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Open Source Sun Tracking System with Solar Panel Monitoring and Heliostat Control System

Gordana Laštovička-Medin

Faculty of Sciences and Mathematics, University of Montenegro
Dzodrdza Vashingtona bb, 20000 Podgorica, Montenegro; gordana.medin@gmail.com

Abstract

Issues, challenges and opportunities in the energy sector clearly address the necessity for innovations not only in technology but importantly also in the education sector. But how to create environment for innovations in energy technologies, regulations and policies is another challenge. An apparent decline in interest and enrolment of young people, especially young women, in engineering, science and technology is widely seen. This sheds new light on the need to develop public and policy awareness and understanding of engineering, affirming the role of engineering as the driver of innovation, social and economic development is of crucial importance. It also emphasizes the need to transform engineering education, curricula and teaching methods to emphasize relevance and a problem-solving approach to engineering. Another challenge is how to integrate both teaching the fundamental sciences such as physics and chemistry and innovations in engineering. The overall objectives of this paper are thus to show how through already existing open source products students may build a flexible, modular and multifunctional sun-tracking set up. The paper is mainly technical report on the work in progress. The method combines both, optical sensors and astronomical calculations. The tracking program (astronomical calculation) is selected as an auxiliary method. The initial set up is built from the SwitchDoc Labs Products such as SunAirPlus Solar Power Controller Board. The board is compatible with the microprocessor Raspberry Pi and the microcontroller Arduino. Furthermore, the board incorporates a number of outstanding features in a very compact, inexpensive single fully assembled and tested PC Board. Moreover, the Field Programmable Gate Arrays (FPGAs) is considered as an appropriate solution to behavioural control of the tracing system. The final aim of this research and main motivation is to use the set-up for the teaching basic measurements in Physics and to encourage students to take role in engineering and energy innovations.

Keywords: Sun tracking; Sensors, Embedded systems; FGPA; SunAirPlus; Auxiliary

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1. Introduction

The photovoltaic (PV) is divided into fixed-type where the angle of PV module is fixed at a certain angle and tracking-type where the azimuth and altitude of the sun is tracked to receive the sunlight perpendicular to the module surface. Tracking the location of sun on the ground includes the method of using optical sensor (passive), the method by astronomical calculations (active), and the method combining the two. The sun tracking device using optical sensor involves operation of an actuator to operate the sun tracking system using the difference of radiation intensity detected through photo sensor. The astronomical calculations are based on information of longitude and latitude of the tracking system installation location.

There are three main tracking systems: auxiliary bifacial solar system, electro-optical sys-tem, and microprocessor/computer system. Aauxiliary bifacial system is the simplest among them. The bifacial auxiliary solar cell is fixed to the rotary axle of the tracker and is placer perpendicular to the main bifacial solar panel array. The sensor cell is mounted directly to the motor (direct current (DC) electromotor or stepper motor) [1]. The electro-optical sys-tem is another relatively simple system. Typically two photoresistors or PV cells are used as sensors for one-axis systems. These sensors are positioned near one another and have a divider or use a collimator to create a useful current and/or voltage difference between the two sensors. A combination of resistors, capacitors, amplifiers, logic gates, diodes, and transistors are used to form a comparison and driver circuit. The output of the comparing circuit powers a driver circuit, which in turn powers a motor and changes direction according to which sensor receives a higher amount of illumination. This orients the solar panel to be perpendicular to the sun [2, 3].

The microprocessor and computer systems make up the last type of system. They are some-times classified into two different groups, but essentially they are quite similar. The main difference to the first two mentioned systems is microprocessor/computer systems use algorithms to determine the position of the sun instead of using sensors. Typically, microprocessor/computer systems only use sensors to reduce error or calibrate the system. Some micro-processor/computer systems even use a current maximization routine for error correction instead. In many systems a cheap microprocessor such as a Programmable Interface Controller (PIC) will have the algorithm for tracking, while information is fed to a computer, for analysis purposes. In [4] the microcontroller has two primary modes, clock mode and sun mode. The clock mode calculates the position of the sun and makes any modification to the algorithm based on the solar error sensors. In the sun mode, the algorithm actively positions the solar panels. If the solar intensity decreases below a set value, the clock mode is activated. This variety of modes helps in better positioning and therefore a higher gain [4].

