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CONTROL AND IMPLEMENTATION OF A MINI CYLINDRICAL PARABOLIC SOLAR CONCENTRATOR

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Keywords: Solar concentration; Solar tracking; Stepper motor; Automatic control; Light-dependent resistors.

This research presents the design and implementation of a solar concentration system utilizing a cylindrical parabolic solar concentrator. The system is designed to capture and focus sunlight onto a tube containing a heat transfer fluid. The resulting heat is harnessed to produce steam, which subsequently drives a steam turbine for electricity generation. A solar tracking mechanism ensures optimal system performance throughout the day. The core of the concentration system comprises a stepper motor integrated into the mechanical structure, with communication facilitated by an Arduino board and MATLAB. The control of the solar concentrator is implemented through two distinct strategies. The first is automatic control based on light-dependent resistors (LDRs), which are used to determine the sun's position. This data is transmitted to the control system, which enables automatic adjustment of the parabolic trough solar concentrator's orientation and positioning. The second one is a manual control based on a MATLAB graphical user interface (GUI), developed to enable manual control of the solar concentrator's stepper motor. This paper investigates the intricate relationship between control precision, error, and the number of motor steps.

1. INTRODUCTION

Solar energy has emerged as a promising alternative to fossil fuels, offering a sustainable and renewable source of power. Numerous studies have been conducted on solar energy to develop conversion techniques and minimize equipment costs for optimal utilization [1–6]. Among various solar energy technologies, concentrating solar power (CSP) has attracted significant attention for its ability to achieve high temperatures and efficient energy conversion. CSP technology is a viable option for generating electricity from the sun. TES systems play a vital role in CSP plants by storing surplus solar heat and making it available when solar energy is insufficient [7]. A common concentrating solar power (CSP) system is the cylindrical parabolic solar concentrator, also known as a parabolic trough. It uses a parabolic trough to focus sunlight onto a linear receiver. This concentrated solar energy heats a working fluid, which can then generate steam or power other thermal processes. The effectiveness of such a concentrator largely depends on its tracking system and control algorithms [8–14].

Algeria is capitalizing on its extensive solar reserves, particularly in the Sahara, by developing solar power plants. A 150 MW solar-gas hybrid project in Hassi R'Mel incorporates a CCP equipped with a robust solar tracking system [15]. This project aims to enhance the performance of solar power systems in the Saharan environment, considering the region's unique climatic challenges.

This paper presents a comprehensive study on the control and implementation of a cylindrical parabolic solar concentrator. The primary objective is to develop an effective control strategy that ensures optimal energy capture and efficient operation of the system. The paper will cover the following key aspects:

System design and components: a detailed description of the cylindrical parabolic solar concentrator, including its mechanical structure, optical system, and tracking mechanism.

Control system architecture: the design and implementation of the control system, including sensors, actuators, and the overall control strategy.

Tracking algorithms: the development and evaluation of different tracking algorithms to ensure accurate solar tracking and maximize energy capture.

System performance evaluation: experimental results demonstrating the performance of the cylindrical parabolic solar concentrator under various operating conditions.

By addressing these aspects, this paper aims to contribute to the advancement of cylindrical-parabolic solar concentrator technology and promote the widespread adoption of sustainable solar energy solutions.

2. METHODOLOGY

This section presents the design and development of an automated control system for a cylindrical parabolic solar concentrator. The system utilizes an Arduino Uno microcontroller, a stepper motor, an L293D motor driver, and two LDRs to track the sun accurately. A MATLAB/GUIDE-based user interface enables manual control and real-time system monitoring.

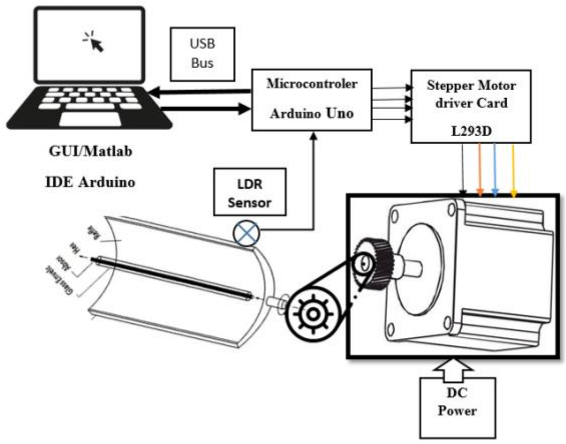

Fig. 1 – Block diagram of the parabolic trough solar concentrator.

