Hindawi Publishing Corporation
Journal of Solar Energy
Volume 2015, Article ID 149852, 6 pages
http://dx.doi.org/10.1155/2015/149852

*Research Article*

# A Novel Solar Tracker Based on Omnidirectional Computer Vision

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Received 29 September 2014; Accepted 11 January 2015

Academic Editor: Mohamed Sabry A. Abdel-Mottaleb



This paper presents a novel solar tracker system based on omnidirectional vision technology. The analysis of acquired images with a catadioptric camera allows extracting accurate information about the sun position toward both elevation and azimuth. The main advantages of this system are its wide field of tracking of 360° horizontally and 200° vertically. The system has the ability to track the sun in real time independently of the spatiotemporal coordinates of the site. The extracted information is used to control the two DC motors of the dual-axis mechanism to achieve the optimal orientation of the photovoltaic panels with the aim of increasing the power generation. Several experimental studies have been conducted and the obtained results confirm the power generation efficiency of the proposed solar tracker.

## 1. Introduction

Solar energy is one of the most promising and fast growing sources of renewable energy. This essential technology aims to replace costly finite fossil fuel consumption by converting free, natural sunlight into clean, renewable electric power. Many innovative research studies are conducted in this field, using advanced measurement and analysis technology to decrease the cost per watt, increase adoption, improve yield, and try also to expand the market through innovative applications. In this same perspective, this study deals with the development of a new acquisition module for optimal photovoltaic panel automatic orientation.

Solar trackers are systems that orient automatically solar collectors such as flat photovoltaic panels, concentrated photovoltaic (CPV), or concentrated solar thermal (CSP) towards the sun. These systems increase the power generation by optimizing the angle of incidence between incoming sunrays and solar collectors [1–5].

There are several common concepts of sun trackers. Generally, they are classified into two major categories: passive trackers and active trackers. Passive ones are those who do not involve any electrical equipment, they are usually based on thermal expansion of matter (as Freon) when active trackers are based on electronic devises. We can also distinguish between sun-tracking systems regarding their mechanical system degrees of freedom. Those who have one degree of freedom are called single axis trackers such as horizontal single axis trackers (HSAT), vertical single axis trackers (VSAT), or tilted single axis trackers (TSAT). Dual-axis trackers have two degrees of freedom making them more efficient. As confirmed in [6, 7], the solar energy generation can be increased by 41% in midlatitude regions when using two axis tracking systems. Abdallah in [8] had achieved a comparative investigation of the effect of using sun-tracking systems on the voltage-current characteristics and power generation of flat plate photovoltaic panels. Experimental results of his study show that the output power increases by 15% in the case of north-south axis tracker, 34% for east-west axis tracker, 37.5% for vertical axis systems, and reaches 44% (yearly) when using a dual-axis tracker. Such results still depend mainly on characteristics of the experimental setup and the period during which the experimental study took place. In the review of Mousazadeh et al. [9], it is reported that the experimental gain of a single axis trackers varies between 20% and 34%. And it ranges from 23% to 44% for dual-axis trackers.

Several technics of sun tracking have been developed and evaluated in the literature. All of them have advantages and drawbacks. For example, passive trackers are quite simple and do not consume any electrical energy but relatively are less efficient and not operational at low temperatures. Good reviews of sun-tracking means were presented in [9, 10] where the cons and pros of each one were discussed.

Conventionally, active sun trackers based on photosensors (Figure 1) are the most commonly used for determining optimal orientation. Various configurations have been developed and used in the literature [11–15]. However, these conventional techniques have several drawbacks as the lack of precision, a limited field of tracking which is unsuitable for high latitude earth regions, and sensitivity to weather changes. Photosensors use the shading effect to determine the optimal orientation towards the sun. When solar irradiation is not sufficiently intense to create enough luminosity difference, they become inoperative. It should be noted that those sensors have a narrow field of tracking of 180° maximum. Some solutions have been presented in the literature to extend the field of tracking. In [16], authors presented a simple design of a sun tracking system with 360° tracking angle; unfortunately, the proposed concept is a single axis tracker; this has limited its performance.

