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A review on sun position sensors used in solar applications

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ABSTRACT

This paper presents an overview of the current state of the developments in sun position sensors used in solar technologies such as photovoltaic modules, satellites, solar collectors and other applications. The working principles and geometric designs of several types of sun position sensors are discussed in detail. The studio considers the evaluation of the advantages and limitations of different design requirements such as accuracy, solar tracking errors, desired properties, field of view (FOV) and commercialization, and the evaluation of outer parameters that affect the performance of sun position sensors (climatic conditions: solar radiation, contamination, and temperature); in order to combine the technologies, increase the efficiency and expand the use of sun position sensors. On the other hand, it was determined that the main barriers that this technology faces are: cost-effectiveness, the operational range of temperature and the effective data transmission, so the future researches should be concentrated around these issues.

1. Introduction

In the last years, the solar energy has gained much attention, due to its potential impacts in solar concentration applications (photovoltaic panels and solar collectors) and aerospace applications. Several studies [1–5] have reported that each solar application have different demands to make the most of solar energy, which involve the geometric optimization, the suitable use of materials and the alignment of the solar systems to the rays of the Sun. This works takes into consideration the demands of solar alignment because their advantages are: to reduce in the energy losses in the solar system, to align the surface of the solar system in the direction of the Sun's rays at all times, and to maximize effective use of solar radiation.

To take full advantage of the Sun's energy, the solar system surface must be perpendicular to the Sun's rays. For this reason, a wide range of solar tracking systems have been proposed by several authors [6–8]. They are classified according the orientation mechanism, freedom degrees and electronic control [9]. The orientation mechanism refers to the type of mechanism that must be used to rotate and position the system. There are many applications that have proposed mechanism with gears, pulleys, belts, motors, hydraulic systems, bar mechanisms, etc. [10–12]. The authors have demonstrated that between 19–30% more solar energy can be captured with the use of sun tracking mechanisms in solar applications. Other authors have analysed efficiency, operational phase, and viability of these systems [13–15]. The authors have demonstrated that these parameters are critical in the competitiveness and profitability of solar systems. Authors such as [16–18] studied the strategies of implementation of sun tracking mechanism, the power consumption, maintenance, failures, structural deformation and its misalignment for wind loads, since they impact on the cost-benefit of the system. In aerospace applications (satellites), the authors [19] investigate the most effective way of controlling the satellite motion and the sun tracker mechanism. For this case, they must consider the kind of design concept, the materials, weight and its implementation in the satellite.

The second aspect, the freedom degrees, refers to the types of movements that the sun tracking mechanisms and sun position sensors will have to make. In other words, the solar systems will have to rotate or follow the Sun from East to West or North to South. According to authors [20,21], this aspect play an important role in investment costs, operational costs, and the precision of solar tracking.

Finally, the electronic control has received increased attention in the last years. The authors have discussed on the use of actuators, sun position sensors or astronomical mathematical models, and control techniques that should be use in solar tracking [22,23]. Many studies related to this issue have implemented astronomical mathematical models in solar applications, due to costs, and their easy implementation. Their main disadvantage is that they do not consider the misalignment of the system by wind disturbances, thermal deformations, and poor installation among others. In this case, authors such as [24–27] have implemented sun position sensors, which can follow the Sun with a high degree of accuracy and interact with the solar system structure. The advantages that offer this device are easy implementation, simpler design, low-cost and adaptability.

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Nowadays, the astronomical mathematical models and sun position sensors have been combined in order to obtain a robust and efficient solar tracking system [28,29]. These studies have focused on the development of new control techniques, the impacts of the use of actuators, sun position sensors or astronomical mathematical models on the thermal efficiency and the implementation strategies. Nevertheless, it has not been found review articles dedicated to discussing the types of sun position sensors that exist in the literature, their principles of operation, advantages and disadvantages, which could lead to misuse of sun position sensor, and limit their efficiency in solar applications. Therefore, this study will attempt to describe and characterize the different sun position sensor designs, their working principle, and their pros and cons in solar applications. It is expected that this study may lead to choice properly sun position sensors according to type of solar application, and that new sun position sensors are developed in the future.

2. Classification of sun position sensors

A sun position sensor is a device that senses the direction of the Sun with respect to the sensor's position. A variety of sun position sensors have been designed and improved over the last few years. It is obvious that the designs, materials, and sizes are dependent on the solar applications. The most general classification of sun position sensors is based on the type of sensors, the type of signals, data transmission, and solar tracking direction. Fig. 1 summarizes the classification of sun position sensors that are going to be discussed thorough this work.