The solar concentrator employs a MATLAB-Arduino-powered tracking mechanism. This system facilitates the concentrator's precise alignment with the sun's trajectory, ensuring its return to the starting point at sunset.

Figure 2 below depicts a parabolic trough solar concentrator. A prototype concentrator was designed and constructed at the University of Laghouat, a device designed to focus sunlight onto a linear receiver. This receiver is typically used to heat water or generate steam.

The experimental device was installed on the rooftop of a residence in Laghouat, Algeria. The experimental research was conducted in May 2023 at the Mhafir site in Laghouat

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(33° 47' 10.396" N 2° 50' 54.959" E). Both manual and automated testing methods were employed, with azimuth angle measurements taken using a manual inclinometer (Figs. 2 and 3) in degrees.

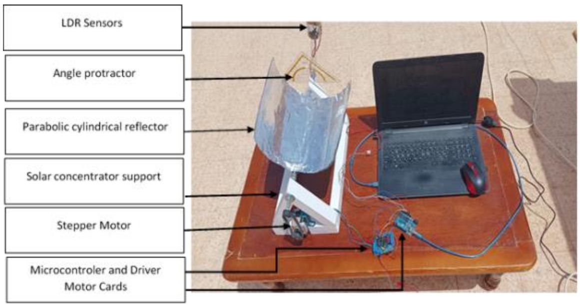

Fig. 2 – Photographic view of the experimental setup.

Solar tracker by LDR sensor: A solar tracker is a device that automatically adjusts the orientation of the cylindrical parabolic collector to follow the sun's path throughout the day. This maximizes the amount of sunlight that the panel receives, leading to increased energy production. A solar tracker using LDR sensors is a straightforward and cost-effective way to optimize the energy output of solar panels by ensuring they always face directly towards the sun.

Control and acquisition system: A Control and Acquisition Solar Concentrator System is a sophisticated system responsible for managing and monitoring the operation of a solar concentrator, such as a Cylindrical Parabolic Solar Concentrator (CPSC). These systems are crucial for optimizing the performance and efficiency of solar concentrators.

This research explores three methods for orienting the concentrator towards the sun: manual control via a graphical interface in MATLAB, automatic tracking using LDR sensors, and blind control based on astronomical calculations to predict the sun's position throughout the year.

Ultimately, this comprehensive methodology lays the groundwork for evaluating the efficacy of diverse control strategies in achieving optimal solar energy capture.

3. RESULTS AND DISCUSSION

This section presents the key findings and analysis derived from the experimental investigation of the solar concentrator's tracking performance. Figure 3 presents the method for measuring the solar concentrator's movement and positioning angles throughout the day. When the concentrator is facing directly upwards (at solar noon), the angle is 0°. An eastward orientation results in an angle of -90°, while a westward orientation results in an angle of +90°.

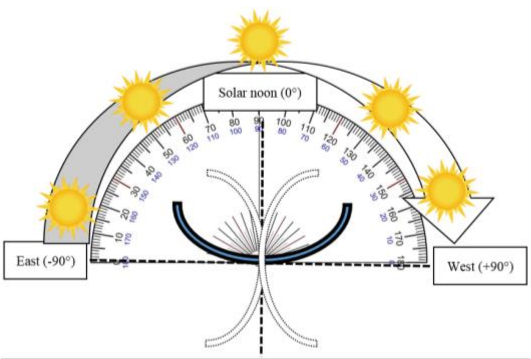

Fig. 3 – Azimuthal angle measurement system using a protractor.

The flowchart in Fig. 4 outlines a basic solar tracking algorithm that continuously adjusts the orientation of a solar collector to maximize the amount of sunlight it receives. The system monitors the sun's position and the intensity of sunlight on different parts of the collector. If the sun's position changes, the collector is rotated accordingly to optimize its alignment with the sun.