In what follows we explore the hybrid version of above discussed tracking systems.

2. The conceptual design

The solar tracking system uses a DC motor as the drive source to rotate the solar panel. The position of the sun is determined by using a tracking sensor, light dependant resistor (LDR). A Light Dependent Resistor (LDR) or a photo resistor is a device whose resistively is a function of the incident electromagnetic radiation. Hence, they are light sensitive devices; they are also called as photo conductive cells or simply photocells. They are made up of semiconductor materials having high resistance. The analogue signal (reading from LDR) is then converted to digital signal by using an analogue digital converter (ADC) and then further passed to a fuzzy logic controller implemented on FPGA card (Figure 1).

The interfaces are crucial components. The SunAirPlus board has the following other interfaces: the built into the board: the built-in I2C data gathering chips for system currents /voltages, the built-in I2C Interface for solar tracking photoresistor devices, the built-in Interface for servo motor or stepper motor and the built-in interface for limit switches.

The Solar Charge Controller on SunAirPlus is based around a CN3065 Lithium Ion Charge Controller to run the charging sequences for the batteries. The CN3065 is a complete constant-current /constant voltage linear charger for single cell Li-ion and Li Polymer rechargeable batteries. The device contains an on-chip power MOSFET and eliminates the need for the external sense resistor and blocking diode. An on-chip 8-bit ADC can adjust charging current automatically based on the output capability of input power supply, so CN3065 is ideally suited for solar powered system The chip does an