Recently a new research trend tried to exploit the artificial vision in the field of renewable energy. In [17], the authors have developed a simplified and automatic heliostat positioning offset correction control system using artificial vision techniques. In this paper, we propose an automatic dual-axis sun-tracking system based on image processing and omnidirectional vision technics. The field of view of the acquisition device covers 360° horizontally ($\theta$) and 200° vertically ($\varphi$). The need of a wide field of view is justified given that azimuth sun path exceeds 120° in many earth regions. In Rabat (Morocco) as an example, the sun path ranges from 120° to 240° east west from winter to summer (Figure 2(a)).

Therefore, by providing a wide field of view, an omnidirectional camera can be very useful for sun tracking. Moreover, unlike classical sensors, catadioptric cameras are able to provide accurate information about the sun position at any time of the day. Practically, the sun position is provided in spherical coordinates $(\theta, \varphi)$ extracted from the acquired omnidirectional images as shown in Figure 2(b).

## 2. The Omnidirectional Sun Tracking System: Design and Control

To study the differences, advantages, and weak points of the proposed solar tracker concept, an experimental prototype named Helianthus360 was designed and constructed. It consists of four major modules: the acquisition unit represented by the catadioptric camera, the control unit, the dual-axis turning mechanism, and a photovoltaic panel. Figure 3 illustrates the architecture of Helianthus360. This dual-axis tracker can achieve 360 degrees azimuth and 90 degrees elevation movements.

The sun position acquisition module is a catadioptric camera composed of a standard CCD camera and a spherical mirror with a radius of 30 mm. This vision system provides quasihemispherical images of the sky as shown in Figure 4(a). Those images are analyzed by the processing unit to extract the spherical coordinates of the sun spectrum, associated with the catadioptric system mark. Once the corrective action is generated, the processing unit sends instructions to the command circuit. This one processes the control actions and drives the motors to achieve the desired solar panel movements. The command circuit is composed of a micro controller and power transistors. It is performing intermediary actions between the processing unit and the mechanical actuators.

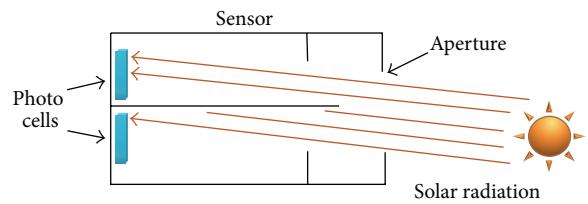



Figure 1: Illumination balancing photosensor.

As described in Figure 4, this sun tracking approach is based on image processing algorithms. Indeed, once the omnidirectional image is acquired, it is converted from RGB to HSV color space; thus, the image will be represented by tree matrixes; Hue (H), Saturation (S), and Value (V). According to the matrix V, the next step consists of determining the maximum value of pixels intensity. Then, a thresholding step is performed in order to generate a binary image (Figure 4(b)), which characterizes the sun spectrum, this process is schematized in Figure 4(c).

