engineering proceedings

Proceeding Paper

Selection of Sensors for Heliostat of Concentrated Solar Thermal Tower Power Plant †

Kamran Mahboob [1,*], Qasim Awais [2], Awais Khan [1], Tabish Fawad [3], Momen Rasool [4], Qasim Nawaz [4] and Umair Ahmed [4]

1 Department of Mechanical Engineering, University of Engineering and Technology, Lahore 54700, Pakistan; awais211@uet.edu.pk
2 Electrical Engineering Department, GIFT University, Gujranwala 52250, Pakistan; qasim.awais@yahoo.com
3 Department of Electrical Engineering, FEAS Riphah International University, Islamabad 45320, Pakistan; tabishfawad666@gmail.com
4 Department of Electrical Engineering, University of Engineering and Technology, Lahore 54700, Pakistan; momen.rasool@yahoo.com (M.R.); qasimccet@gmail.com (Q.N.); umairccet@gmail.com (U.A.)
* Correspondence: mahboobccet@gmail.com
† Presented at the 1st International Conference on Energy, Power and Environment, Gujrat, Pakistan, 11–12 November 2021.

Abstract: As the energy demand of the world is rising, more and more efforts are being made to harness different forms of energy available. Current pollution due to fossil fuels has directed the world to shift to cleaner renewable energies, such as solar. Photovoltaic, as well as concentrated solar technologies, are developed to harness solar energy. The concentrated solar tower power plant is an emerging technology and is under development having vast areas of improvement. The efficiency of the concentrated solar tower power plant depends upon the accuracy of the tracking system of the heliostats placed all around the central tower of the plant. A closed-loop tracking system a feedback method is a need. In addition, to check the accuracy of the system, a calibration system is required. This system uses different types of sensors. In this study, an effort is made to enlist different types of sensors available and their use in the tracking system of the solar thermal tower power plant. In addition, different sensors are suggested that are best suited for calibration and correction purposes.

Keywords: sensor; tracking system; heliostat; solar thermal tower power plant; renewable energy

Citation: Mahboob, K.; Awais, Q.; Khan, A.; Fawad, T.; Rasool, M.; Nawaz, Q.; Ahmed, U. Selection of Sensors for Heliostat of Concentrated Solar Thermal Tower Power Plant. *Eng. Proc.* **2021**, *12*, 41. https://doi.org/10.3390/engproc2021012041

Academic Editor: Shahid Iqbal

Published: 27 December 2021

1. Introduction

Solar Thermal Tower power plant (STTPP) is an emerging technology compared to parabolic trough [1,2]. This solar system has been under investigation since 1976 and was first introduced in 1983. Different prototypes and demonstration plants were built to study this Concentrated Solar Power (CSP) technology. The success of these plants established as the foundation of many large STTPP projects implemented worldwide. For example, in October 2013, Solar Reserve launched its first commercial project to create crescent dunes in Nevada. This was for a capacity of 110 MW and storage for 10 h. The Atacama STTPP plant is a 110 MW power station with a storage capacity of 17.5 h. Today, molten salt-based technology is the most cost-effective technology for autonomous power generation due to its high heat storage capacity. The STTPP uses distributed mirrors known as heliostats that track the sun all day long and focus the light on top of the receiver [3,4]. The receiver transfers the energy from the focus field radiation to the thermoelectric cycle. Working fluid absorbs the solar energy and then generates the steam for operating a turbine. For cylindrical receivers, the heliostats should be located around the tower. In addition to the distance between the heliostat levels, the purpose of these configurations is to increase the luminous efficiency, minimizing the heliostat blocking and obscuring, thereby reducing the cost of solar energy [5,6]. Running a simple heliostat domain does not cause any serious problems, but the heliostat field design is very important. It accounts for about 45% of the total STTPP value. The receiving area and the heliostat should be investigated together to increase thermal efficiency and reduce the cost of the heliostat field [7]. The efficiency of the plant depends upon the accuracy of the heliostat tracking. The tracking system consists of actuators or drives that place the heliostat in the desired azimuth and elevation position. The control system is designed to have accurate tracking. This control system controls the actuators, and the accuracy of the control system paves the way for accurate tracking of heliostat [8].