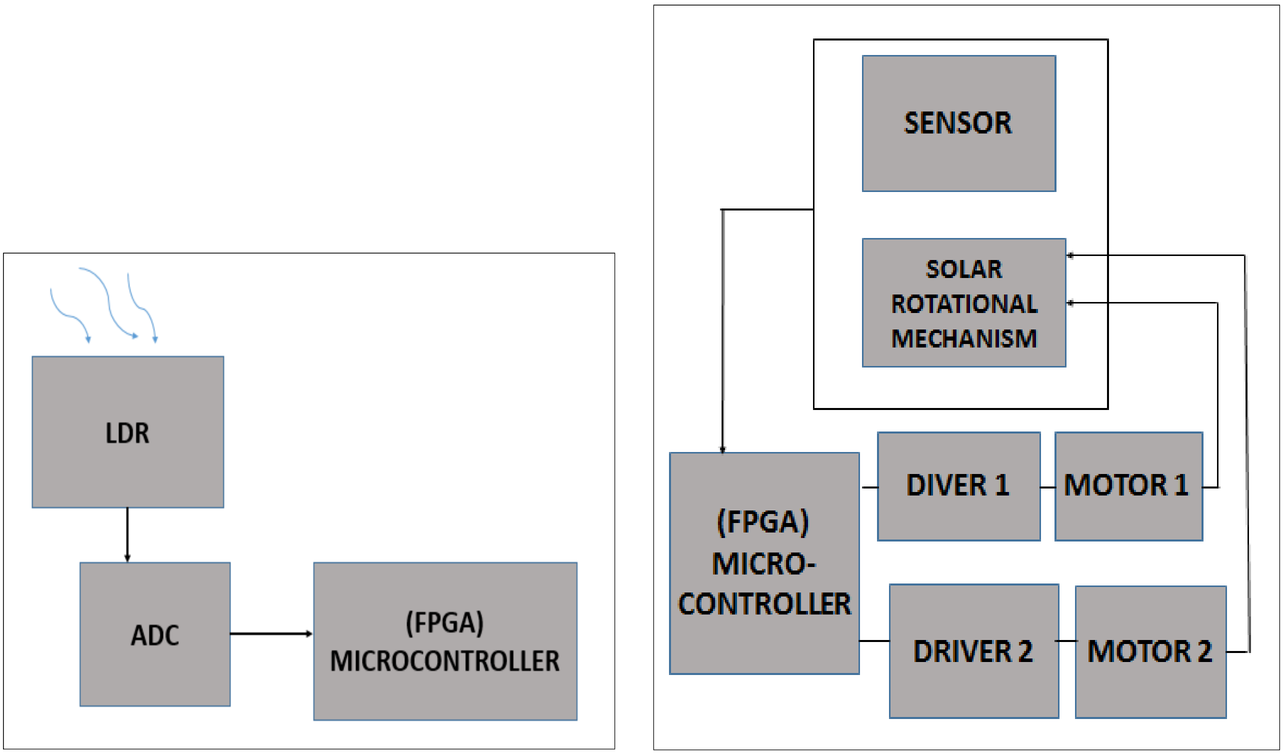

Figure 1. Solar tracking control architecture

ideally suited for solar powered system The chip does an approximation of the Maximum Power Transfer Tracking (MPPT). Thus, it is the purpose of the MPPT system to sample the output of the cells and to apply the proper resistance (load) in order to obtain the maximum power for any given battery and the temperature conditions. Furthermore, the SunAirPlus contains the robust ADS1015 A/D converters, INA3221 voltage and current sensing circuitry and an optional stepper motor controller which allows user to expand the project.

The controller output is connected to the driver of the DC motor in order to rotate PV panel in two axes until it faces the sun. In order to reduce the control problems, the two drive motors (for azimuthal and attitude angle) are decoupled, i.e., the rotation angle of one motor does not influence that of the other motor. Thus, the processor is the main control core and adjusts the two-axis motor so that the platform is optimally located for efficient electricity generation. The logic flow design of the system is implemented with an embedded processor control circuit. When the tracking control circuit is activated, the system performs tracking, energy conservation, and system protection, as well as system control and external anti-interference measures. External interference includes weather influences, such as wind and rain. Thus, the embedded processor acts as the control center and integrates the two-axis control chip.

The Field Programmable Gate Arrays (FPGAs) is considered as an appropriate solution to the behavioural control of the tracing system. Here we will give brief description of FPGA. A field-programmable gate array (FPGA) is an integrated circuit (IC) that can be programmed in the field after manufacture. FPGAs are similar in principle to programmable read-only memory (PROM). In this building project the FPGA supports an intelligent tracking prototype that move around and explore the area while sending back reports. At the same time the system may track the sun position and extract the weather conditions following the sensor information and compared it to the sun position using astronomical data. Furthermore, FPGA can be programmed to calculate solar efficiency and radiation emissions, managing a power budget tightly and providing a platform for testing new sensors and equipment as they become available.

2.1. The azimuth positioning and the elevation control

Figure 2 shows a motor driver shield for Arduino boards. Its features are as follows: it can control up to 4 bi-directional DC motors with an individual 8-bit speed selection, or 2 stepper motors (unipolar or bipolar) with a single coil, double coil, interleaved or micro-stepping and 2 connections for 5V 'hobby' servos connected to the Arduino's high-resolution dedicated timer [5]. The shield contains two L293D motor drivers and one 74HC595 shift register. The shift register expands 3 pins of the Arduino to 8 pins to control the direction for the motor drivers. The output enable of the L293D is directly connected to the pulse width modulation (PWM) outputs of the Arduino. Pulse-width modulation (PWM), or pulse-duration modulation (PDM), is a modulation technique used to encode a message into a pulsing signal. Although this modulation technique can be used to encode information for transmission, its main use is to allow the control of the power supplied to electrical devices, especially to inertial loads such as motors. This project uses a stepper motors to control the position of solar energy collectors. One of the possible concepts is to use bipolar stepper motors to rotate 2 photovoltaic cells around the altitude and azimuth axes. Alternative option is to use a servo motor geared for high-torque controls the azimuth positioning of the solar panel, and a 12 VDC linear actuator to control the elevation. It is important to note however, that stepper motors operate at full torque while the advantage of a servo motor is the ability to control torque in an application.

