Solar Energy 174 (2018) 826–836

Contents lists available at ScienceDirect

Solar Energy

journal homepage: www.elsevier.com/locate/solener

New low-cost solar tracking system based on open source hardware for educational purposes

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A R T I C L E I N F O

Keywords:
Solar energy
Solar tracker
Automatic control and computer sciences
Computer vision
Low cost
Raspberry pi
Educational tool
Open source

A B S T R A C T

In this paper, due to the detected educational demands regarding automatic control and training in management of solar tracker systems, a small prototype based on low cost open source hardware and computer vision is built to test the control algorithms developed in Mathematica and Simulink. The new prototype has been developed with the aim of being a powerful tool for a wide range of applications regarding to the learning of automatic in solar energy. Finally, its educational application is discussed.

1. Introduction

Energy plays an essential role in the development of society, it has promoted great advances and has also generated inequalities and conflicts throughout history (Smil, 2010). In the last decades, due to industrial evolution and population growth, world's energy demand has been continuously increasing (Melorose et al., 2015).

Nowadays, different energy forms are consumed, electricity which is the most demanded is not a natural energy form and must be obtained from other energy sources. It is estimated that 77.9% of electricity is generated by traditional methods (fossil and nuclear) (Schou, 2000), which are heavily polluting the environment and contributing to the climate change and global warming (Kannan and Vakeesan, 2016). The continuous use of fossil energy sources may lead to climate change, which may in turn end up with heavy natural disasters (Schou, 2000).

Therefore it is crucial to go for ecofriendly energy sources, even more when the development carried out in different renewable energies sources (solar, wind, hydropower and geothermal) makes them viable sources of energy, even in places rich in fuel reserves. Recent studies (Scheer, 2013; Hohmeyer and Bohm, 2015; Jacobson et al., 2015) indicate that 100% of renewable electricity and energy in general supply can be achieved in the top industrialized countries, how the transition should be and its economic, environmental and social benefits. These studies include all renewable energy sources to provide energy and propose an energy mix.

The transition to 100% of renewable supply demands a global agreement to focus the education on renewable energies (Broman, 1992). Although the need for this, education for suitable development at all levels is globally recognized (Kandpal and Broman, 2014), an extended review shows that the situation of the renewable energy educational practices is not satisfactory because it is not as developed as it should be (Ciriminna et al., 2016).

It is vital for the success of new renewable energy education programmes to use modern educational technology, accessible and low cost (Kandpal and Broman, 2014), which facilitates the integration with the emerging smart world (Liu et al., 2017). In the last decade, different educational paradigms had made use of flexible and modern educational technology (Jennings, 2009) like on-line educational programs, due to the urgent need for on-the-job training in renewable energies and to reach a wider audience. Educational tools based on videocast techniques (Torres-Ramírez et al., 2014) and virtual and/or remote labs have proven to be powerful tools with lot of benefits (Fabregas et al., 2011; Chao et al., 2015), great scientific impact (Heradio et al., 2016) and able to extend the access to science and engineering (Colwell et al., 2002).

Of all renewable energies, solar energy is the most abundant energy source (Panwar et al., 2011), it is inexhaustible and exceeds output efficiencies given by other energy sources, it does not have any negative

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https://doi.org/10.1016/j.solener.2018.09.064
Received 14 July 2018; Received in revised form 18 September 2018; Accepted 22 September 2018

impact on the ecosystem and can help us to mitigate inequalities due to traditional energy sources.

The amount of scientific production (Sheikh et al., 2016) demonstrates that the solar energy is in demand, its use is growing and many researchers are undertaking investigations in order to increase efficiency and reduce cost (Kannan and Vakeesan, 2016). There are different technologies based on solar energy that improve the efficiency of the system by means of concentrating the solar flux with optical systems that demand a solar tracking system to control the system alignment with the Sun, becoming the solar tracking a key issue for the general system efficiency.

Despite the increasing interest and the educational demands in solar energy, there are few educational tools related to it. In solar photovoltaic technology some educational tools can be found, the most interesting ones being: photovoltaic solar cell remote trigger virtual lab (Freeman et al., 2012), e-training system for the renewable energy systems (Drigas et al., 2005), experimental determination of the current-voltage characteristic curve of a photovoltaic panel (Kandpal and Broman, 2014) and web based education resources for self-education in renewable energies (Bauer et al., 2013). Regarding to low and medium temperature solar systems, HTI e-learning laboratory (Michaelides et al., 2005), mobile remote lab system to monitor in situ thermal solar installations (Saez de Arregui et al., 2013) and an interactive tool to teach solar parabolic trough concepts (Silva et al., 2011) are available. It is necessary to increase the number of these resources and make them generally available.

