Solar Tracker Platform Development for Energy Efficiency Improvement of Photovoltaic Panels

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Abstract—**Solar energy systems have emerged over the last decades as the cleanest and most abundant renewable energy resources available worldwide. Solar trackers are devices specially developed to enhance the energy efficiency of solar energy systems. This paper presents the design and implementation stages of a reconfigurable hardware technology-based two-axis solar tracker platform, specially conceived to improve the energy efficiency of photovoltaic (PV) panels. The main module of this platform is the NI-MyRIO ready-to-use development system built upon a high-performance Field Programmable Gate Array (FPGA) processor that controls the entire solar tracker unit. Optimal tracking of the sun movement and obtaining the maximal energy efficiency rate is achieved by simultaneous real-time controlling both the captured sunlight intensity and PV cell temperature magnitudes. In this way, a robust and versatile positioning system has been developed that performs a high precision and accurate tracking pathway. All the control algorithms are implemented there under the LabView graphical programming software toolkit. The final solution boosts in a useful and modularized tracking system that looks useful in a wide range of applications both in industrial and domestic project sites with different power scales.**

Keywords—tracking system; energy efficiency; reconfigurable technology; FPGA processor; PV panel.

I. INTRODUCTION

It is well known that solar PV modules and panels work on their maximal energy conversion rate when their absorbing surface area remains perpendicular to the suns incoming rays. While static PV panels remain physically fixed in their surrounding environment, their mobile counterparts continuously are oriented directly to the suns radiant energy, in order to capture the maximal sun light intensity and achieve optimal energy transfer benefit. In fact, solar trackers are positioning systems for "orientating" panels toward the sun actual position. The challenge in getting the maximum solar power conversion efficiency is to ensure that the complete PV array (or module) is optimally oriented with regards to the incoming sunlight all day long and in everyday of the year. Obviously, the ideal solar tracker platform is the one mounted along the equatorial latitude, in a similar way that are placed the high performance telescopes or complex satellite communication antennas. Unfortunately, such ideal solutions would be very expensive and also unreachable for most of the industrial and domestic customers. However, it is no doubt that nowadays solar trackers are rising in popularity and represents highly accepted solutions in a wide range of solar energy conversion applications. In this circumstance it looks not without importance to take a short survey and evidence their major advantages and drawbacks in concrete situations.

First of all, among the major advantages of solar trackers may be mentioned the followings [1]:

- the energy conversion rate of a given size PV module used in a solar tracker mounting configuration is significantly higher (with around 10-20%) that its corresponding fixed-mount counterpart with the same surface or array;

- are ideal for optimizing land usage because produces more energy that the fixed-mount solution ones in the same space;

- maintenance issues related to tracking systems have been greatly reduced thanks to the important advancements reached in mechanics-, electronics- and digital system's reliability.

Beside all the above ranked, solar trackers also shares important shortcomings, such as:

- are more complex electromechanical systems that their fixed-mount counterparts;

- they are more expensive that their stationary counterparts;

- tracking systems accommodate with more difficulty harsh environments in comparison with the fixed-mount solar PV panel systems;

- they require higher supervising and service than (cleaning, conservation and maintenance) than the fixed-mount similar devices.

In spite of all these advantages/disadvantages mentioned, solar tracker systems emerges as a well-fitted solution for a wide range of industrial and domestic applications, ranging from microwatt order even to megawatt order installed power sites.