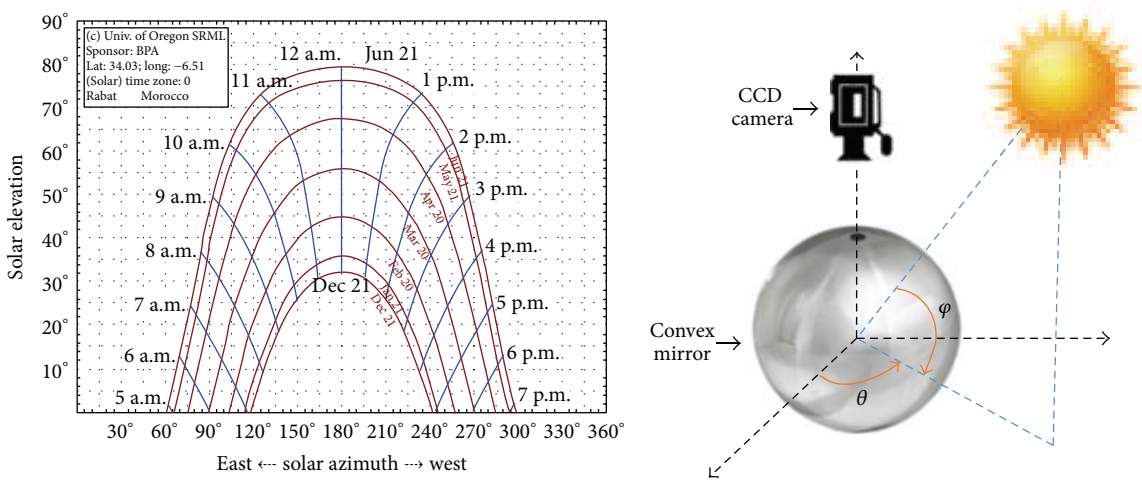
The sun spectrum centroid coordinates are calculated according the following equations:

$$\theta_c = \sum_{i=1}^{n} \frac{\theta_i}{n}, \qquad \varphi_c = \sum_{i=1}^{n} \frac{\varphi_i}{n}. \tag{1}$$

$\theta_i$ and $\varphi_i$ are spherical coordinates of each sun spectrum's pixel in the binary image according to the catadioptric imaging system mark (see Figure 2), when $n$ is the total number of those pixels. Henceforth, the sun position is identified by $\theta_c$ and $\varphi_c$ coordinates of the sun's centroid. The fundamental idea of the sun tracking process is to achieve the required mechanical movements toward both elevation and azimuth orientations with the aim of bringing back the sun centroid to the omnidirectional image center, which corresponds to the optimal panel orientation toward solar-rays. Since the main optical axis of the omnidirectional camera is calibrated to be perpendicular to the panel plan.

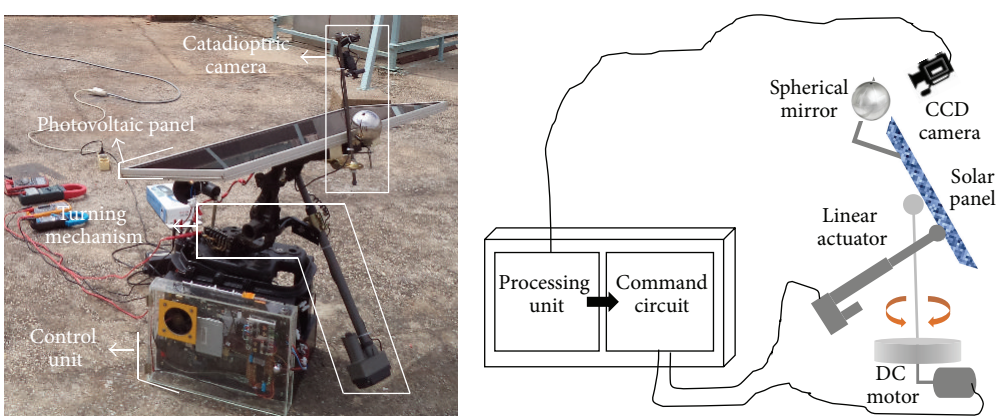
## 3. Experimentation

In this section, the results of the developed approach will be presented. In order to evaluate the efficiency of the




(a) (b)

Figure 2: (a) Sun path chart for Rabat, Morocco. (b) Illustration of sun localization using a catadioptric camera.