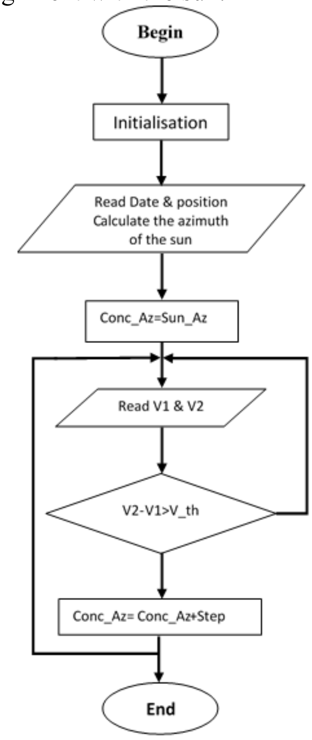

Fig. 4 – Flowchart of automatic concentrator control system.

Initialization: This step initializes any necessary variables or parameters for the system.

Read Date & Position, Calculate Sun Azimuth: The system reads the current date and the solar tracking device's geographical position (latitude and longitude). It then calculates the sun's azimuth angle, which is the angle between the sun's direction and true north.

Conc_Az = Sun_Az: The concentration angle (Conc_Az) is initially set to the calculated sun azimuth (Sun_Az).

Read V1 & V2: V1 and V2 are the voltages measured across the resistor in series with the LDR sensor. We can theoretically determine these voltages using the voltage divider theorem.

Vth is the threshold voltage, typically in the millivolt (mV) range. System precision increases inversely with the magnitude of Vth.

V2-V1 > V_th: This is a decision block. If the difference between V2 and V1 is greater than a threshold voltage (V_th), it means that the sun's position has shifted, and the solar collector needs to be adjusted.

Conc_Az = Conc_Az + Step: If the condition in the previous step is true, the concentration angle (Conc_Az) is incremented by a small step value. This adjustment aims to align the solar collector with the sun's new position.

End: This is the final step of the algorithm, indicating the end of the process.

Each curve on the graph (Fig. 5) represents a specific day of the year (*e.g.*, January 1st, February 1st). The shape of each curve reveals how the sun's azimuth angle changes over the course of the day. It begins in the East (negative angles) in the morning, reaches its peak (zero degrees) around noon, and then moves towards the West (positive angles) in the afternoon.

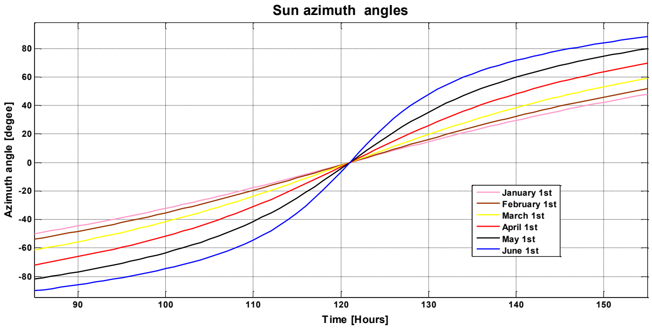

Fig. 5 – The sun azimuth angle curves of different days of the year in the Laghouat region.

The steepness of the curve indicates the speed of the sun's apparent movement across the sky. Steeper curves, typically seen in winter months, signify faster movement, while flatter curves, common in summer months, indicate slower movement. This information is crucial for solar energy applications, such as the design of solar panels and concentrators to maximize energy output.

Table 1 compares azimuth values measured with a manual inclinometer with those obtained from the astronomical equation for the sun's azimuth [16–24]. The data spans the time from 08:30 to 15:30, and measurements were taken every 30 minutes.

Table 2

Azimuth test results (29-05-2024).

Time	Azimuth real (degrees)	Azimuth measure (degrees)	Error (degrees)
08:30	-89.82	-87	2.82
09 :00	-85.39	-82	3.39
09 :30	-80.28	-78	2.28
10 :00	-74	-73	1.00
10 :30	-65.69	-64	1.69
11 :00	-53.67	-51	2.67
11 :30	-34.82	-33	1.82
12 :00	-6.44	-5	1.44
12 :30	24.56	24	0.56
13 :00	47.17	47	0.17
13 :30	61.47	60	1.47
14 :00	70.99	71	0.01
14 :30	77.94	76	1.94
15 :00	83.45	82	1.45
15 :30	88.11	85	3.11

The observed discrepancy between the azimuth angle measured with the manual inclinometer and the values obtained from the astronomical equation for the sun's azimuth is minimal. This suggests that the accuracy of the control system provided by Guide/MATLAB is acceptable.

