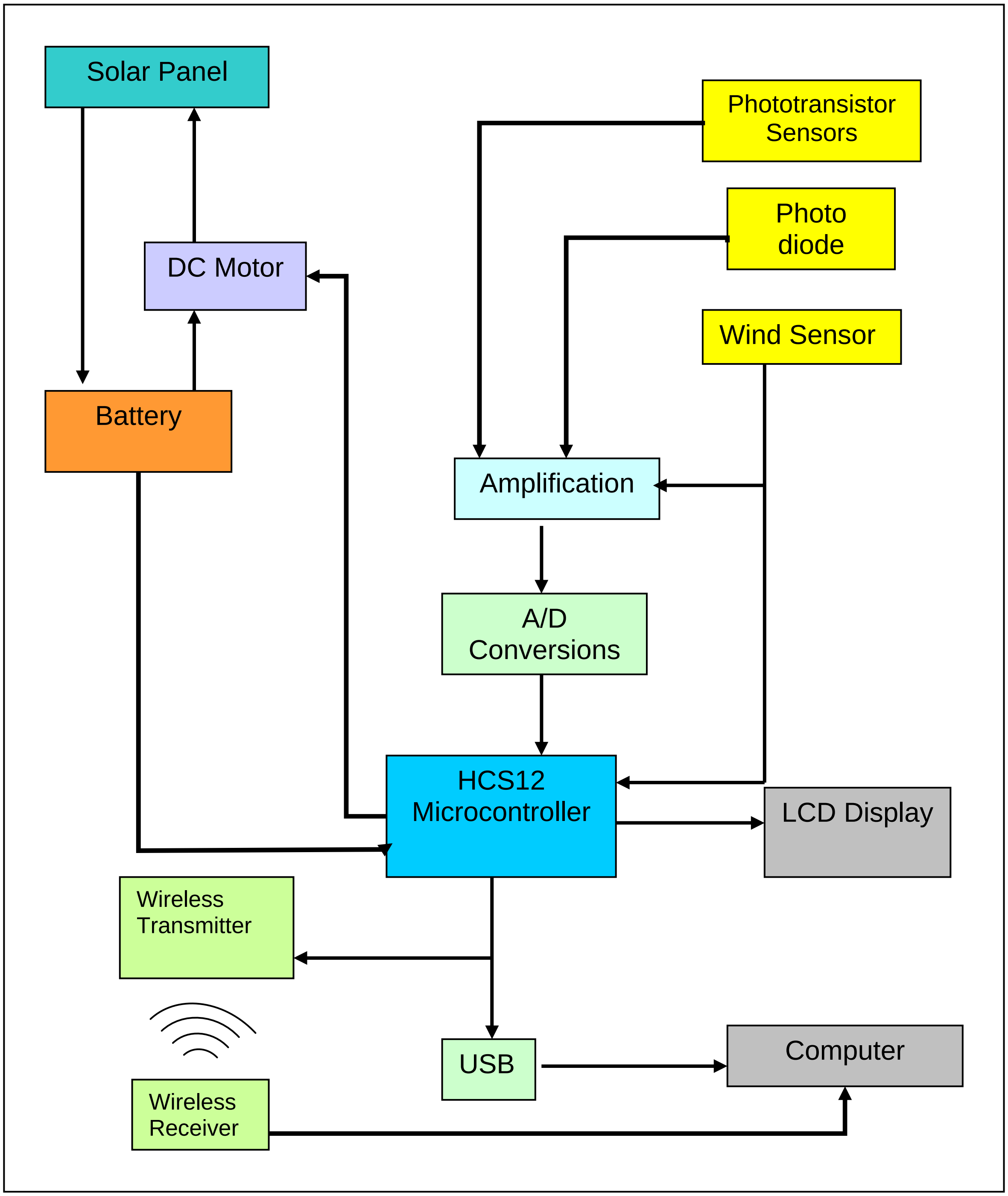
The prototype developed was completed in two phase: hardware design and software design. The hardware design was broken down into three parts. The first part dealt with constructing the solar tracking system. It included the solar panel, the DC motor, and the 9V battery. The second part consisted of the hardware design and sensor implementation. The analog output signals were converted to digital signals using Analog-to-Digital (ATD) converters. And the third part of the hardware design was to develop an interface for data transmission. This section included the USB and wireless transmission.

The second phase in building our project was the software design. It required the integration of all sensors together. Appropriate software code was developed to manage the solar tracking system, to perform ATD conversions, to display data on LCD display, and to transfer acquired data. After completing the hardware and software designs, the system was first tested at sub-system level and finally at system level. Figure 2 depicts the project prototype of portable self-powered solar insolation measurement system.