(a) (b)

Figure 3: (a) Helianthus360 solar tracker. (b) Architecture of the proposed solar tracker.

presented solar tracker, two experimental studies have been conducted. The purpose of the first one is to compare the power generation of a photovoltaic panel embedded on the computer vision based solar tracker to a fixed one. Outdoor experiments started from July 17, 2013, to September 20, 2013. The two identical photovoltaic panels generate a voltage of 18 V, with a peak power of 12 W. To avoid the influence of the batteries charge level on power generation, the panels were connected directly to an over estimated resistive load of 15 W. The fixed panel was oriented as common toward south with an elevation of 34° which corresponds to Rabat (Morocco) latitude. The measurements were accomplished for both voltage and current generation for each panel in the same conditions. Figure 5(a) shows the obtained measurements on July 17, 2013, from 11:42 AM to 5:41 PM during a partly cloudy day. When Figure 5(b) represents obtained measurements on September 20, 2013 (Sunny day), from 9:30 AM to 5:30 PM.

The power generation gain $E_h$ of the studied solar tracker $E_h$ is given by the following equation:

$$E_h = \frac{P_h - P_f}{P_f}, \tag{2}$$

where $P_h$ is the power generation of Helianthus360 and $P_f$ is the power generation of fixed panel.

It can be seen from both measurements that power generation of the solar tracker is constantly higher than the fixed one. In fact, during the first day of experimentation (Figure 6(a)) the minimum increase of power generation increase from Helianthus360 is 30% with an average daily-total power generation increase of 92%. The effect of clear weather was noticeable during the second experimental investigation (Figure 6(b)) where the minimum of $E_h$ was 44% and the average $E_h$ reached 94%.

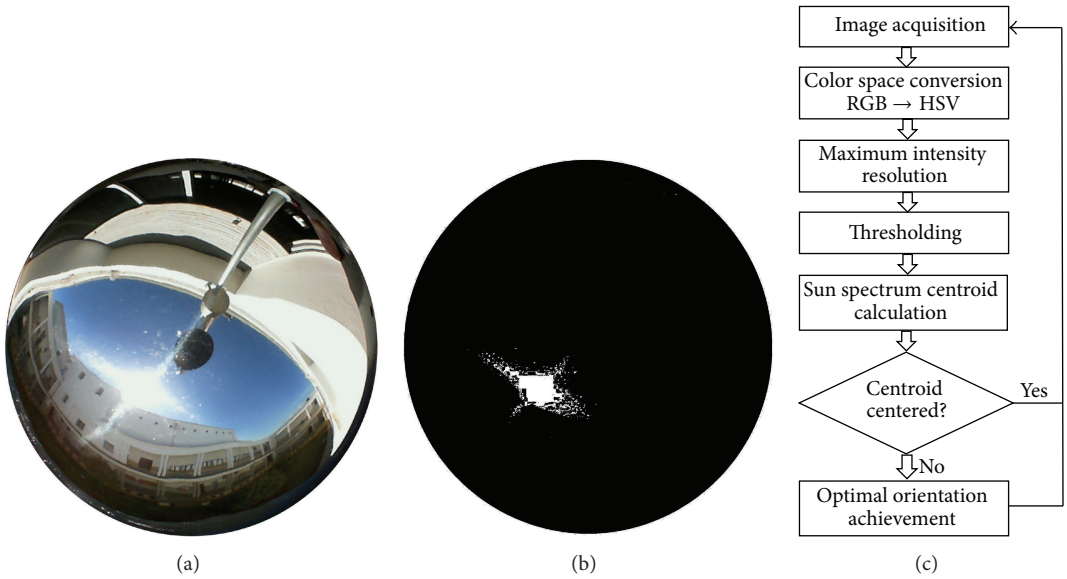



Figure 4: (a) Sample omnidirectional image of a partial sky. (b) Omnidirectional image after thresholding. (c) Schematization of the sun tracking process.