With the aim of providing a powerful tool for solar educational purposes and specifically for solar tracking fields, reducing fixed costs associated with traditional labs and control system, a new solar tracking system based on computer vision (*CV*) implemented in low cost open source hardware has been developed and its main features are explained in the next sections. Also, the code has been published for free use (GitLab, 2018).

2. Solar energy

2.1. Solar concentration technology

Renewable energies can be classified into categories such as wind power, solar energy, geothermal energy, ocean energy, hydro power, biomass and waste energy (Guney, 2016), although most of the energy sources on Earth are indirect solar energy kinds.

Solar energy technologies are those which employ directly the solar flux that reaches the solar system in three different ways: thermally (*heat engine or process heating*), photo chemically (*photosynthesis*) and photo physically (*photovoltaic*), to produce heat, chemical energy and electricity respectively in a collecting element (*receiver*). To increase the performance of the solar energy systems it is usual to previously concentrate the solar flux that reaches the solar system receiver to achieve higher peak temperatures and solar flux densities, improving thermodynamic efficiencies and reducing the heat loss area in relation to the receiver area (Khan and Arsalan, 2016).

This task is carried on by *solar concentrator systems*, that usually use mirrors (parabolic trough, heliostat, dish, or linear Fresnel) or lenses to concentrate and reflect the solar flux on the receiver, see Fig. 1. Two main types of solar concentration technologies can be found: concentrated solar thermal power (*CSP*) and concentrated photovoltaic (*CPV*). In *CSP* the concentrated solar flux heats water or any other kind of heat transfer fluid flowing through the receiver. Usually *CSP* facilities produce high temperature heat, that can be used directly in a process (process heat) or to produce steam to spin turbines and generate electricity. On the other hand, *CPV* uses the concentrated solar radiation onto small photovoltaic cells that are made by specialized semiconductor materials. In these systems, each cell transforms the concentrated solar flux into electricity directly with a power-generating efficiency of more than 30%. Recently, the research advances have achieved the combination of the two technologies, *CPV* with *CSP*, which is called *concentrated photovoltaic thermal* (*CPVT*). Studies show the very high potential of the *CPVT* technology due their unique features (Sharaf and Orhan, 2015a,b).

2.2. Solar tracking

As commented before, solar energy technologies take advantage of the solar flux to produce another type of energy, therefore knowing the availability and the nature of the source of energy is a key issue. The Earth is in a constant rotation, so the relative position of the Sun in the sky continuously changes but can be defined by means of *solar position algorithms* or optically, with enough precision. Most of the solar concentrators demand a mechanism that controls the systems alignment with the Sun (*solar tracker*), being this a key issue for the general system efficiency.

Solar trackers can be classified regarding the number and position of rotation axes. Systems with one rotation axis are employed with solar concentration systems like parabolic troughs or linear Fresnel, called linear concentrator systems. Horizontal, vertical and tilted-axis systems can be found as subcategories. On the other hand, systems with two rotation axes, called point-focus systems, are employed with heliostats and dish modules. Azimuth-elevation, target aligned and polar trackers can be found as subcategories depending on the rotation axes position.

Solar trackers can also be classified regarding to the control type as passive and active solar trackers. Passive solar trackers are composed by a couple of actuators working against each other, which are based on thermal expansion. Due to the different solar radiation conditions, these trackers orient the system in the direction where the radiation over both actuators is the same (Mousazadeh et al., 2009). Active trackers can be classified in microprocessor and electro-optical sensor based, PC controlled date and time based, auxiliary bi-facial solar cell based and a combination of these three systems (Mousazadeh et al., 2009). Sun trackers can guide the system with continuous or discrete movement depending on the rotation system and the controller. Most Sun tracker systems are developed for a specific solar technology.

Regarding control for active solar trackers, both closed-loop and open-loop controllers can be found. Closed-loop controllers of solar trackers are based on feedback transferred from sensors which measure environmental variables. On the other hand, an open-loop controller, estimates its inputs using only the current state and a computer algorithm, to determine if its inputs have achieved the desired goal without

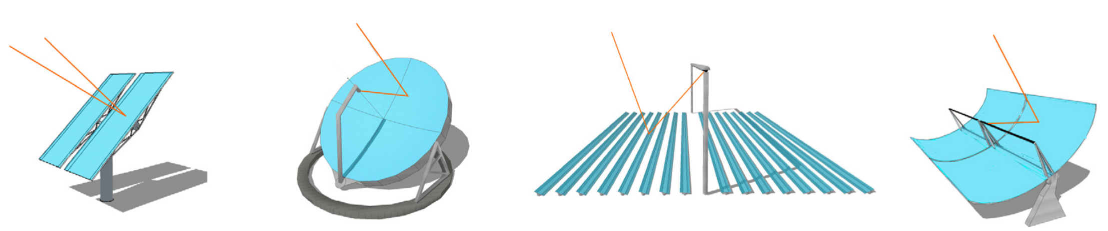

Fig. 1. Solar concentrator systems.