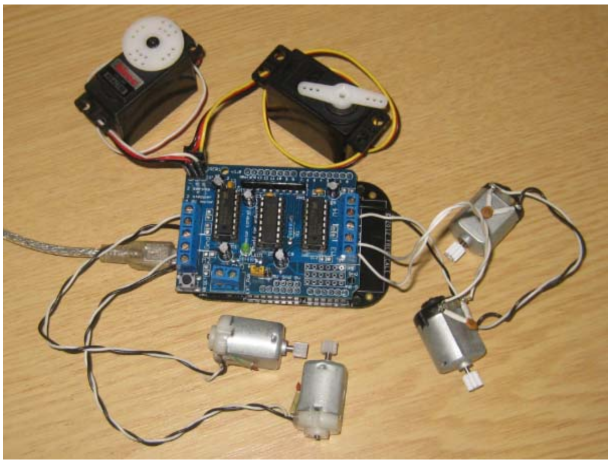

Figure 2. Arduino boards that can control up to 4 bi-directional DC motors with individual 8-bit speed selection, or 2 stepper motors (unipolar or bipolar)

2.2. Optical sensing and processing: The sun tracking sensor

LDR (Light Dependent Resistance) is used as a sensor for generating an electric signal proportional to intensity of light falling on tracking system. The idea is to mount the LDR at the focus of reflector which is directly mounted on solar energy collectors. The LDRs are connected via a 4-conductor cable to analog input pins of the Arduino; azimuth is determined by the light levels sensed by two of these side-by-side, and elevation is determined by averaging the levels of those two and comparing to the light sensed by the third LDR positioned below them. This arrangement allows the Arduino to orient the face of the solar panel towards the direction with the most light by driving the servo and linear actuator. The Arduino communicates with the Aduino Motor Shield using I2C over pins A4 (SDA) and A5 (SCL). The servo motor is controlled using an output from the Arduino on pin 9. The linear actuator has a built-in potentiometer for indicating its position. One end (yellow wire) of the pot resistor is connected to +5V. The other end is tied to the wiper (white and blue wires) which are then connected to pin A3 through a 10k resistor, forming a voltage divider allowing the Arduino to sense the position of the actuator.

2.3. The control subsystem / Raspberry Pi

The microprocessor Raspberry Pi 2 additionally enables image processing. This processor could run both the PiCamera, and the light emission diodes (LEDs).

2.4. LOGI FPGA communication to control subsystem (Raspberry Pi)

LOGI is an open-source closed-loop FPGA (Field Programmable Gate Arrays) development solution consisting of an ecosystem of FPGA hardware, software, drivers and applications which builds on the BeagleBone or Raspberry Pi platforms. Its distinctive feathers are as follows: it has gateway for MCU/CPU users to learn and use FPGA, seamless FPGA and CPU development on BeagleBone or Raspberry Pi, plug-and-play for Arduino compatible and Pmod peripheral modules, supports Raspberry Pi and BeagleBone Black. Furthermore it allows the dynamic reconfiguration of FPGA from the host CPU.

2.5. SunAirPlus: Single axis azimuthal tracker

SunAirPlus is a solar power controller / sun tracker / power supply system developed by SwitchDoc Labs to power Arduino and Raspberry Pi based systems. The board consists of solar panel/charge control system, a voltage booster, two A/D systems and GPIO interface circuitry systems. The interface systems is used to shift the voltage level and also for the servo motors as well as for the stepper motor control. The SunAirPlus contains robust ADS1015 A/D converters, INA3221 voltage and current sensing circuitry and an optional stepper motor controller built into the SunAirPlus board [6]. It does not have dual auxiliary system for azimuthal and elevation tracking. The internal A/D converters on the Arduino are sufficient for reading the photoresistors used by SunAirPlus to track the sun, but since the Raspberry Pi has no built-in A/D converters, SunAirPlus includes a circuit to do this. The current/voltage sensors are one of the most interesting parts of the SunAirPlus board since they allow user to receive dynamic and accurate information on how Solar Power system is running. Interfacing a stepper motor to SunAirPlus is a little more complicated but there is an excellent tutorial in [6-7].