Resources Used

A complete list of components used and their cost breakdown is as follows:

- 10 Watt Solar Panel[3] - 12 V, Stainless Steel, from SolarTech – 70$
- Microcontroller HCS12 Dragon 12 board[4], from Wytec -- $150



` Figure 1: Solar Insolation Measurement System Block Diagram

- La Crosse TX-15 Wind Sensor[5] – $35
- Battery 12V[6], 5 Amp, from AltE Store -- $16
- DC motors[7], 12V, 50 rpm, 12 lb torque, reversible – 2 x $12

- Photodiode SLSD-71N300[8] from Allied Electronics – $9
- Frequency to voltage converter[9] LM2917, from Avnet – 8 x $0.9
- Bluetooth USB & Serial Pair [10] BluePlug/Firefly, from Gridconnect, $104
- Temperature sensors [11] BPWR21, from Allied Electronics – 4 x $8
- Miscellaneous $30, the approximate *total* cost equals: $ 477

Contractual Aspects

The project was not sponsored through any commercial venture; therefore it did not involve any legal or contractual aspects.

Project Schedule

Table 2 shows the project milestone matrix, and Figure 3 presents the project Gantt chart.

Evaluation Methods/Testing plan:

The testing of the system was conducted in the following manner: hardware was tested first and then the software. The hardware components tested first were solar panel, photodiodes, wind sensor, and battery. In the first phase of testing, the photodiodes and the wind sensor were connected and tested for their optimal output levels. The photodiodes were tested for a desired output voltage range of 0 V to 5 V. The wind sensor was tested for a desired output voltage range of 38mV to 5V. The solar panel was tested for the desired current (I = 0.47 A) and voltage (V_{max} = 15.3 V). In addition, the battery was tested for desired current (I_{max} = 7.2 A) and voltage levels (V_{max} = 12 V).

Since the system has no user input, the software code was mainly tested for correct output levels. The analog to digital conversion was tested for the output ranging between 0 and 255 bits. The solar insolation was expected to be in range from 0 to 800 W/m^2. The wind sensor was tested for a correct output in range from 1 mile per hour to 128 miles per hour. The data transfer was tested from the Dragon-12 Board to the computer via USB cable. The system was tested for accurate transfer by comparing the values on the LCD screen and the computer screen. The wireless transmission was tested in radius of 100 meters (0.06 miles). The completed system was tested in Rockford, IL. The solar insolation data measured with the prototype was compared against the published solar insolation data available for Rockford, IL.[12] The measured data was within the ±5% desired accuracy.

Problems Encountered

Hardware Problems: There were several problems the project group experienced during the implementation of the system. Some of the hardware problems encountered were the interfacing of the H-bridge to the DC motors, wind sensor, and the tracking system's frame. The problem with the H-bridge was that it was connected to LED's and a seven-segment display. The group experienced difficulties with running both motors and with using the seven-segment display. The

Table 2: Project Milestone Matrix

Project Task/Milestones	Who is responsible?	Time allocation/ Task	Slack time
Project Approval	Adnan, Azeem, Velina	2 Weeks	-
Research	Adnan, Azeem, Velina	5 Weeks	-
Hardware Design	Adnan, Azeem	4 Weeks	1 Week
Software Design	Adnan, Velina	5 Weeks	1Week
Development of Testing plan	Adnan, Azeem, Velina	1Weeks	-
Develop and Implement Prototype System	Adnan, Azeem, Velina	2 Weeks	-
Prototype testing	Adnan, Azeem, Velina	2 Weeks	1Week
Project Report Development	Adnan, Velina	1 Week	-
Project Oral Presentation	Adnan, Azeem,Velina	1Weeks	-
Project Web Page Development	Velina	I Week	-

group solved the problem by eliminating the use of seven-segment display. Instead, it was decided to use the LCD screen to display the results. The second problem with the hardware design was the wind sensor implementation. The group had difficulty in making the wind sensor work properly using a frequency to voltage converter (LM2917). It was discovered that the LM2917 required input frequency was greater than what was obtained from the wind sensor. To solve the problem the Dragon Board (HCS12) was employed.

Software Problems: During software testing the group encountered problems figuring out how to integrate ATD for the sensor used by the tracking system and the solar insolation. The ATD that was active on the Dragon Board only had two ATD converters available, but the project needed five ATD converters. The problem was solved by enabling the second ATD.

Figure 2. Project prototype of Portable Self-powered
Solar Insolation Measurement System

Synthesis of Learning

Despite various hardware and software problems which were encountered the project prototype was successfully implemented and demonstrated. The ECET program provided a solid educational experience that allowed the development of the solar insolation measurement system. Each course in the sequence has proven useful in the development process of the project. Since the team consisted of two Electrical Engineering Technology (EET) students and one Computer Engineering Technology (CET) student, the team members had the opportunity to learn outside of their field. Team members thus learned how to integrate electrical engineering theories with the computer engineering concepts. The project also enabled the team to incorporate concepts learned in the introductory classes of electronics and programming. The project has widened the scope of learning and knowledge in the electronics and computer fields for the team members. The project also helped the group members` to develop higher levels of knowledge by learning totally new items that were not covered during the course work.

