Tracking of photovoltaic facilities based on omnidirectional sensor

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Abstract

This work describes an omnidirectional sensor that tracks the celestial vault and determines the direction of maximum solar irradiance from instantaneous measurements. For that purpose, the sensor incorporates an ex professo algorithm that considers the directions for which inter-shading between collectors would occur. Additionally, the sensor has been developed with free software and hardware, thus contributing to open science. As a result, technologists and scientists will be able to optimise the presented system by enriching and improving it. In that way, the omnidirectional sensor presented is a low-cost device that can work as a position server for dual-axis solar trackers in photovoltaic facilities, optimizing the trajectory of the trackers and the radiative capture and energy production of the PV plant. The aim is to improve the performance of the solar collectors by adapting to changing weather conditions, thus avoiding the often-complex tracking.

Keywords: Free and open-source hardware (FOSH), Sun Position Sensor, Omnidirectional Sensor, Solar Trackers, PV Plants, backtracking.

1. Introduction

In the last decades, Photovoltaics (PV) is becoming a promising source of electricity generation (Eldin et al., 2016), thanks largely to ongoing research that have led to the progress of the technology and its cost reduction. One of these lines of research is the tracking in PV plants that consist of the reorientation of the collectors towards directions that increase solar irradiance collection. Depending on the degrees of freedom of the movement, tracking can be classified into single-axis and dual-axis tracking. Collectors with single-axis tracking moves around a unique axis whereas those with dual-axis tracking moves around two different axes so that they can be oriented to any direction of the celestial vault (Lee et al., 2009). Different works have proved that energy production is higher in PV plants with tracking than in those without it (Nsengiyumva et al., 2018; Sumathi et al., 2017). For that reasons, although PV plants with tracking have higher costs than those with fixed collectors, this technology is spreading around the world and multiple research is being developed to enhance the technology and its efficiency/cost ratio (Eldin et al., 2016).

On the other hand, according to the tracking strategy, most researchers propose the astronomical tracking which is based on the movement of the Sun and is aimed in minimising the angle of solar incidence θ, that is, the angle between the solar rays and the normal to the collectors. Accordingly, astronomical tracking only considers the direct component of the irradiance and not the reflected and diffuse components which can have a significant impact depending on the atmospheric conditions, specially, on cloudy days (Duffie & Beckman, 2013).

Moreover, the astronomical tracking not only does it not consider the effect of clouds, but also the possible inter-shading between collectors which can lead to significant losses in the electricity production of PV plants. As a solution to the latter problem, different authors propose the backtracking which consists of shifting the collectors to non-shaded positions (Lorenzo et al., 2011; Narvarte & Lorenzo, 2008). In that sense, a new solar tracking/backtracking strategy has been proposed to maximize the solar irradiance collection as well as avoiding inter-shading between PV panels with dual-axis trackers (Fernández-Ahumada et al., 2020a, 2020b).

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This work merges both lines of research and presents an omnidirectional sensor that searches for the direction of maximum solar irradiance by tracking the whole celestial vault except for those directions for which inter-shading between collectors would occur. Thus, the omnidirectional sensor proposed can be used as position server in PV facilities with dual-axis trackers.

2. Design of the proposed solution

The search for irradiance optimisation of the irradiance captured by the collectors guides all the work presented here. An important improvement is to discriminate, upstream of the sky tracking, between the directions taken by the collector that would cause shading between adjacent panels. By avoiding these directions, the prototype generates a trajectory that gives a premium to collection.

Fig. 1 shows the prototype of the omnidirectional sensor proposed. It consists of a flat surface with two degrees of freedom so that the irradiance sensor located on that surface can be oriented to any direction of the celestial sphere, characterized by its azimuth (γ) and its elevation (α). The prototype has been built using additive printing on acrylonitrile butadiene styrene (ABS) filament, a thermoplastic polymer with 96ºC and 93ºC as distortion and softening temperatures, respectively. Additionally, the device is protected from adverse weather conditions by means of a transparent methacrylate dome.

Fig. 1: Prototype of the omnidirectional sensor

On the other hand, the device also includes a microprocessor to control the movement of the surface, the irradiance measurements, and their transmission to the solar trackers. This is the TTGO ESP32 board whose structure accumulates analogue and digital sensors and outputs, various ways of data communication both wired and wireless. With regard to the sensors, the real time clocks (DS1307) to establish the working times are noteworthy. Equally important are the calibrated PV cells dedicated to measuring the irradiance at any given moment. The motors responsible for the azimuth and elevation movements are extremely precise and are of the stepper type. Regarding the propagation of the information and, being aware of the different situations that can occur as obstacles in the direct path between sensors and receiver boards, signals ranging from 3 to 15 km can be sent. Fig. 2 shows the main electronical components.