2. Sensors of Heliostat for Sun Tracking

Electrical sensors are devices used to detect or measure a physical quantity, such as light, sound, heat, mass, voltage, etc., by converting them to voltage or current whose magnitude is directly proportional to the magnitude of input physical quantity. This converted signal is then processed using a control system to synchronize the output to dynamic real-time inputs. Therefore, sensors are the backbone of a closed-loop or hybrid system. Sensors are characterized through their application, i.e., open-loop sensors and closed-loop sensors. From their name, it is clear that open-loop sensors are employed in open-loop systems while others are used in closed-loop systems. Different types of commonly used sensors in STTPP are as follows:

2.1. Encoder

The encoder is an electromechanical system that converts the position of the system into an electrical signal. It can be divided into two types, absolute and relative encoders. An absolute encoder signal gives an accurate position within the travel area without requiring previous information. An incremental encoder signal is cyclical and gives the position relative to the current cyclic position of the system. The absolute encoder is more vigorous to intermission in the transducer signal, whereas the incremental encoder reports position changes in real-time. These can be used for positioning the heliostat in the required orientation [9].

2.2. Accelerometer, IMU (MEMS)

Accelerometer measures acceleration properly, meaning that the acceleration of a body in its instantaneous rest frame is not the same as coordinate acceleration, the acceleration in a fixed coordinate system. Harper et al. [10] used a combination of a 3-axis MEMs accelerometer and optical sensors mounted on the back of the heliostat. The MEMs give the initial aiming after which optical trackers control the heliostat.

2.3. GPS

Geolocation is the estimation of the location of an object geographically in the real world, such as a cell phone, radar source, or computer terminal with internet connected. Ruelas et al. [11] used the RTC module, inertial measurement sensors, geolocation with a vision sensor based on a microcontroller to show the incident ray angle as well as sensor position and tilt.

2.4. Pyrheliometer

Pyrheliometer is a tool for measuring direct solar beam irradiance. The daylight enters the instrument through a window and goes to the thermopile which converts the heat energy into an electrical signal. Roth et al. [12] designed and manufactured an electromechanical framework to track the position of the sun using real-time technology.

2.5. Photosensors—LDR, PTransis, PV

Photosensors are light sensors or other electromagnetic radiation sensors. A p-n junction is contained by these photo sensors that convert photons of light into current. The electron-hole pairs are formed by the absorbed photons in the depleted area. The image sensor generally applies to tracking applications on the axis where the collector rotates to face the sun. Aiuchi et al. [13] used this to control the heliostat by applying a photosensor in front of the heliostat mirror. Arbab et al. [14] implement a bar shadow mechanism to detect the position of the sun using a camera for detecting its shadow on the screen. Lee et al. [15] proposed an optimal real-time design for solar tracking of heliostat using an illuminance sensor (CdS) and Simulink program for maximizing the efficiency of solar absorption in the receiver. Convery et al. [16] proposed a closed-loop system that used photodiodes surrounding the thermal receiver to detect the vibration signal of misaligned heliostats that can be generated using piezoelectric actuators under heliostat surface. Lynch et al. [17] designed a solar tracker using a low-cost control system and two electro-optical sensors. The first sensor is mounted on a tracker plane, is a four PV-Cell pyramid, and the second one fixed facing south is a sunlight beam sensor using phototransistors.

2.6. APS/CMOS

APS are also known as image sensors or CMOS sensors due to the use of complementary metal-oxide-semiconductor (CMOS) process in its manufacturing; they are used in webcams, cell phone cameras, and DSLRs. Arbab et al. [14] implemented a bar shadow mechanism to determine the position of the sun using a camera for detecting its shadow on the screen. Arturo et al. [18] proposed an innovative system using a commercial webcam for sun tracking as it has less sensitivity to weather, temperature, and humidity. Lee et al. [19] designed a sun tracking device using a 15× Cassegrain-type telescope and a high-resolution webcam. Wei et al. [20] proposed a novel method for sun tracking by tracking the brightest region of the sky using a camera. Harper et al. [10] proposed MEMS and optical sensors combination placed on the back of the heliostat using a simple machine learning algorithm for solar tracking. Coquand et al. [21] suggested a backward-gazing method using four cameras placed near the receiver for optomechanical errors calculation of heliostats. Ruelas et al. [11] proposed the design of a sensor that contains a microcontroller with a clock, IMU sensor, GPS, and a camera for accurate solar tracking. Hénault et al. [22] proposed a tracking system using a matrix of cameras located near the solar receiver.