II. SOLAR TRACKER SYSTEMS THEORETICAL BACKGROUND

In essence, solar tracking systems currently being used are divided into two main categories: single-axis tracking systems and dual-axis solar tracking systems. In the first case solar PV panels can turn around their central axis (tracking the East-

West solar motion, *E-W*), the second ones has two independent rotation axes that allows it a two-degree of freedom and orientate as a mirror that captures the solar light in a perpendicular incidence. In this last situation both the East-West and South-North (*S-N*) axis motion is performed in the same time. Such systems in international references are also named as solar panel azimuth-zenith orientation systems [2]. For better understanding the above used terms, let's consider the simple explications given next in figure 1.
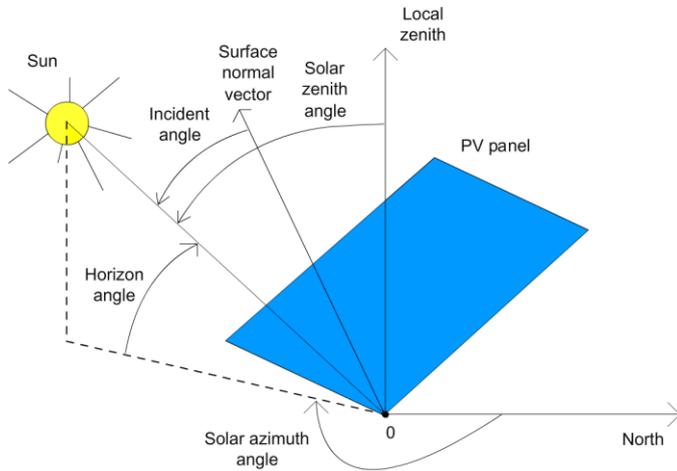
Fig. 1. Definition of the azimuth and zenith angles in solar orientation systems

According to this figure, the azimuth is the compass angle of the sun as it moves through the sky from *E* to *W* during the 24 hours of the day. The zenith is the angle between local zenith vector and the position of the sun in the sky. The entire solar panel orientation strategy relies upon these two values.

In the related international references often is mentioned that solar tracking systems performs in essence two main operations at the same time: solar panel rotation and solar panel tilt [2]. Solar panel orientation refers to the azimuth angle setting during the day. Therefore, for orientation the PV platform it should be turned towards the terrestrial equator line and the panel will catch the greatest amount of solar radiation.
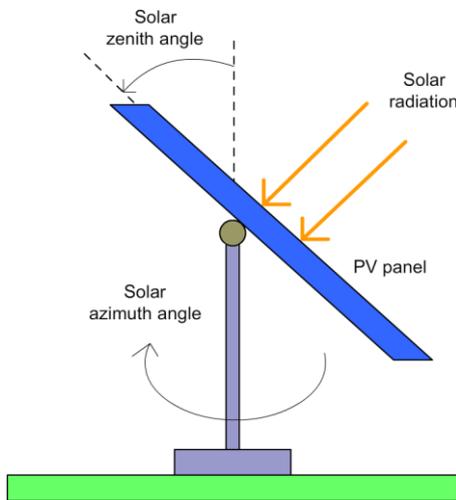
Fig. 2. Solar tracker system operation principle

In a similar way, solar panel tilt refers to the zenith angle setting. Results that such kind of a solar tracker system should operate according to the basic principle exposed before in figure 2. This is in fact a dual-axis solar tracking system allowing a two-degree of freedom to orientate the PV panel or module. In this way the solar radiation may be captured in a perpendicular incidence and the platform can operate on its maximal energy conversion rate achieving its highest efficiency possible.

On the other hand is well known that the general efficiency of a PV module also depends by variables such as the ambient temperature (T_A), the cell operation temperature (T_C), or material properties. In reference [3] this interdependence is expressed with the mathematical relationship:

$$\eta = \eta_r \cdot [1 - \beta_r \cdot (T_C - T_r) + \log_{10} \cdot G(t)]. \qquad (1)$$

