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Optimum design and performance comparison of a redundantly actuated solar tracker and its nonredundant counterpart

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Abstract

This paper proposes a novel U-3PSS two-axis sun-tracking mechanism with parallel mechanism. The tracker is energy saving due to most of the gravity of mobile platform and solar mirror/panel supported by the passive U chain. Two most important performance indices of a solar tracker, workspace and energy consumption are studied and the optimum design is investigated utilizing a complex method. Based on workspace and energy consumption, optimal configurations of the U-3PSS solar tracker and its nonredudnant counterpart are analyzed, respectively. By taking Beijing as a sample city where the tracker is placed, the trajectory planning of the tracker is investigated and the direction of two orthogonal axes of the U joint is studied. The power of the U-3PSS solar tracker and its nonredudnant counterpart with their optimal configurations in spring equinox, summer solstice, autumn equinox and winter solstice are compared. Furthermore, the workspace and consumed energy of two solar trackers are compared. The results show that the U-3PSS solar tracker has a bigger workspace and smaller energy consumption in one year than its counterpart – U-2PSS solar tracker.

Keywords: Solar tracker; Parallel mechanism; Energy; Optimum design; Workspace

1. Introduction

Large solar mirror collectors are a major subsystem of many solar energy systems, particularly for solar thermal generators. Parabolic dish concentrators offer the highest thermal and optical efficiencies of all the current concentrator options (Figueredo, 2011; O'Rourke, 2011; Agee et al., 2007). Parabolic dish system consists of a solar tracker and parabolic-shaped dish concentrator that reflects solar radiation onto a receiver mounted at the focal point. The concentrator is mounted on the solar tracker which is a device that keeps the concentrator in an optimum position perpendicular to the solar radiation throughout the day. The diurnal and seasonal movement of earth affects the radiation intensity on the solar systems. Solar trackers move the solar systems to compensate for these motions and increase the collected energy (Mousazadeh et al., 2009; Li and Dubowsky, 2011; Lovegrove et al., 2011). Solar track-

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ers are a necessary component of concentrated solar power and photovoltaics.

Solar trackers are usually divided in those with a unique axis and those with two axes. Single-axis trackers are simple and can be used in trough-style systems which require only single-axis tracking. Two-axis solar trackers allow to obtain an optimal tracking of the sun's path since they keep the orientation of the collectors perpendicular to the solar radiation at any time in any season (Eke and Senturk, 2012; Diaz-Dorado, 2011; Neber et al., xxxx). Due to these advantages, dual-axis trackers are more popular in all types of concentrated solar technologies, with the exception of the trough-style system. However, the predominant two-axis tracker is commonly designed based on classical serial mechanism (Tomson, 2008; Roth et al., 2005; Barker et al., 2013). The trackers require a very stout pole to be drilled into the ground to support normal loading. In all cases, the pole height is at least one half of the panel height above the ground so that the tracker can orient toward the sun at low elevation angles. Being serial, their main disadvantage is the need for a heavy structure in order to keep rigidity at levels sufficient to sustain solar panel loads. These drive units contain multiple sets of gears that must be designed to handle very large moments and loads, therefore making them heavy duty pieces of equipment. Also, they often are fitted with heavy counter balances. This results in larger actuators requirements making their power consumption far from optimal.

Although solar trackers improve the amount of energy absorbed, maintaining the collectors perpendicular to the sun radiation involves the energy consumption (Battezzato et al., 2012). Thus, minimizing the energy consumption is a very important design requirement for solar trackers. In comparison to classical serial mechanisms, parallel mechanisms provide some advantages such as higher payload to weight ratio, higher dynamics and higher stiffness (Wu et al., 2009, 2013). Asada's research (Asada and Youcef-Toumi, 1984) showed that a five-bar-link parallel manipulator has a lower power dissipation than a serial 2-DOF manipulator. If parallel mechanisms are used to develop solar trackers, it is possible to scale-down the dimensions of the mounting and to reduce the complexity of the system in terms of the number of its components and its assembly (Altuzarra et al., 2013; Cammarata, 2015). These result in less powerful actuator. However, parallel mechanisms suffer from some drawbacks, including small workspace to installation space ratio as well as the presence of singular configurations within the workspace. Redundancy is an effective solution for eliminating singularities in parallel mechanisms and thus enlarging the workspace (Wu et al., 2014). Reliability is also important for a tracking system. For redundant actuation, the number of actuators would be larger than the DOF number of manipulator and it has been suggested for fault tolerant designs. The effect of redundancy in joint displacement sensing for parallel manipulators has been investigated to facilitate the joint sensor fault detection, isolation and recovery (Notash, 2011).

In this paper, a novel U-3PSS (U, P and S represent respectively the universal, prismatic and spherical joints) two-axis solar tracker with parallel mechanism is proposed and the optimum design is investigated. The dynamic model is derived by using the principle of virtual work. The workspace and energy consumption are analyzed and the optimum design is studied using a complex method. Based on workspace and energy consumption, the system configurations of the U-3PSS solar tracker and its nonredudnant counterpart are analyzed, respectively. The trajectory planning of the tracker is investigated and the direction of two orthogonal axes of the U joint is studied. The power and consumed energy of the U-3PSS and U-2PSS solar trackers are compared.

2. System architecture

Two-axis systems allow to obtain an optimal tracking of the sun's path, since they keep the orientation of collectors perpendicular to the solar radiation at any time in any season. Thus, dual-axis tracker is more popular in all types of concentrated solar technologies, with the exception of the trough-style system. Based on the motion analysis of two-axis trackers, a U-3PSS parallel mechanism which can meet the requirement of a two-axis tracker is proposed as a solar tracker, as shown in Fig. 1. The mobile platform of parallel mechanism is connected to a U chain and three links of constant length by means of spherical joints. The other end of each link is linked to a slider with a spherical joint. Each slider can move up and down along the corresponding vertical slideway fixed to a column. The link of constant length has no kinematic constraint to the mobile platform and only the U joint limits its output. The U joint allows the rotations about two orthogonal axes of U joint. Thus, the mobile platform of the parallel mechanism has two output DOFs. A solar mirror/panel can be fixed on

Fig. 1. 3-D model of the solar tracker.