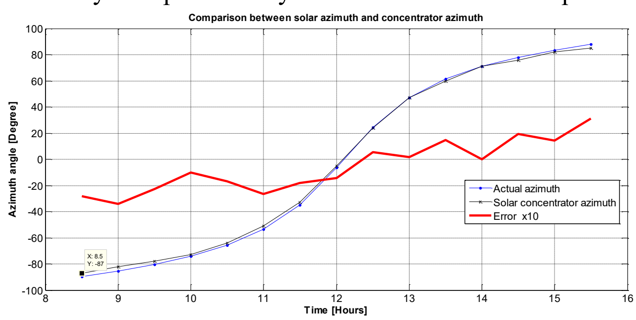

Fig. 6 – Azimuth tracking error of the solar concentrator system.

As depicted in Fig. 6, the azimuth trajectories determined by manual inclinometer measurements and astronomical calculations are superimposed. A visual inspection of the curves indicates that the average discrepancy between the two methods is less than 1.47°. The error between the two azimuths is plotted on a different scale (multiplied by 10) to highlight its magnitude. The error appears to fluctuate, with some periods of larger deviation and others with smaller deviation.

In the following section, we will investigate in detail the interrelationship between control precision, error, and the number of motor steps. A direct proportionality exists between energy consumption and the number of steps, meaning that as the number of steps increases, so does the energy consumption. Therefore, it is crucial to carefully select control conditions to achieve a balance between low energy consumption, high control precision, and minimal error. The data presented in Fig. 7 pertains to May 28, 2024. Figure Y, on the other hand, illustrates the results obtained on the subsequent day, May 29, 2024.

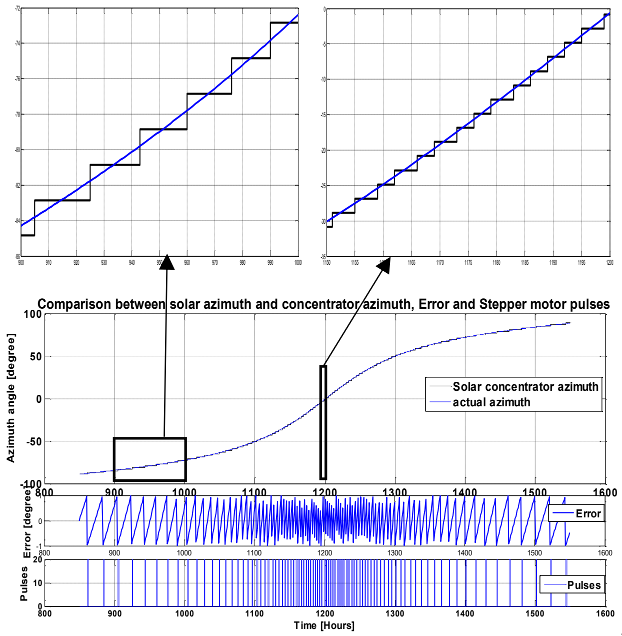

Fig. 7 – Comparison between solar azimuth and concentrator azimuth for May 28, 2024.

Figure 7 illustrates a comparison of the concentrator and solar azimuths for May 28, 2024. The control parameters were set to a 1° condition and a 2° step.

Table 2.

Quantified impact of step and condition size on control system error/

Cases	Condition	Step	Number of steps	Error	Err_moy
01	8	16	11	2.73 10^3	3.8963
02	8	8	22	2.74 10^3	3.9151
03	4	8	22	1.37 10^3	1.96
04	2	4	44	696.10	0.9930
05	1	2	89	351.96	0.5021
06	0.5	1	178	174.84	0.2494
07	*0.3*	*0.6*	*296*	*149.29*	*0.2130*
08	0.2	0.4	444	3.6 10^3	5.2658
09	0.2	0.6	296	159.82	0.2280
10	0.2	0.8	222	176.64	0.2520

This graph shows the difference between the solar concentrator azimuth and the actual azimuth at each point in time. A positive error indicates that the concentrator is lagging behind the sun, while a negative error means it's leading ahead. The error fluctuated between -1° and +1°, resulting in a total daily error of 351.96°. The average error was 0.5021°, and the motor step shadow was 89 steps. (See Table 2).