In this formula η_r means the energy conversion efficiency at standard test conditions (STC: G_r=1000 W/m^2, T_r=25°C), the temperature coefficient β_r usually is given by the PV manufacturer, and γ is a material coefficient. The temperature coefficient is given by the equation:

$$\beta_r = \frac{1}{T_o - T_r}, \qquad (2)$$

where T_0 is the high temperature at which the conversion efficiency drops down to zero [4]. For variations of ambient temperature and irradiance intensity it is considered the empirical relationship which determines the operating temperature of the module [5, 6]:

$$T_C = \frac{(T_N - 20)}{0.8} \cdot G + T_A \qquad (3)$$

where T_A represents the ambient temperature *(K)* and T_N is the nominal operating cell temperature *(K)* given in the manufacturer's datasheet. Results that:

$$\eta = \eta_r \cdot [1 - \beta_r \cdot [T_A - T_r + (T_N - 20) \cdot \frac{G(t)}{G_r}] +$$
$$+ \gamma \cdot \log_{10} \cdot G(t)] \cdot 100. \qquad (4)$$

In most of cases authors consider β_r=0.0045K, T_N=45°C, and η_r is given as a catalogue data. The equation (4) defines completely the PV module energy conversion efficiency as function of the ambient temperature and solar irradiation intensity variations. Results that in order to achieve the highest efficiency rate is not sufficient to capture only the maximal solar radiation intensity, it is recommended also to measure the ambient temperature. This last observation lead to the conclusion that maybe is better to conceive a two-axis solar tracking system that operates as function of two external variables: the solar radiation intensity *G(t)* and the ambient temperature T_A. Then, once these two magnitudes have been measured may be found the maximal value of the conversion efficiency. In other words, is better to maximize the energy conversion rate as function of booth these two variables.

III. THE SOLAR TRACKER PLATFORM DEVELOPMENT

Considering the theoretical remarks unfolded in the previous paragraph, it is proposed a two-axis solar tracker platform as is presented in the block diagram shown next in figure 3. There is plotted a specially conceived mechanical structure that supports the PV panel selected for experimental measurements and laboratory test operations.
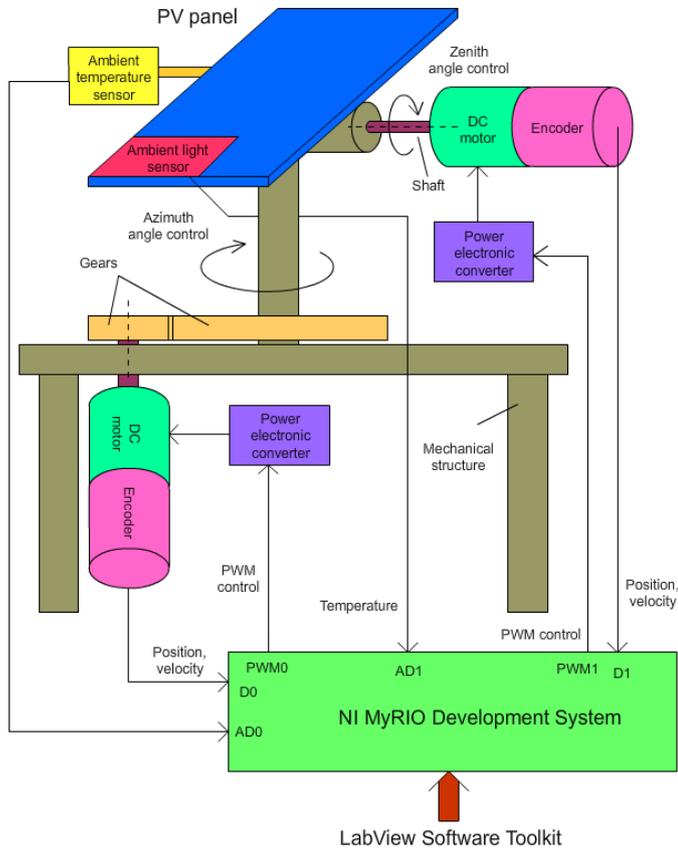
Fig. 3. The solar tracker platform block diagram