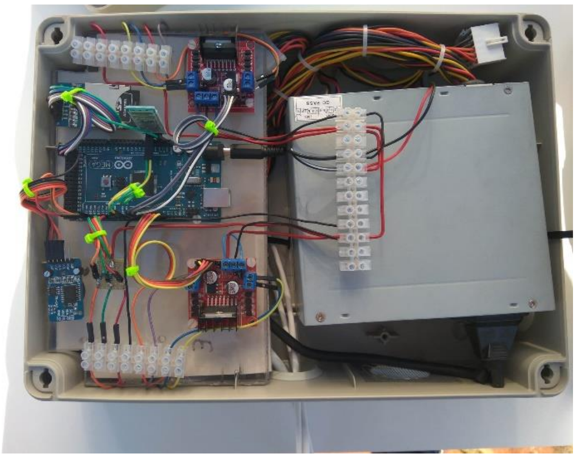

Fig. 2: Kit of electronical components

As far as the movement of the sensor is concerned, the device incorporates the algorithm proposed by Fernández-Ahumada et al. (2020a, 2020b) to determine the direction for which inter-shading between collectors would occur. Thus, the sensor scans the whole celestial vault measuring the solar irradiance, except for those directions with inter-shading. From these instantaneous measurements, the orientation with maximum irradiance and not shading is determined and its azimuth (γ) and elevation (α) angles are made available to the solar trackers so that the PV collectors can be orientated towards the position of maximum capture.

The complete architecture of the device has been developed with Free and Open-Source hardware (FOSH) and IoT technologies. Thus, the sensor proposed becomes an economically competitive tilt and azimuth server to favor the optimization of energy production in PV plants with dual-axis trackers.

3. Results

Figs. 3, 4, 5 and 6 shows the representation of the data obtained by the proposed omnidirectional sensor at different times of the year in a Lambert projection hemispheric diagram mode for the "Peñarroya I" PV plant, situated at a location of 38.299224º N latitude and -5.303114º longitude. The grey region of the figure represents the orientations which imply inter-shading between PV collectors while the blue region represents the directions with no inter-shading. Thus, irradiance measurements (in W/m^2), represented in these figures by iso-level curves (grey lines), are only made in the blue region.

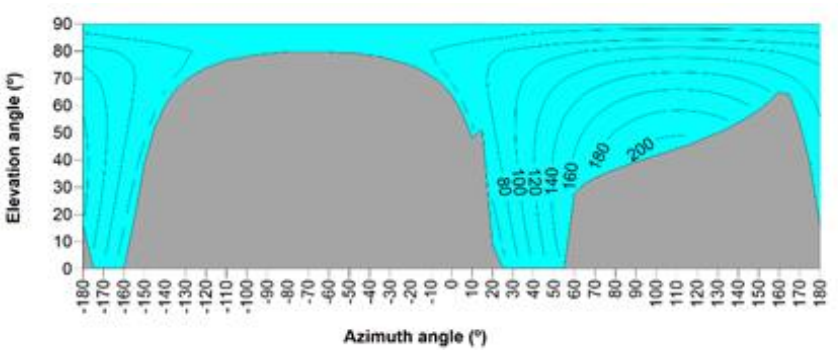

Fig. 3. Data registered by the omnidirectional sensor proposed on June 21st at 15:48 pm (True Solar Time).

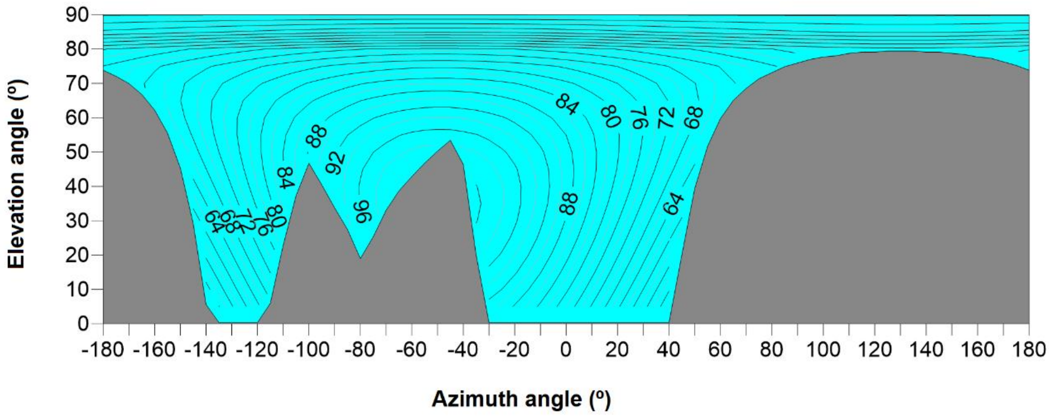

Fig. 4. Data registered by the omnidirectional sensor proposed on December 21st at 8:24 am (True Solar Time).