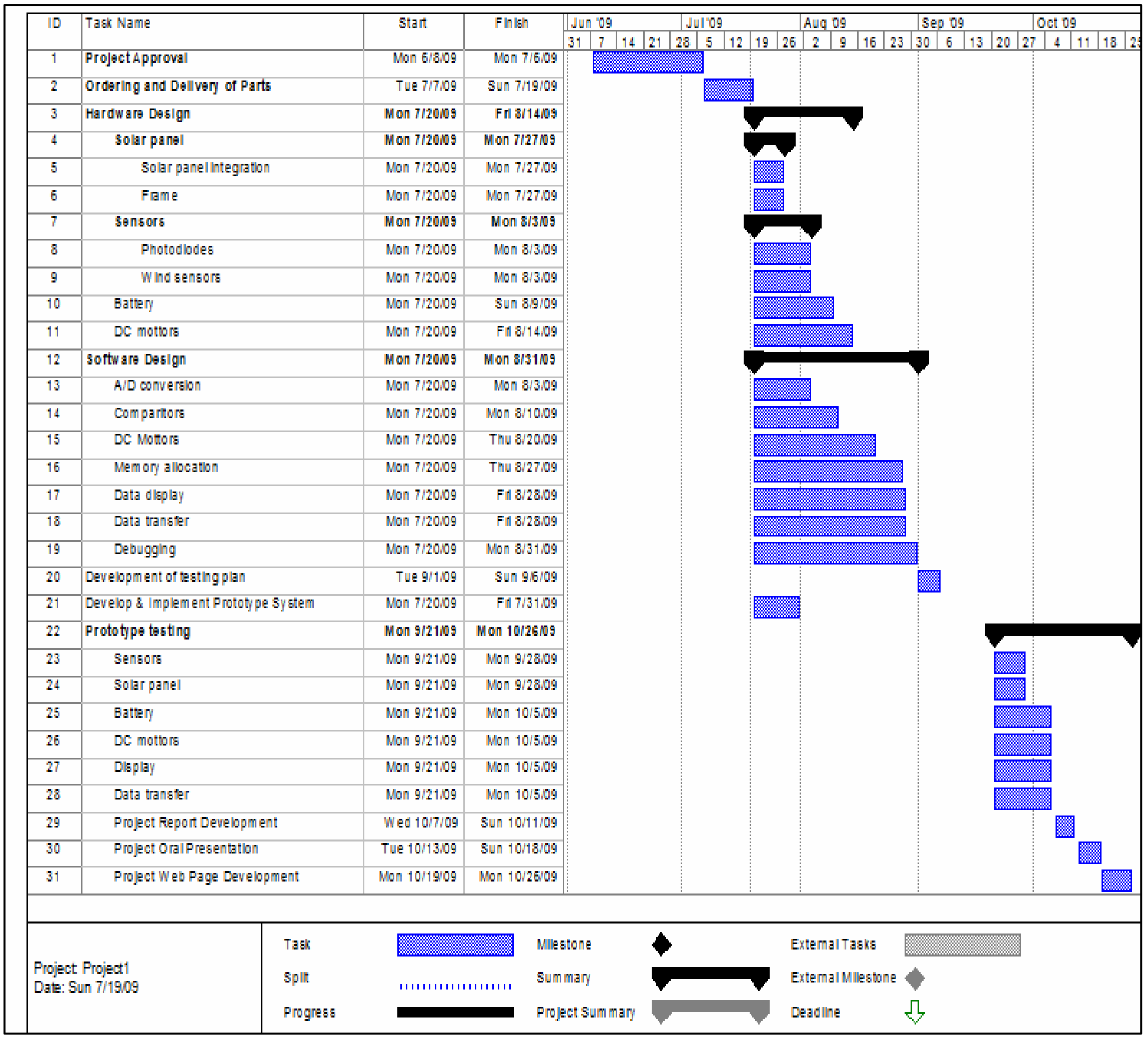


Figure 3: Project Gantt chart

Conclusion

This paper described the design and successful implementation of a senior project titled "Solar Insolation Measurement System." The designed system allows experts and non-experts to measure solar intensity data, and have it transferred to a computer via USB or wireless mode. Its simple interface allows for an easy operation and the low cost makes it affordable for small businesses and personal use as well. Moreover, the paper discussed the details of a senior project completed in a capstone course at DeVry University, Addison, IL. The capstone course requires students to work in a team environment to design and implement a software/hardware-based solution to an engineering problem, and thus enables students to enhance their problem solving and critical thinking skills.

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