The solar tracking orientation of the PV module is performed by using two DC motors that ensure the optimal azimuth- and zenith angle control (Fig. 4).
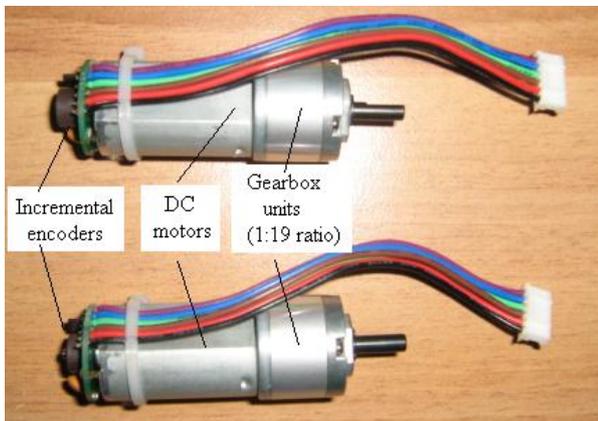
Fig. 4. The DC motors used for azimuth and zenith angle control

These are in fact DC motor/Gearbox units with rugged, heavy duty construction that includes incremental encoder for sensing rotation and speed [3]. The gear ratio is 1:19 and the motors may be supplied with custom voltage up to 12V. Figure 4 shows a picture that evidences the electromechanical construction of these two modularized DC motors. They are driven by two stand-alone Digilent Co. made Pmod HB5-type power electronic converters [8].

Fig. 5. The Pmod HB5 converter PCB for DC motors drive [8]

The HB5 converter is in fact a 2A H-bridge circuit for small to medium size DC motors drive. The PCB also include two sensor feedback pins to capture position/velocity information from the DC motor/gearbox, respectively other two pins to enable the H-bridge full operation and to set up the servomotor rotation sense [8]. The solar radiation intensity it is measured by using the Pmod ALS sensor that is physically mounted right on the surface of the analyzed PV panel [9].

Fig. 6. The Pmod ALS ambient light sensor PCB [9]

The Digilent Co. Pmod ALS converts light intensity into digital information with 8-bit resolution by using the ADC081S021 analog to digital converter IC. The board communicates with a host board via the serial-parallel interface protocol. It is delivered a single reading in a 16 SCLK clock cycles (Pmod ALS requires the frequency of SCLK between 1÷4MHz) and the location of this communication line is marked on the Pmod header. The recommended optimal supply voltage of the ALS sensor is 3.3V [9]. Next, for the ambient temperature measurement it is used the Pmod TMP3 digital sensor that is mechanical fixed near to the PV module [10].
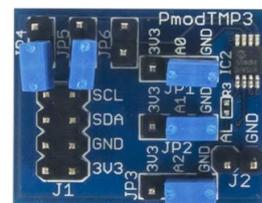
Fig. 7. The Pmod TMP3 temperature sensor PCB [10]

The Digilent Pmod TMP3 temperature sensor has been built around the TCN75A integrated circuit that provides users with

up to 12 bits of resolution information about its environment temperature. The typical accuracy of this circuit is ±1 ˚C, with a maximal resolution of 0.0625 ˚C and 30÷240 ms conversion time. The TMP3 communicates with a host board via the well-known I^2C protocol. The serial clock and serial data lines need to be pulled up to the logic high voltage level through pull-up resistors [10].

Finally, the information captured from the Pmod ALS and Pmod TMP3 sensors is acquired by the host board NI MyRIO Development Kit. This is a ready-to-use compact embedded system manufactured by the National instruments Co. that provides analog input, analog output, digital input/output and audio channels to communicate with external devices [11]. The analog input channels are placed on MyRIO expansion ports *A* and *B*, on connector *C* and a stereo audio input connector. All these input channels are multiplexed to a simple analog-to-digital converter. The analog output channels are placed on the same connectors. Each one has a dedicated digital-to-analog converter therefore they allow simultaneous digital/analog conversions. Toward, the NI MyRIO development system provides 16bit digital input/output lines both on the *A* and *B* connectors, UART port, buttons, status and user LEDs, four PWM channels for motor control purposes, respectively three embedded accelerometers [11]. In accordance with the implementation strategy plotted in figure 3, the temperature and light intensity information are captured by using the analog input channels of the MyRIO system, the two DC motors will by driven via the available PWM channels and the position and velocity information from the encoders are acquired through digital input lines. In this way a versatile and high performance embedded digital system may be implemented for real-time control of the solar tracker platform.

