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# Development of a machine vision dual-axis solar tracking system

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ABSTRACT

The main solution for modern societies is to resort to renewable energies. This imperative became more serious following the 1970's energy crisis. Solar energy has been recently in the spotlight as a renewable energy, which can be directly converted into electricity through solar panels. The power output of photovoltaic systems is directly dependent upon the amount of solar irradiation received. Therefore, these panels should be perpendicular to solar irradiation in order to harvest the maximum possible power. Thus accurate solar trackers are central to the performance of solar systems. This study proposes a dual-axial tracker that works based on processing images of a bar shadow. The system was composed of a shadow casting object, a webcam, electronic circuits, computer controls, and stepper motors. The webcam was used to capture images of the shadow. The study results showed that the tracker system followed the sun with an accuracy of about ± 2° and maintained the panel perpendicular to the irradiation direction. This system works independent of its initial settings and can be used in any geographical regions. It managed to hold the panel perpendicular to irradiation to receive the maximum solar energy and thus generate the highest power output.

## 1. Introduction

Renewable energies have been viewed as a great source for the past two decade, and are currently widely-used in industrial and household applications. Besides its other benefits, solar energy, as a renewable source, is infinite and pollution-less. One of the important methods to improve the output of solar panels is through increasing their irradiation gain. Solar trackers are the most appropriate technology for improving solar panel outputs by keeping these panels perpendicular to solar irradiation (More and Kulkarni, 2014). There are three types of trackers by their degree of freedom: Fixed, single-axis and dual-axis systems. They are additionally divided into active and passive systems based on their control unit (Kvasznicza and Elmer, 2006, Mousazadeh et al., 2009).

Active systems are basically an open-loop system and need no feedback as the Sun's position in a specific geographical location at different times of the day and different seasons follows the Sun's orbit function. Accordingly, the tracker calculates the required information for orienting the payload to a correct position where the normal vector of the panel is perpendicular to the irradiation direction. Active systems have also four different types: based on microprocessor and sensor; based on time and date; based on auxiliary bifacial solar cell; and based on a combination of sensor and time/date (Kelly and Gibson, 2009, Lim et al., 2014).

These four types of active systems are further described in the following.

Based on microprocessor and sensor: These types of trackers use the light difference in photosensors to orient the system toward the lower light difference (ideally zero). These trackers are intricate and expensive.

Mousazadeh et al. (2011) maximized energy gain of an array photovoltaic (PV) cells by designing and mounting a solar panel on a Solar Assist Plug-in Hybrid Electric Tractor (SAPHT), a mobile phone-based solar tracker that uses four Light Dependant Resistors (LDRs) dependent on the solar tracker system. Using the mobile phone on SAPHT, time and date were updated in the system. Four LDRs were used to assess radiation intensity. A microcontroller-based electronic drive served as the software-hardware link. Experimental results showed that the developed solar tracker increased energy gain by 30% compared to the fixed system. The tracker consumes a maximum of 1.8% of the total gain. Gai et al. (2014) developed an automated microcontroller-based solar tracker. The system consisted of a control unit, which contained a microcontroller, a sensing unit, a drive and power supply. The motor control drives were triggered by the signals collected by the sensors to track the Sun and keep the panels normal to the irradiation direction. In other trackers, operational amplifiers (op-amps) were also used to boost

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the output signal in addition to LDRs that have potentially low resistance variations. Normanyo and Awingot, 2016 presented a microcontroller-based dynamic dual axis solar tracker for solar energy optimization. It used a solar panel to determine which part of the sky delivers the most power to the load and two stepper motors for alignment. The system consisted of a microcontroller, two stepper motors, two stepper motor drivers, two gear drives and a monocrystalline solar panel. The results showed that cost effective and will go a long way to help rural electrification as well as reduce the burden on grid supply. Arul Kumar and Arjun, 2016 developed an automatic solar tracking system. This solar tracking was single axis, five positions in LDR sensor and was designed for low power and the rotation of the electric motor was controlled by a PLC controller.