3. Type of sensors

The type of sensors refer to all physical and operating aspects of the sun position sensors, i.e, the geometrical design, the working principle (how the sensor measures the Sun's position), the performance and their efficiency. In this classification, are considered four main categories [30]: a) collimated sun sensor, b) sun-pointing sensor, c) tilted-mount photosensor, and d) hybrid sensors. The following section explains in detail these classifications.

3.1. Collimating sensor

The collimating sun sensor is a device that narrows the Sun's rays at a specific point inside the sensor. It has been identified two design based on working principle: (1) Detection on a plane and (2) Detection on Four-quadrant. In this section, summary of selected papers are presented on this issue.

3.1.1. Single detection

The concept of single detection refers to detection on a plane, i.e, the detector will measure the Sun's position when sunlight passes through a collimator (focusing tube), generating different currents. This sensor consists of a photosensor, a collimator, and a control system. The photosensor is the heart of the sun position sensor and is typically used a photodiode to measure sunlight intensity. The main advantages of this sensor are: easy to build, and simple detection. Some studies on collimated sensors with single detection are presented as follows:

In 2007, Luque et al. [31] used a sun position sensor to position photovoltaic panels perpendicular to the sunlight. This sensor was basically composed of a collimator, a position sensitive detector (PSD) that measures the Sun's position in two-directions (North-South and East-West), a structure, a mechanical drive and a control system (microcontroller and electronic), as shown in Fig. 2. The working principle is based on measuring the difference in photocurrents generated by the PSDs, when the light passed through the aperture of the collimated tube and hit the photodiodes. The authors combined a model based on a calibrated approach with a free-predictive-approach

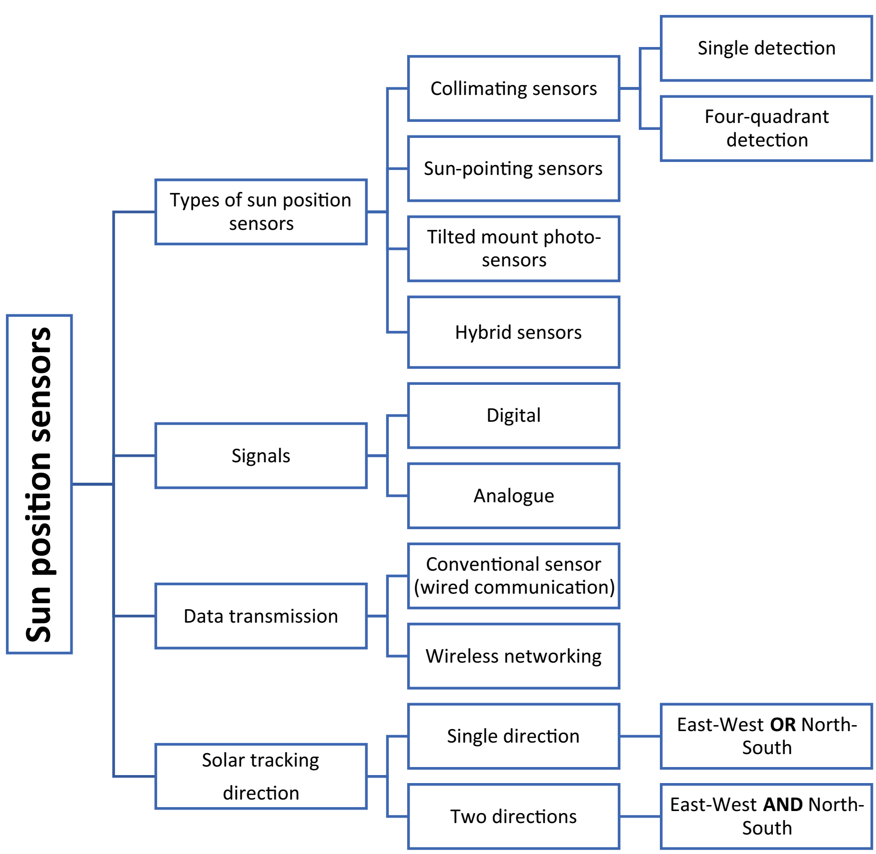

Fig. 1. Classification of sun position sensors.