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Innovative Applications of Euclidean Distance Algorithm in the Development of Dual-Axes Solar Tracking System



Abstract: - The main aim of this manuscript is to present the innovative applications of the Euclidean distance algorithm (EDA) for the development of the dual-axes solar tracking system. By positioning the solar panel perpendicular to the sun, this system intends to optimize solar energy harvesting efficiency. Applied using a quantitative approach, the EDA helped to find the optimum solar panel angle continuously depending on the sun's location. The system was developed using LabVIEW software and data acquisition (DAQ) system. The design and installation of the dual-axes solar tracking system included evaluation of performance metrics under different weather conditions. Data was collected over a set time to assess the effectiveness of system. Results established that the dual-axes solar tracking system significantly increased energy output. The algorithm was effectively used to improve the system's performance by accurately finding the optimal solar panel position throughout the day. By aiming the likelihood of higher solar energy efficacy through effective algorithmic techniques, the results provide the prospect for farther research and development in solar energy systems. By directing the invention of more effective renewable energy solutions, the knowledge gained may ultimately help to execute sustainability goals.

Keywords: — Solar panel, Euclidean distance, dual-axes and optimization.

I. INTRODUCTION

The constant increase in energy demand, combined with environmental pollution, has spurred research into alternate and renewable energy fuels [1]. Solar technologies are one of the most promising renewable energy sources due to their ever-increasing production efficiency, capacity to be used in a range of locales, and environmental friendliness [2]. Maximizing the efficiency of solar panels necessitates their right orientation and tilt angles [3]. It is imperative that the panels are positioned to receive the most sunlight possible throughout the day [4]. To optimize power production from a solar panel system, the panels must be routinely adjusted to align with the sun at its best angle throughout the day and year, as the sun's position varies with the seasons and time of the day [5]. Solar tracking systems are engineered to enhance solar energy capture by continuously shifting the angle of solar panels to align with the sun's position during the day, hence greatly increasing electricity generation compared to stationary panels [6].

A dual-axes solar tracking system, whereby changes in azimuthal and elevation angles can be made, offers a big improvement over fixed solar panel setup [7]. Dual-axes trackers might vastly improve the efficiency of solar power plants by allowing panels to tilt and swivel [8]. Further improving their performance is the incorporation of sophisticated algorithms and computational technologies into the design and operation of these tracking systems [9]. The EDA has become a potent instrument for maximizing solar panel placement among these algorithms [10]. Based on geometric concepts, the EDA is quite common across several domains including machine learning (ML), computer vision, and robotics [11]. In solar tracking systems, it is used to determine the perfect angle at which solar panels should be set to maximize exposure to light [8]. By calculating the distance between the sun's location-based optimal position and the current position of the solar panel, EDA enables exact changes that improve energy acquisition [12]. This algorithm is vital for the advancement of intelligent solar technologies to adjust to shifting environmental conditions as well as the efficiency of solar tracking systems [13].

In dual-axes solar tracking systems, creative use of the EDA illustrates how math, engineering, and environmental science all meet [14]. It stresses how vital interdisciplinary solutions are for tackling the difficult problems linked with renewable energy technologies [15]. Through the use of mathematical algorithms, engineers will create more effective solar tracking systems that can dynamically respond to the movement of the sun, therefore boosting the general performance of solar energy sites [18]. Furthermore, the incorporation of the EDA into solar tracking systems suggests a more general movement toward the employment of data-driven techniques in energy management [16]. Sensors everywhere and the rise of the Internet of Things (IoT) have made possible the gathering of enormous quantities of solar energy generation and environmental conditions data [17]. Using methods like the EDA makes it possible to analyze the information, therefore resulting in improved operational

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effectiveness and intelligent decision-setting [18]. The changing global energy scene will probably make these innovative algorithms even more important in maximizing renewable energy systems [19].

The creative uses of the EDA in the construction of dual-axes solar tracking systems are a major step forward in the search for effective solar energy use [20]. This strategy shows the power of interdisciplinary cooperation in the area of renewable energy as it improves energy capture by using mathematical principles to maximize solar panel orientation [21]. Advanced algorithms and intelligent technologies incorporated will be crucial in propelling the development of solar energy systems as the need for sustainable energy solutions keep increasing [22].

II. LITERATURE REVIEW

EDA is a fundamental principle in geometry and serves as the most intuitive metric for spatial separation between points [23]. The computation is a fundamental mathematical activity utilized in diverse fields, such as linear algebra, optimization, data analysis, and ML [24]. Euclidean distance is a commonly executed computing operation in numerous algorithms within these domains and frequently serves as a principal bottleneck in large-scale optimization challenges, including clustering, nearest-neighbor searches (NNs), and high-dimensional data applications [25]. Thus, enhancing fundamental processes such as distance calculations that can result in considerable advancements in the overall efficacy of numerous distance-dependent algorithms [26]. In extensive datasets or real-time processing applications, minimizing the overhead of distance computations can significantly enhance the performance and scalability of algorithms such as K-means clustering or K-nearest neighbors (KNNs) [27]. This necessitates a profound comprehension of the mathematical attributes of Euclidean distance [28].