In time/date-based trackers, a computer or a processor calculates the Sun's position based on the formula/algorithm of time and date in a specific geographical location, and sends it as a signal to an electric motor. Engin and Engin (2013) presented a solar tracker to improve the performance of photovoltaic systems. The system had two software and hardware parts. The hardware included a microcontroller, motor drive circuitry, control unit, pyranometer, GPS and anemometer. The pyranometer consistently sent the irradiation data to the microcontroller. The GPS however updated longitude, latitude, altitude, date, and actual time/hour data. The system was tested in two weather conditions, and the results showed that in the general weather conditions the energy gain can be improved by 7.40% whereas, in overcast conditions, the improvement was 32.1% compared to the fixed state. Kadmiri et al. (2015) presented a novel solar tracker system based on omnidirectional vision technology. The system consisted of a spherical mirror, a CCD camera, a linear actuator, a DC motor and a processing unit. This system used an omnidirectional imaging system to provide accurate information about the sun position toward both elevation and azimuth. Some trackers used auxiliary solar cells that were connected directly to a Permanent Magnet DC (PMDC) motor with a single rotating axis that supplied the energy required for tracking.

Karimov et al. (2005) designed a PV tracker with four solar modules mounted on a single axis on a rotor, while the other axis was manually adjustable to the set the tilt angle of modules on 23°, 34° and 45°. The rotation unit used two pairs of modules at a fixed angle (170°) on the upper side of the system. The four modules and the DC motor were connected to a bridge circuit for solar tracking. If the output voltage of a module was not equal to the input voltage of the DC motor, the motor started to turn. Research shows that, unlike fixed modules, the output voltage of trackers is different in the morning and at night, and the energy gain is 30% higher in tracking systems.

Mohammad and Karim (2013) designed implemented a hybrid microcontroller-based solar tracker, and analyzed it in four different modes (hybrid tracking, dual-axis tracking, single-axis tracking, and fixed module). Results showed that the dual-axis tracking system yielded 18% more power than the single-axis system. The power output of the hybrid tracking system was 54% higher than the fixed-angle system at 23.5°.Ruelas et al. (2013) implemented and analyzed the dual-axis system. The system consisted of a video processing sensor that was connected to a microcontroller, which used an algorithm to calculate the Sun's position. The center of mass of the solar image was used to show Sun's movement direction. analysis results showed that mean tracking accuracy was 0.0135° for angle and 0.0196° for height. Yao et al. (2014) proposed a dual-axis multi-purpose solar tracker with two tracking strategies. The tracker was controlled in a compound manner based on time, date and sensor data. A microprocessor was embedded to calculate the Sun's position and receive signals from the positioning sensor. The sensor was basically used at sunrise. During overcast weather conditions, the tracker was solely controlled based on time due to limited sensor output. Their results showed that mean energy conversion rate was 23.6% higher than the fixed mode. The parameter was improved by 31.8% using daily adjustment.

The related studies on sun trackers were summarized in a Table 1

**Table 1**
Investigations on sun trackers.

| Researcher | Type tracker | Used equipment | Single axis or two axes | Precision | Increased energy |
|---|---|---|---|---|---|
| Mousazadeh et al. (2011) | Microprocessor and electro-optical sensor base | LDR, mobile phone, electronic drive | Dual axis | Not specify | 30% |
| Gai et al. (2014) | Microprocessor and electro-optical sensor base | LDR, microcontroller, drive and power supply | Dual axis | Not specify | Not specify |
| Normanyo and Awingot (2016) | Microprocessor and electro-optical sensor base | Microcontroller, stepper motors, drivers, gear drives and monocrystalline | Dual axis | Not specify | Not specify |
| Arul Kumar and Arjun. (2016 | Microprocessor and electro-optical sensor base | LDR, electric motor, PLC controller | Single axis | Not specify | Not specify |
| Engin and Engin. (2013) | Date and time based | Microcontroller, motor drive circuitry, control unit, pyranometer, GPS and anemometer | Dual axis | Not specify | 32.1% |
| Kadmiri et al. (2015) | Date and time based | Spherical mirror, CCD camera, linear actuator, DC motor and processing unit | Dual axis | Not specify | 30% |
| Karimov et al. (2005) | Auxiliary bifacial solar cell based | Four modules and the DC motor | Single axis | Not specify | 30% |
| Mohammad and Karim (2013) | Combination of sensor and date/time based | Microcontroller | Single axis | Not specify | 54% |
| Ruelas et al. (2013) | Combination of sensor and date/time based | Video processing sensor that was connected to a microcontroller | Dual axis | 0.0196 | Not specify |
| Yao et al. (2014) | Combination of sensor and date/time based | Microprocessor | Dual axis | Not specify | 23.6% |