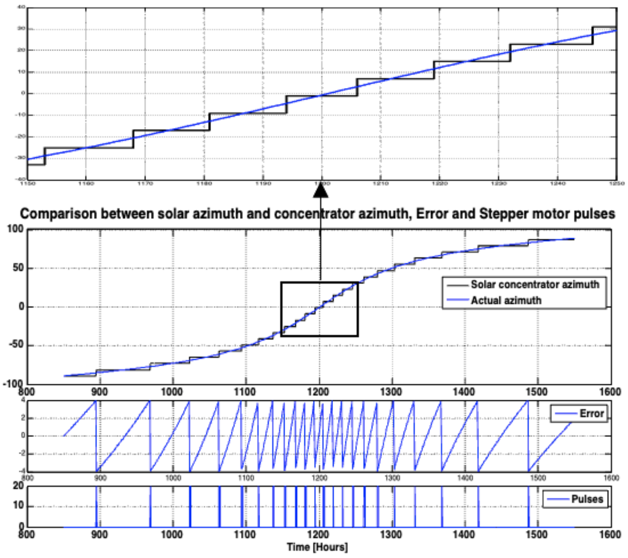

Fig. 8 – Comparison between solar azimuth and concentrator azimuth for May 29, 2024

Figure 8 illustrates a comparison of the concentrator and solar azimuths for May 29, 2024. The control parameters were set to a 4° condition and an 8° step. The data presented in Figure 8 indicates that increasing the condition and step count to 4° and 8°, respectively, resulted in a wider error range of -4 to +4 (See Table 2). Although this is a negative outcome, the positive aspect is a reduction in the number of motor steps, leading to decreased energy consumption. Table 2 displays the outcomes of the control strategy implemented on the parabolic trough solar concentrator. This strategy involved modifying the condition and concentrator steps, followed by calculating the necessary motor steps and the resulting error.

Upon analyzing Table 2, it is apparent that the most advantageous result is obtained with a condition of 0.3° and a step size of 0.6°. However, this optimal configuration requires 296 steps, thereby increasing the electrical energy consumption needed to power the concentrator throughout the day. A notable relationship exists between the condition and the number of steps (Condition = step/2), in which a decrease in the condition value leads to an increase in the number of steps. For Case 9, a condition of 0.2° and a step of 0.4° were implemented. However, the number of steps and the resulting error were significantly larger compared to other cases. This deviation can be attributed to the concentrator's inability to maintain its tracking trajectory during the middle of the day, which is likely due to specific solar movement patterns at that time. Overall, these results underscore the intricate relationship between control parameters, tracking accuracy, and energy efficiency, providing valuable insights for the practical optimization of solar concentrator systems.

4. CONCLUSIONS

This study investigated the development and implementation of a solar tracking system for a parabolic trough solar concentrator. The system's performance was evaluated through various experiments, analyzing the impact of control parameters on tracking accuracy and energy consumption. The solar tracking system demonstrated accurate tracking of the sun's azimuth angle, with minimal deviations between measured and calculated values. The control parameters, specifically the condition and step size, significantly impact the system's performance. Smaller condition and step sizes result in higher accuracy but increased energy consumption due to a larger number of motor steps. A balance must be struck between tracking accuracy and energy efficiency. Optimal control parameters can minimize energy consumption while maintaining acceptable tracking accuracy. Implementing more sophisticated control algorithms, such as predictive control or adaptive control, could further enhance tracking accuracy and energy efficiency. The results presented in this paper validate the feasibility of using this prototype CPSC as a testbed for solar tracking algorithms and control strategies.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Abdelfettah Zeghoudi: conception, methodology, writing - original draft preparation, supervision.
Khairedine Bouzidi: prototype production, data curation.