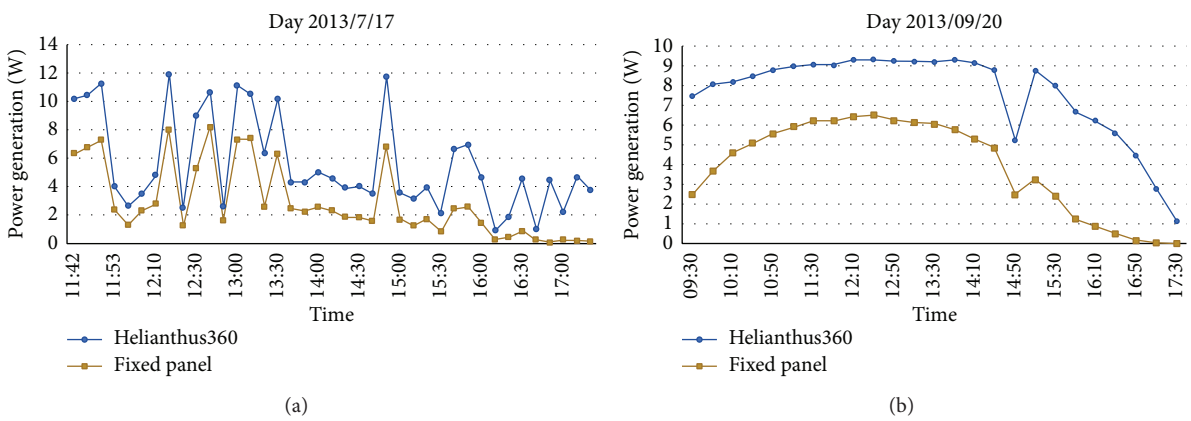
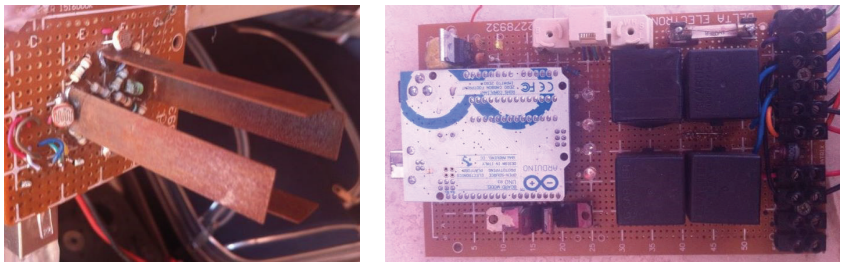



Figure 5: (a) Measurements on September 20, from 9:30 AM to 5:30 PM. (b) Measurements on July 17, 2013 from 11:42 AM to 5:41 PM.


Figure 6: (a) First experiment July 17, 2013. Daily solar total radiation: 25.7 MJ/m$^2$ day. (b) Second experiment. September 20, 2013. Daily solar total radiation: 21 MJ/m$^2$ day.



(a) (b)

Figure 7: (a) Illumination balancing acquisition module. (b) Command circuit of the classical solar tracker.

The second stage of the experimental investigation consists of comparing daily-total power generation gain of the proposed solar tracker to a classical one. The classical solar tracker employs the same dual-axis mechanism but uses a four LDRs (light dependent resistors) illumination balancing sensor as an acquisition module of optimal orientation (Figure 7(a)). Two horizontal LDRs provide information about azimuthal sun orientation; the two vertical ones are used to determine the orientation towards elevation. The four LDRs are separated by four perpendicular opaque elements. When the plate of this acquisition module is well positioned towards the sun, there is no shadow, and all resistors receive the same amount of sun light and then have approximately the same resistance. Values of these resistors are evaluated in real time using a microcontroller which drives the two DC motors via a command circuit (Figure 7(b)) to achieve optimal orientation. Such solar tracking techniques have been widely adopted in the literature because of the simplicity of their conception [18–22].

Power generation measurements have been collected during five days of May 2014. Voltage-current characteristics were measured daily, from 08:00 PM to 05:30 PM every 30 minutes. The daily-total power generation gain of both trackers was calculated relatively to a fixed panel. Obtained results are given in Table 1.