Importantly, the SunAirPlus contains a space for a stepper motor driver utilizing the L293D Dual H-Bridge Motor Driver. L293D is a typical motor driver or Motor Driver Integrated Circuit (IC) which allows DC motor to drive on either direction. To be more precise, L293D is a 16-pin IC which can control a set of two DC motors simultaneously in any direction. It means that you can control two DC motor with a single L293D IC. It works on the concept of H-bridge. H-bridge is a circuit which allows the voltage to be flown in either direction. The voltage needs to change its direction for being able to rotate the motor in clockwise or anticlockwise direction. Thus, H-bridge IC is ideal for driving a DC motor.

Another interesting component is Quad Power Management Board that is also SwitchDoc Labs Product. This way the solar power susbsystem incorporate both the SwitchDoc Labs SunAirPlus solar power control board and the Quad Power Management Board. The Quad Power Management I2C Board allows user to switch on and off batteries, power supplies and solar panels. It is like an I2C controlled quad solid–state relay. Its technical features are the following: it has I2C controlled, four independent solid state relays each equipped with LEDs (where each LED is able to switch 20 V and 2.3 A), and four additional GPIOs.

2.6. I2C control subsystem

One of the challenges is to be able to develop and prototype/manufacture smart objects and systems that closely integrate sensors, actuators, innovative microelectromechanical systems (MEMS), embedded memory and communication capabilities. For this purpose, the I2C bus (Figures 3 and 4) connects together the vast majority of the sensors and the various motor controllers inside of SunTracker. The Inter-Integrated Circuit, I2C, is a multi-master, multi-slave, single-ended, serial computer bus invented by Philips Semiconductor (now NXP Semiconductors). It is typically used for attaching lower-speed peripheral ICs to processors and microcontrollers in short-distance, intra-board communication. In design, explored here, there are two groups of I2C busses, one for the microcontroller Arduino and one for the microprocessor Raspberry Pi. The SwitchDoc Labs I2C 4 Channel Multiplexer has potential to isolate address ranges. It has both 3.3V and 5.0V I2C busses and communicates to both, the Arduino