IV. EXPERIMENTAL IMPLEMENTATION

Obviously, the design and development steps presented in the previous paragraph have been followed by implementation and test operations. Figure 8 presents the laboratory setup built-up to experiment the solar tracker platform prototype.
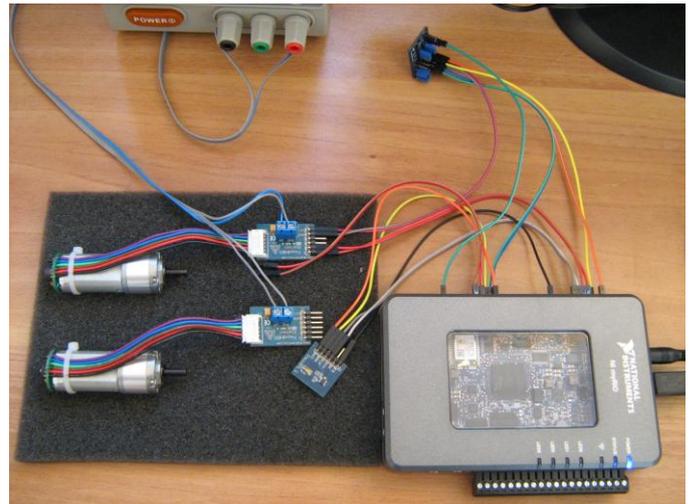
Fig. 8. The NI MyRIO development kit interfaced with the temperature and ambient light sensors and two DC motors

There it is possible to identify the NI MyRIO development board that is interfaced with the rest of components of the tracking system. The TMP3 temperature sensor it has been wired to the *A* connector of the board, the Pmod ALS ambient sensor to the *B* connector and the Pmod HB5 inverter units to each one of the above two expansion connectors. The power converter modules drive the two DC motors of the azimuth and zenith angles control. A full picture of the entire development setup for laboratory experiments and test operations is shown next in figure 9. In this situation the digital system communicates with a host PC computer on which has been developed the full control algorithm under the LabView graphical software programming platform. The two DC motors are supplied by using a 12V power unit.
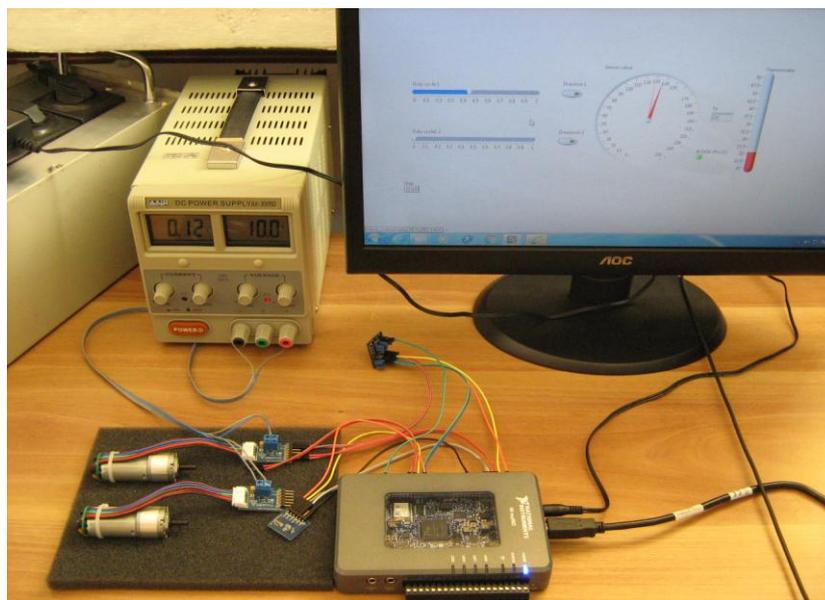
Fig. 9. The laboratory setup for test operations and experiments