Most intuitive measure of spatial separation between points is Euclidean distance, a basic geometric concept [29]. Its calculation is a fundamental mathematical operation found throughout several fields including data analysis, linear algebra, optimization, and ML [30]. Many algorithms in these fields have Euclidean distance as one of the most often carried computational operations and often a major limitation in massive optimization assignments including clustering, KNNs, or high dimensional data applications [31]. Therefore, improving general operations such distance calculations might greatly enhance the total output of lots of distance-dependent programs [32]. For example, in big data sets or real-time processing scenarios, lowering the overhead of distance computations might significantly enhance the speed and scalability of algorithms such K-means grouping or KNNs [33]. This calls for a thorough knowledge of the particular features of the given issue as well as the mathematical qualities of Euclidean distance pertinent to it [34].

Figure 1 illustrates a representation of the distance metric between two objects for variables X and Y utilizing Euclidean distances [35]. It presents a simplified representation of Euclidean distance, indicating that this metric can be generalized to different distance forms, hence illustrating the generic calculation of distance measures [36]. Consider two points (X_1, Y_1) and (X_2, Y_2) in a 2-dimensional space; the Euclidean distance between them is given by utilizing equation 1 [38].

$$d = \sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2} \quad (1)$$

where d is Euclidean distance, X_1, Y_1 are coordinated of the first point and X_2, Y_2 are coordinates of the second point [39]. Temperature forecasting algorithm based on the EDA with 24 solar terms was proposed for solar tracking system. In the proposed method, the historical data was classified by the 24 solar terms. The EDA was used to determine the historical data with the most similarity to the historical temperature in the database [40].

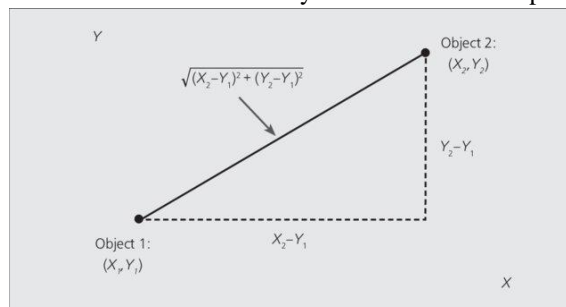


Fig. 1: An example of Euclidean distance between two objects on variables [37].

Optimizing solar panel efficiency with tracking systems entails using technology to allow solar panels to constantly follow the sun's movement throughout the day, resulting in substantially more sunlight caught and thus more power generated than stationary panels [41]. This significantly enhances the overall efficiency of a solar energy system [8]. Of these, dual-axes solar tracking systems have become a major breakthrough in energy capture

since they change both orientation and tilt angles of the solar panels to track the sun's path [41]. A promising computational technique to enhance the performance of these tracking systems is the EDA [42]. Studies investigating several mechanical and electronic options started the groundwork on solar tracking systems [43]. [44] believe that conventional single-axis tracking systems have greatly improved energy capture; dual-axes systems, on the other hand, offer even more efficiency by enabling modification of both azimuth and elevation angle. [45] pointed out that dual-axes systems may improve energy output by up to 40 % over fixed installations, this ability is important in areas with different solar angles over the year.

Improvements in control algorithms have recently further increased the performance of dual-axes solar trackers [46]. Applied to real-time optimization of solar panel placement, the mathematical technique known as the EDA measures point-to-point distance in Euclidean space [47]. [48] projects show how EDA might simplify the tracking process by determining the best angle for solar panels from the sun's position and regional geographic information. In addition to enhancing tracking accuracy, this algorithm reduces the computational load on control systems, therefore making it a good option for real-time uses [49]. Furthermore, recent investigations have focused on the incorporation of EDA with other optimization approaches [31]. [50], for example, investigated how combining EDA with ML techniques could improve the predictive capacity of solar tracking systems. Their work shows how ML can use past solar data to predict sun position and thereby, when combined with EDA, enable early changes in panel orientation [51]. This blended method has shown great advancements in energy efficiency, thus highlighting the promise of cross-disciplinary approaches in solar technology [52]. Studies have also looked at the environmental effect of solar tracking technologies [7]. [8] study showed that using dual-axes tracking systems might cut carbon emissions as it minimizes the number of solar panels needed while also maximizing solar energy output. These systems help create a more sustainable energy situation by maximizing energy capture and thereby lowering dependence on hydrocarbons [53]. In this setting, the use of EDA not only improves results but also supports world sustainability targets as set forth by the United Nations Sustainable Development Goals (UN, 2015) [54].