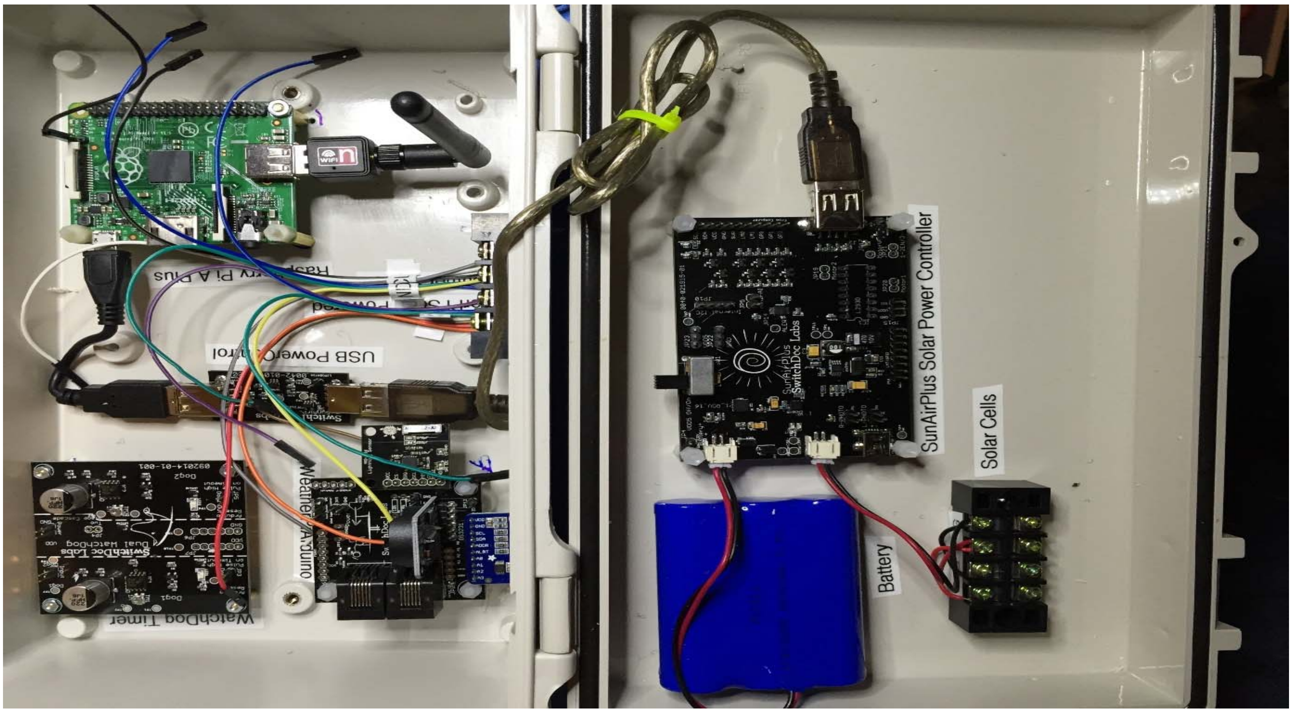

Figure 3. Solar tracking system built by WatchDoc Lab.