On the PC screen may be observed the LabView front panel of the application that controls the solar tracker platform. There it is plotted an indicator that graphically shows the variation of the measured ambient temperature, one other indicator that plots the instantaneous value of the acquired ambient light intensity. Two slide-switches adjust the duty cycle of the generated PWM pulses that controls the DC motors velocity respectively two user buttons sets the rotation sense of these servomotors. A more detailed view of the above discussed control panel implemented as a virtual instrument (VI) is presented below in figure 10.
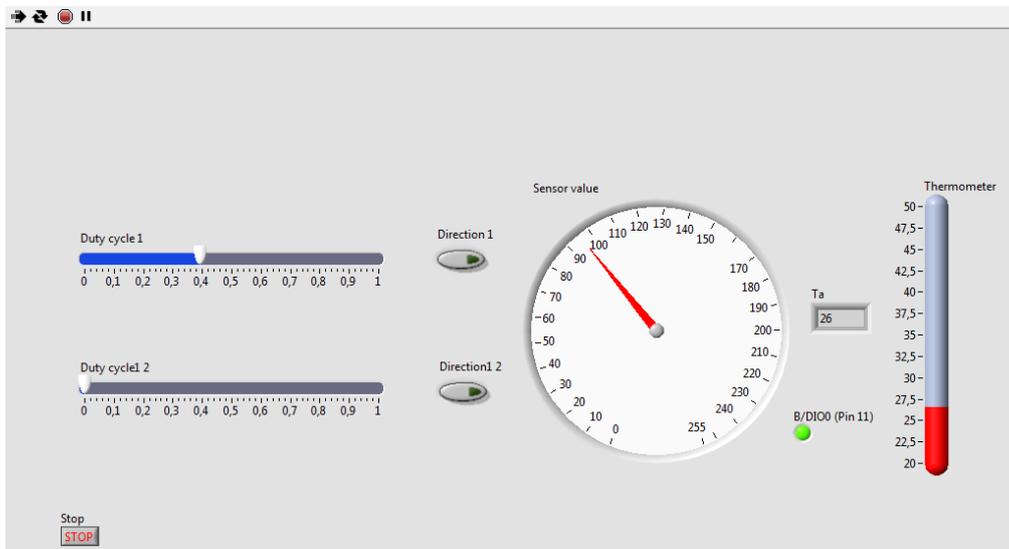
Fig. 10. The LabView front panel of the VI developed for the solar tracking platform control
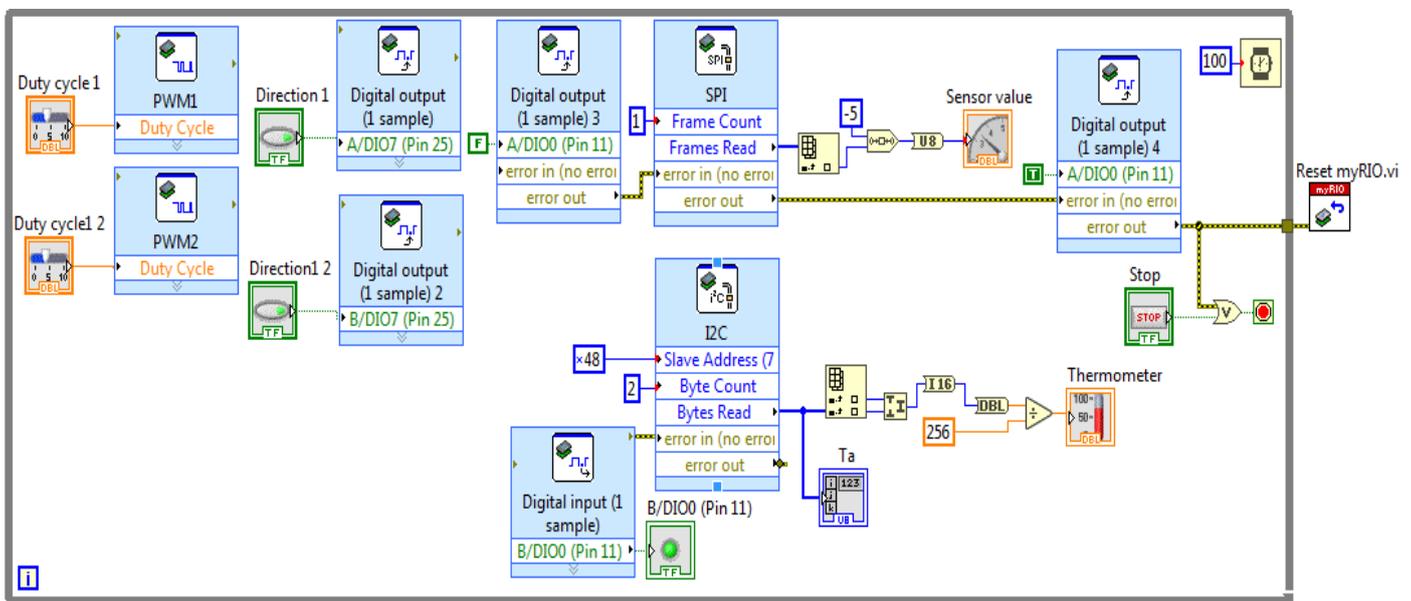
Fig. 11. The LabView block diagram of the VI developed for the solar tracking platform control