Table 1: Daily-total power generation gain (DTPGG) of both compared solar trackers.

| Date | DTPGG of Helianthus360 (%) | DTPGG of the classical tracker (%) |
|---|---|---|
| 05/25/2014 | 120 | 114 |
| 05/26/2014 | 111 | 104 |
| 05/27/2014 | 134 | 123 |
| 05/28/2014 | 121 | 119 |
| 05/31/2014 | 131 | 111 |

## 4. Discussion and Perspectives

From the present experimental results it can be shown that the power generation gain using the proposed sun tracking system is considerable. The power generation gain is increased further by 30% at least and can reache 135%. Those results still relative to the short-term experimental study conducted. A long-term study should be examined as a goal. The second experimental study has proved that the computer vision based solar tracker provides constantly a higher power generation gain than a classical one. In fact, the sun's position is resolved with a fixed tracking accuracy of 0.175 rad, regardless of the solar radiation. While the tracking precision of a classical tracker still depends on the illumination conditions and implicitly on weather. We would point out that when the sun light is not sufficiently enough to generate shade, the classical tracker still blocked. And once the sun is out of its field of tracking, the tracking process stops. On the other hand, by using the catadioptric camera as an acquisition module, the tracker is still able to resume the tracking process in the morning, even if the panel was oriented towards the direction of sunset.

It is well known that every active solar tracker consume energy as it optimizes its production. This energy consumption is dissipated by the processing units and the electrical actuators. In the case of the proposed system, the processing unit consumption is about 12 W, and even if the tracking is performed in real time, the two DC motors are actioned only for about 3 seconds every 30 minutes; thus, their energy consumption is negligible. However, for the purpose of a precise and objective comparative study, both processing unit and motors were power supplied by an external source. It is obvious that the proposed system is efficient only if the increase of power generation exceeds internal power consumption, a compromise that should be assumed during the system design and dimensioning phase. The proposed system can be enhanced by using a small onboard computer with less energy consumption.

Mobile units such as caravans, mobile medical units, and boats equipped with solar panels, certainly can derive great benefit from the use of the developed solar tracker. Indeed, it has three main advantages in terms of optimizing energy production efficiency, compared to other tracking techniques: the first one is that the process of tracking requires no supervised initialization, thanks to the wide field of view of its acquisition module, the position of the sun can be located at any moment. The second advantage to note is that the process of tracking is done regardless of geographic location. The last one concerns the remarkable impact on energy efficiency of the proposed system resulting of a real-time tracking.

Of course, this solar tracker will be of high interest in the case of an industrial scale energy production unit. Indeed, in this case, the initial investment is undoubtedly important and requires maximum profitability. Virtually, the proposed concept can be extended to optimize the production of a photovoltaic solar energy station. With regard to the concept of the tracker, which combines separate modules, namely, acquisition unit represented by the catadioptric camera, processing module, and the mechanical module, the extension of its use in the case of several panels needs only one acquisition and processing module and an adaptation of the mechanical system. This adaptation can be performed according to two concepts: the first is to connect several solar panels mechanically; in this case only, two motors will be required to ensure the movement of elevation and azimuth which are the two degrees of freedom required. The second concept we suggest is to control the solar panels separately with two mechanical actuators mounted on each panel. It should be specified that the choice of a concept to another depends on characteristics of the planned solar power station; these characteristics relate to the unitary power of selected panels, size, weight, and the geometry of the park.

## 5. Conclusion

We presented a novel solar tracker based on computer vision technology. It uses an omnidirectional imaging system to provide accurate information about the sun position toward both elevation and azimuth. The tracking is done in real time independently of the spatiotemporal coordinates with less sensitivity to weather conditions. The proposed system provides a wide field of view of 360° horizontally and 200° vertically. Several experiments were conducted comparing the power generation efficiency of this solar tracker with a fixed panel. The reliability of this concept was confirmed.

## Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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