REFERENCES

1. K. Benmouiza, *Nonlinear clustered adaptive-network-based fuzzy inference system model for hourly solar irradiation estimation*, Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., **68**, *1*, pp. 7–11 (2023).
2. S.M. Ulaganathan, R. Muniraj, R. Vijayanand, and D. Devaraj, *Novel solar photovoltaic emulation for validating the maximum power point algorithm and power converter*, Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., **68**, *4*, pp. 407–412 (2023).
3. G.G. Tolun and Y.A. Kaplan, *Development of backpropagation algorithm for estimating solar radiation: a case study in Turkey*, Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., **68**, *3*, pp. 313–316 (2023).
4. V.G. Dogaru, F.D. Dogaru, V. Năvrăpescu, and L.M. Constantinescu, *From the photovoltaic effect to a low voltage photovoltaic grid challenge – a review*, Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., **69**, *3*, pp. 263–268 (2024).
5. M.I. Abdelwanis and A.A. Zakymaximum, *Maximum power point tracking in a perovskite solar pumping system with a six-phase induction motor*, Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., **69**, *1*, pp. 15–20 (2024).
6. S. Seba, M. Birane, and K. Benmouiza, *A comparative analysis of boost converter topologies for photovoltaic systems using MPPT (PO) and beta methods under partial shading*, Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., **68**, *4*, pp. 375–380 (2023).
7. A.H. Alami, A.G. Olabi, A. Mdallal, A. Rezk, A. Radwan, S.M.A. Rahman, and M.A. Abdelkareem, *Concentrating solar power (CSP) technologies: Status and analysis*, International Journal of Thermofluids, **18**, 100340 (2023).
8. A. Gama, M. Haddadi, and A. Malek, *Étude et réalisation d'un concentrateur cylindro-parabolique avec poursuite solaire aveugle*, Journal of Renewable Energies, **11**, *3*, pp. 437–451 (2008).
9. W.E. Sánchez, M.P. Jiménez, C.A. Mantilla, J.M. Toro, M.A. Villa, and G. Sinchiguano, *Design and implementation of a parabolic cylinder collector with solar tracking to obtain hot water*, In E3S Web of Conferences, Vol. 57, 02003, EDP Sciences (2018).
10. A.K. Bhakta, N.K. Panday, and S.N. Singh, *Performance study of a cylindrical parabolic concentrating solar water heater with nail-type twisted tape inserts in the copper absorber tube*, Energies, **11**, *1*, 204 (2018).
11. A. Gama, C. Larbes, A. Malek, and F. Yettou, *Etude et réalisation d'un dispositif de poursuite solaire sensible destiné à un prototype d'un concentrateur cylindro-parabolique*, Revue des sciences fondamentales et appliquées, **2**, *1*, pp. 137–148 (2010).

12. Y.D. Arbuzov, V.M. Evdokimov, and O.V. Shepovalova, *Theory of concentration distribution over the surface of axisymmetrical receiver in cylindrical parabolic mirror solar energy concentrator*, Energy Reports, **6**, pp. 380–394 (2020).
13. N. Nouah, N. Djennaoui, and T. Hassani, *Modélisation d'un capteur solaire cylindro-parabolique*, Journal of Renewable Energies, **17**, *4*, pp. 559–567 (2014).
14. S. Niyonsaba and J.B. Niyonzima, *Design and sizing of a solar thermal power plant with parabolic trough collectors*, Journal of Renewable Energies, **27**, *1*, pp. 81–98 (2024).
15. A. Messai, Y. Benkedda, S. Bouaichaoui, and M. Benzerga, *Feasibility study of parabolic trough solar power plant under Algerian climate*, Energy Procedia, **42**, pp. 73–82 (2013).
16. A.B. Sproul, *Derivation of the solar geometric relationships using vector analysis*, Renewable Energy, **32**, pp. 1187–1205 (2007).
17. J.A. Duffie and W.A. Beckman, *Solar engineering of thermal processes*, 2nd ed., Wiley & Sons, New York, NY (1991).
18. J.E. Braun and J.C. Michell, *Solar geometry for fixed and tracking surfaces*, Solar Energy, **31**, *5*, pp. 439–444 (1983).
19. M. Iqbal, *An introduction to solar radiation*, Academic Press, New York (1983).
20. R. Kittler and S. Darula, *Determination of time and sun position system*, Solar Energy, **93**, pp. 72–79 (2013).
21. T. Muneer, *Solar radiation & daylight models for the energy efficient design of buildings*, Architectural Press, Oxford (1997).
22. R. Buckner, *Astronomic and grid azimuth*, Landmark Enterprises, Rancho Cordova (1984).
23. A.T. Ali, *An error modeling framework for the Sun azimuth obtained at a location with the hour angle method*, Positioning, **3**, pp. 21–29 (2012).
24. M.H.M. Sidek, N. Azis, W.Z.W. Hasan, M.Z.A. Ab Kadir, S. Shafie, and M.A.M. Radzi, *Automated positioning dual-axis solar tracking system with precision elevation and azimuth angle control*, Energy, **124**, pp. 160–170 (2017).