The corresponding block diagram of the VI is plotted next in figure 11. There are evidenced the standard VI component blocks implemented on the digital control system. For example, the two PWM blocks (*PWM1* and *PWM2*) provides the constant frequency but variable duty cycle pulse trains for the DC motors drive. Their rotation sense has been set previously via the *A/DIO7* and *B/DIO7* digital output lines.

In a similar way, the information corresponding to the instantaneous ambient temperature is captured by using the *I2C* standard VI for serial communication that has been programmed with the constant values prescribed in the catalogue datasheet of the used TCN75A IC. After same minor adjustments the acquired information becomes suitable for plot in decimal °C units. The *SPI* (Serial Parallel Interface)

VI ensures the high precision measurement of the ambient light intensity and plots the processed information on an adequate rotational indicator. If any error occurs during all these measurement operations the NI MyRIO board will be turn on into its initial reset state.

However, entire solar tracking system is still under full development. The presented program operates properly but is missing yet some calibration and precision adjustment tasks, or measurements regarding the PV panel overall energy efficiency. Therefore the presented program is not finished yet and is under a continuous development and improvement process. Additionally a concrete algorithm for precise tracking the sun movement in the sky is waiting for implementation and test operations. In spite of all these shortcomings, the presented and implemented solar tracking platform looks an efficient and high reliability embedded system for researches and studies that targets the energy efficiency improvement of modern solar PV panels or modules.

V. Conclusions

In international references a plenty of high quality research is dedicated to solar energy transformation processes in renewable electrical energy. Between these an important amount is focused to improve energy efficiency of PV panels or modules. This paper presents the development steps of a reconfigurable hardware technology-based two-axis solar tracker platform specially conceived to improve solar PV panel's energy efficiency. The main idea is that both the ambient temperature and ambient light intensity information simultaneous real-time control is necessary to reach the highest energy efficiency rate of a photovoltaic module. The solution to use the ready-to-use NI MyRIO development kit with the adequate standard interface modules looks a proper choice in order to achieve a high performance and versatile embedded solar tracking control system. This setup provide high reliability and accurate tracking, respectively looks useful in a wide range of applications both in industrial and domestic project sited with different power scales. The presented solution it is also recommended as a useful system for researchers involved in studies related to improve PV panels efficiency and solar energy conversion rate.

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