2.7. CCD

Charge-coupled devices, or CCD, are also known as image sensors, usually used in photography, digital cinematography, and astronomy. Before CCD, photographic plates were used for such applications. Kribus et al. [23] presented a system for measuring incident radiations on the receiver and to detect the aiming errors by using a calorimeter, radiometers, and processing images of four remotely controlled CCD cameras around the receiver, at the fringes of the target to feedback the correction signal to the system. Berenguel et al. [24] proposed a system to track the sun and rotate the heliostat accordingly using a B/W CCD camera and artificial vision algorithm to correct deviations of volumetric receiver solar power plant. Threshold-based image processing is applied on the distance between the sunbeam centroid and the target on the tower is used for offset correction. Younis et al. [25] designed a wireless system using Zigbee protocol to broadcast the real-time 3D motion of the sun using a CCD camera to heliostats. The control unit of each heliostat is independent and moves each facet to maximize reflection onto the receiver.

2.8. Piezoelectric Actuators

Piezo materials are a rare type of material that extends or contracts when an electrical charge is delivered, resulting in movement and strength. As a result of their conversion from electrical energy to mechanical dynamism, piezoelectric devices are often referred to as motors, but actuators are used interchangeably. Convery et al. [16] represented a closed-loop control system that produced the desired input by causing small mechanical vibrations on the surface of the heliostat reflector using piezoelectric actuators.