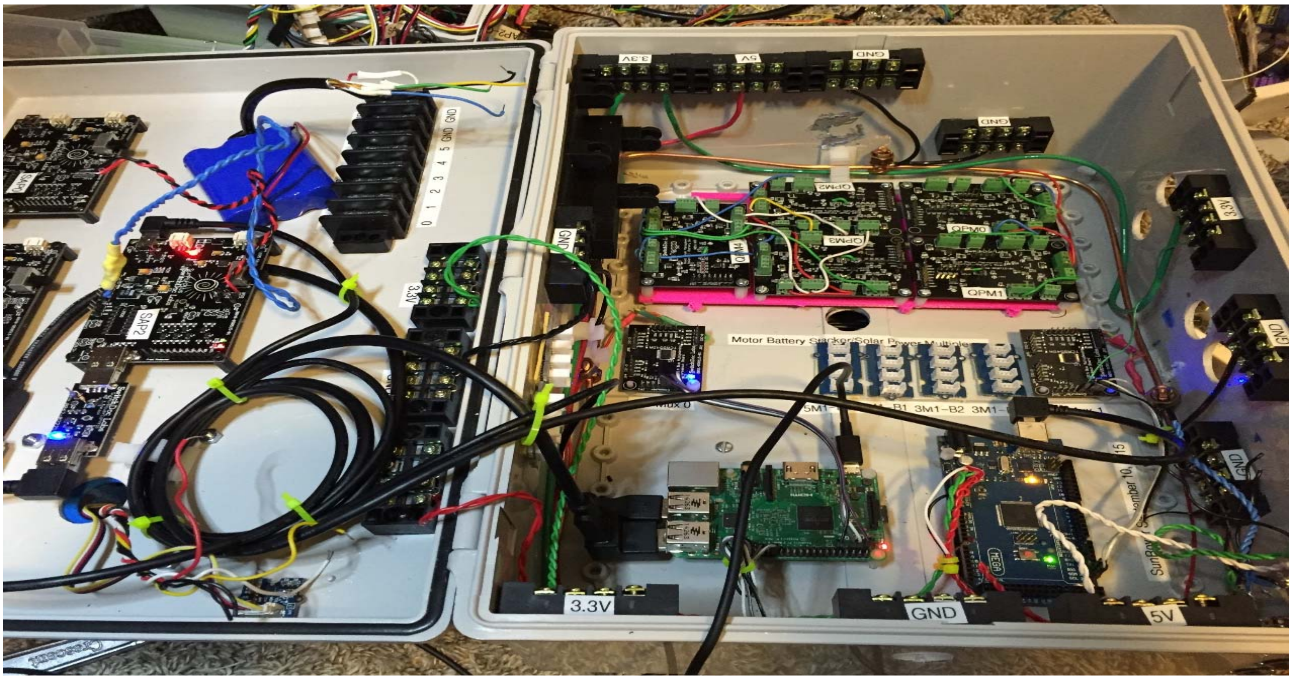

Figure 4. More expanded version of SolarSunAir [8]

and to the Raspberry Pi. This a very careful software that controls the two I2C Muxes; in electronics, a multiplexer (or mux) is a device that selects one of several analog or digital input signals and forwards the selected input into a single line. An external device can also communicate to the same I2C (like the motor controller).

3. The azimuthal orientation program

To perform heliostat system, an azimuthal orientation program based on statistical metrological data has to include the following functions: latitude and longitudinal input, location selection, geographical data acquisition, processing of data, calculating the number of vertical and horizontal steps which provides calculations of steps to be performed by bipolar stepper motor [9] that realize two axes orientation.

4. Conclusions and the possible potentials for advanced lab measurements

This paper presented the work in progress. The main motivation was to create innovative ecosystem for students through developing a modular and multifunctional set-up which might be use to demonstrate energy harvesting and for the lab-measurement exercise.

The first phase of project is completed and as outcome we presented the hardware design and features of the electronic components. The proposed design is based on open source software and hardware components. It includes also embedded technologies. The second phase – building the experiment and as its outcome – the measurement results together with study of correlations of variables, is under developing. The simulation/modelling of sensor behaviours is also under development. Lack of some sensor components and furthermore delay with the fabrication of some mechanisms further delayed the study.

The proposed tracking system scheme is tested on a hardware prototype experimental set-up. For future work, we will do performance testing in the field and iteratively adjust all parameters of the Sun tracking algorithms to develop an optimal tracking system.

The solar tracking design includes the solar tracking system, sun tracking system, sun tracker system, solar track system, sun positioning system, and sun path tracking with follow the sun position calculation (azimuth, elevation, zenith), sun trajectory, etc. It requires automatic solar tracking software and solar positioning algorithms. As a result of the apparent motion of the sun, a sun-path on-axis sun tracking system such as the attitude-azimuthal dual axis or multi-axis solar tracker systems use a sun tracking algorithm or ray tracing sensors or soft-ware to ensure that sun passing through the sky is traced accurately and his position deter-mined with high accuracy in automated applications using sun positional astronomy. Sun Surveyor and Sun Position computer software for tracking the sun are now available as pen source code, sources that are listed in [10]. Automatic sun tracking system software includes algorithms for solar attitude azimuth angle calculations required in following the sun across the sky. In using the longitude, latitude GPS coordinates of solar tracker location supports precision solar tracking by determining the solar attitude×azimuth coordinates for the sun trajectory. As emphasized in [10] many open source tracking algorithms are freely available. All above mentioned provides a rich pool of opportunities for lab exercises that encourage students to be engaged in energy prototyping innovations and research.

Although using sun-tracker is not essential, its use can boost the collected energy 10–100% in different periods of time and geographical conditions. But, it is not recommended to use tracking system for the small solar panels because of high energy losses in the driving systems. It was found that the power consumption by tracking device is 2%–3% of the increased energy. The proposed prototype can offer a tool for the systematic and comprehensive study on this issue. Furthermore, the reviews about sun-tracking methods for maximizing solar systems' output [11, 12] can be used for further upgrade or comparative studies. Image Pro-cessing described in [13] is an interesting proposal to be considered. Moreover, the heat transfer from heliostat to receiver that is delivered by solar radiation can be further investigated and adjustment applied to control heliostat. Among other topics, the energy returned on energy invested, is an interesting topic of research to be considered, too.

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