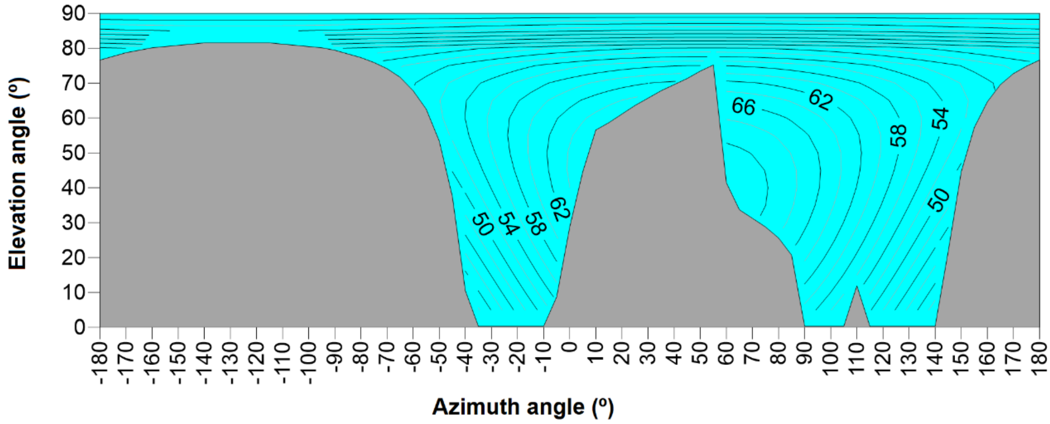

Fig. 5. Data registered by the omnidirectional sensor proposed on December 21st at 15:24 (True Solar Time).

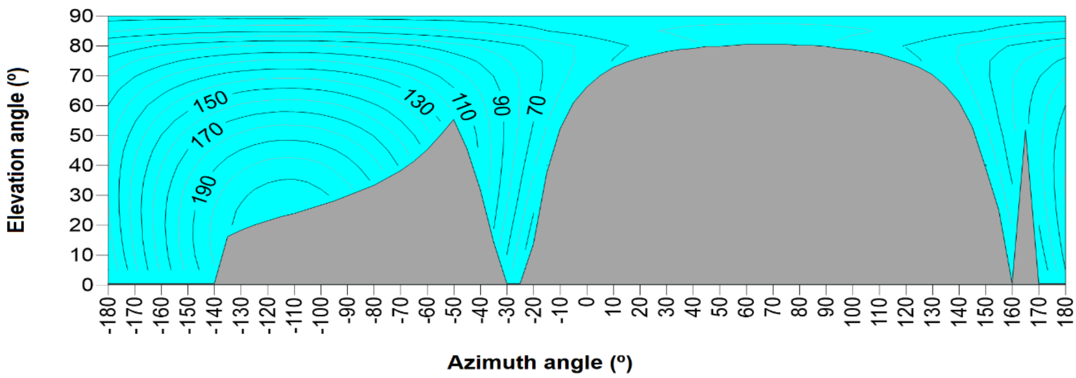

Fig. 6. Data registered by the omnidirectional sensor proposed on June 21st at 7:24 am (True Solar Time).

4. Conclusions

The present work presents the design and manufacture of an omnidirectional sensor to determine the orientation of the collectors of a dual-axis PV plant that guarantees maximum solar irradiance capture with no inter-shading between collectors. The device has been developed as Free and open-source hardware (FOSH) contributing to the advance of open science and the improvement of the PV tracking technology. It is remarkable that the device continuously calculates the locations that generate shading between adjacent collectors. The system also avoids the continuous calculation of the direction of maximum irradiance of the astronomical method and replaces it with internally implemented methodologies for tracking and backtracking.

Thus, the omnidirectional sensor presented will enable the optimization of the energy production in PV plants with dual-axis trackers.

5. References

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