3. Conclusions

The solar thermal tower power plant is a form of concentrated solar power technology that has high efficiency due to greater concentrations. The efficiency of the solar thermal tower power plant is dependent upon heliostat field efficiency. An accurate heliostat field is required and to keep this alignment different types of feedback systems can be used that need certain sensors. In this research, an effort is made to enlist these sensors. Accuracy of the tracking system is enlisted in this research, and for different types of tracking systems, suitable types of sensors are suggested.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Alonso-Montesinos, J.; Polo, J.; Ballestrín, J.; Batlles, F.; Portillo, C. Impact of DNI forecasting on CSP tower plant power production. *Renew. Energy* **2019**, *138*, 368–377. [CrossRef]
2. Mahboob, K.; Khan, A.A.; Khan, M.A.; Sarwar, J.; Khan, T.A. Comparison of Li_2CO_3-Na_2CO_3-K_2CO_3, KCl-$MgCl_2$ and $NaNO_3$-KNO_3 as heat transfer fluid for different sCO_2 and steam power cycles in CSP tower plant under different DNI conditions. *Adv. Mech. Eng.* **2021**, *13*, 16878140211011900. [CrossRef]
3. Ashley, T.; Carrizosa, E.; Fernández-Cara, E. Heliostat field cleaning scheduling for Solar Power Tower plants: A heuristic approach. *Appl. Energy* **2019**, *235*, 653–660. [CrossRef]
4. Farges, O.; Bézian, J.-J.; El Hafi, M. Global optimization of solar power tower systems using a Monte Carlo algorithm: Application to a redesign of the PS10 solar thermal power plant. *Renew. Energy* **2018**, *119*, 345–353. [CrossRef]
5. Luo, Y.; Lu, T.; Du, X. Novel optimization design strategy for solar power tower plants. *Energy Convers. Manag.* **2018**, *177*, 682–692. [CrossRef]
6. Cavallaro, F.; Zavadskas, E.K.; Streimikiene, D. Concentrated solar power (CSP) hybridized systems. Ranking based on an intuitionistic fuzzy multi-criteria algorithm. *J. Clean. Prod.* **2018**, *179*, 407–416. [CrossRef]
7. Schöttl, P.; Bern, G.; Flesch, J.; Fluri, T.; Nitz, P. Efficient modeling of variable solar flux distribution on Solar Tower receivers by interpolation of few discrete representations. *Sol. Energy* **2018**, *160*, 43–55. [CrossRef]
8. Wang, W.-Q.; Qiu, Y.; Li, M.-J.; Cao, F.; Liu, Z.-B. Optical efficiency improvement of solar power tower by employing and optimizing novel fin-like receivers. *Energy Convers. Manag.* **2019**, *184*, 219–234. [CrossRef]
9. Chong, K.; Lim, C.; Hiew, C. Cost-effective solar furnace system using fixed geometry Non-Imaging Focusing Heliostat and secondary parabolic concentrator. *Renew. Energy* **2011**, *36*, 1595–1602. [CrossRef]
10. Harper, P.J.; Dreijer, J.; Malan, K.; Larmuth, J.; Gauche, P. Use of MEMs and optical sensors for closed loop heliostat control. In Proceedings of the SOLARPACES 2015: International Conference on Concentrating Solar Power and Chemical Energy Systems, Cape Town, South Africa, 13–16 October 2015.
11. Ruelas, A.; Velázquez, N.; Villa-Angulo, C.; Acuña, A.; Rosales, P.; Suastegui, J. A Solar Position Sensor Based on Image Vision. *Sensors* **2017**, *17*, 1742. [CrossRef] [PubMed]
12. Roth, P.; Georgiev, A.; Boudinov, H. Design and construction of a system for sun-tracking. *Renew. Energy* **2004**, *29*, 393–402. [CrossRef]
13. Aiuchi, K.; Yoshida, K.; Onozaki, M.; Katayama, Y.; Nakamura, M.; Nakamura, K. Sensor-controlled heliostat with an equatorial mount. *Sol. Energy* **2006**, *80*, 1089–1097. [CrossRef]
14. Arbab, H.; Jazi, B.; Rezagholizadeh, M. A computer tracking system of solar dish with two-axis degree freedoms based on picture processing of bar shadow. *Renew. Energy* **2009**, *34*, 1114–1118. [CrossRef]
15. Lee, D.I.; Jeon, W.J.; Baek, S.W.; Ali, N.T. Optimal Design and Control of Heliostat for Solar Power Generation. *Int. J. Eng. Technol.* **2012**, *4*, 388. [CrossRef]
16. Convery, M.R. Closed-loop control for power tower heliostats. In Proceedings of the High and Low Concentrator Systems for Solar Electric Applications VI, San Diego, CA, USA, 22–24 August 2011; p. 81080M.
17. Lynch, W.A.; Salameh, Z.M. Simple electro-optically controlled dual-axis sun tracker. *Sol. Energy* **1990**, *45*, 65–69. [CrossRef]
18. Arturo, M.M.; Alejandro, G.P. High-precision solar tracking system. In Proceedings of the World Congress on Engineering 2010 Vol II WCE 2010, London, UK, 30 June–2 July 2010; pp. 844–846.
19. Lee, C.-D.; Huang, H.-C.; Yeh, H.-Y. The development of sun-tracking system using image processing. *Sensors* **2013**, *13*, 5448–5459. [CrossRef] [PubMed]
20. Wei, C.-C.; Song, Y.-C.; Chang, C.-C.; Lin, C.-B. Design of a solar tracking system using the brightest region in the sky image sensor. *Sensors* **2016**, *16*, 1995. [CrossRef] [PubMed]
21. Coquand, M.; Henault, F.; Caliot, C. Backward-gazing method for measuring solar concentrators shape errors. *Appl. Opt.* **2017**, *56*, 2029–2037. [CrossRef] [PubMed]
22. Hénault, F.; Coquand, M.; Defieux, P.-H.; Caliot, C. Sun backward gazing method with multiple cameras for characterizing solar concentrators. *Sol. Energy* **2018**, *166*, 103–114. [CrossRef]
23. Kribus, A.; Vishnevetsky, I.; Yogev, A.; Rubinov, T. Closed loop control of heliostats. *Energy* **2004**, *29*, 905–913. [CrossRef]

24. Berenguel, M.; Rubio, F.; Valverde, A.; Lara, P.; Arahal, M.; Camacho, E.; López, M. An artificial vision-based control system for automatic heliostat positioning offset correction in a central receiver solar power plant. *Sol. Energy* **2004**, *76*, 563–575. [CrossRef]
25. Younis, M.; Al-Shehhi, H.; Al Hamar, N.; Meribout, M. A wireless sensor network-based heliostat system using real-time image processing techniques. In Proceedings of the 2011 IEEE GCC Conference and Exhibition (GCC), Dubai, United Arab Emirates, 19–22 February 2011; pp. 465–468.