Scholarly works have thoroughly covered the financial consequences of implementing sophisticated tracking technologies [55]. [41] study revealed that although the front cost of dual-axes systems might be more than for fixed setups, the long-term advantages in power generation and cost savings validate the expenditure. [56] stated that integration of EDA into the solar tracking system can increase energy output, subsequently speeds up the payback period for solar initiatives. [57] stressed that EDA integration can further increase the return on investment. Apart from these developments, dual-axes solar tracking systems have caught interest in the part of user-friendly interfaces and automation [58]. As [59] pointed out, the creation of intuitive control systems using EDA makes system administration and user interaction much simpler. Particularly in residential solar projects where consumers might lack technical knowledge, this initiative is absolutely necessary for broad acceptance.

III. RESEARCH METHODOLOGY

Figure 2 shows the EDA controller block diagram in the LabVIEW user interface program. It is essential to state that the LabVIEW's block diagrams for the whole system were too huge to be incorporated in this paper and only block diagrams relevant to the EDA execution were incorporated. The program is a multiple inputs and multiple outputs system (MIMO). The system makes use of its measured voltage as feedback for the EDA execution. The algorithm calculates the straight-line distance between two points (two coordinates) in a multidimensional space, considering the differences in each coordinate. The algorithm minimizes the sum of Euclidean distances between data points and certain reference points to find the arrangement of points that minimizes the overall distance between them. The algorithm considers the variations of the solar panel's operating points (voltage), and then establishes the optimum operating point obtained.

At 06h00 when the program executes, the PV module is moved to its starting position (-90° orientation and 0° N tilt angle). The date-time string function (point I) in the block diagram instructs the system to iterate from 06h00 to 18h00 every day. An analog input signal is interpreted by the EDA circuit and converted in a definite decision that will adjust the tilt angle. The system measures the instantaneous analog voltage from the PV module, and then compares it to the previous voltage readings read from the shift register (point J). If the latest readings are greater or equal to the previous value, then the PV module tilts forward to check if the readings improve. If the latest voltage reading is less than the previous reading, then the PV module tilts backward, monitoring the subsequent change in voltage readings. The PV module movements happen once every 30 seconds preventing oscillating. The following can be observed from figure 2:

- The analog signal (voltage from PV modules) is acquired from the DAQ system (point A);

- The analog signal (current from PV modules) is acquired from the DAQ system (point B);
- The output signal from the DAQ system to the linear actuators (point C).

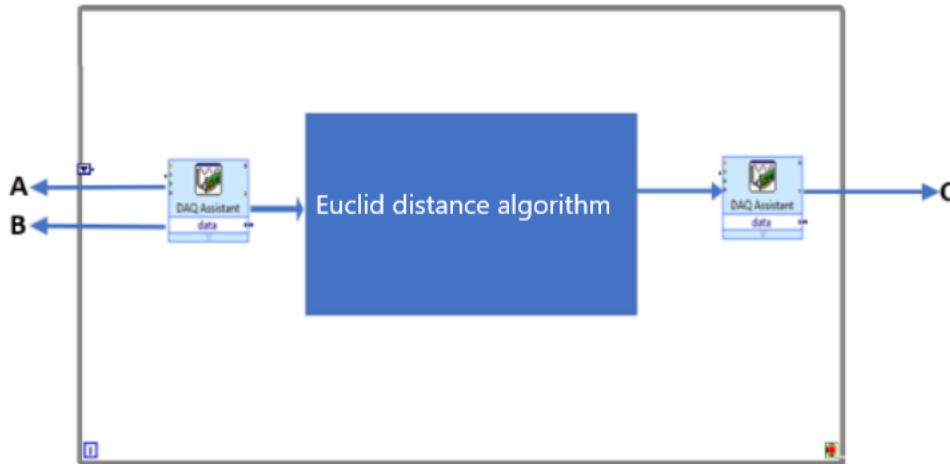


Fig. 2: The Euclidean distance algorithm block diagram in LabVIEW.

Figure 3 illustrates the hardware EDA system with the three redundant fixed-system PV modules that were used for another study. The EDA tracking system is equipped to track the position of the sun from sunrise to sunset. The system is equipped with two linear actuators in order to move the solar panel horizontally and the third linear actuator moves the panel vertically. It is essential to state that the linear actuators are instructed by the DAQ system that communicates directly with the LabVIEW user interface.



Fig. 3: The practical system.

IV. RESULTS AND DISCUSSION

It is evident from figure 4 that the EDA took advantage of the perpendicular position to the sun as it started with higher voltage readings (about 19 V) at the beginning of the system’s execution and also ends at the higher voltage readings (about 13 V). It is essential to state that at around 10h00 am, there was a voltage deep that might be due to shading. The sun is at its lowest point in the sky at the crack of dawn and just before sunset. At midday, when the sun is at its zenith (solar noon), its rays penetrate the atmosphere more deeply than they do at crack of dawn and just before sunset. Solar noon is when the sun’s rays hit a solar collector at their strongest on days with good visibility. That translate to the maximum power that the solar panels generate. The EDA system operated optimally as early as 07h00 am until 17h00 pm. That makes the EDA an alternative for the solar tracking systems.

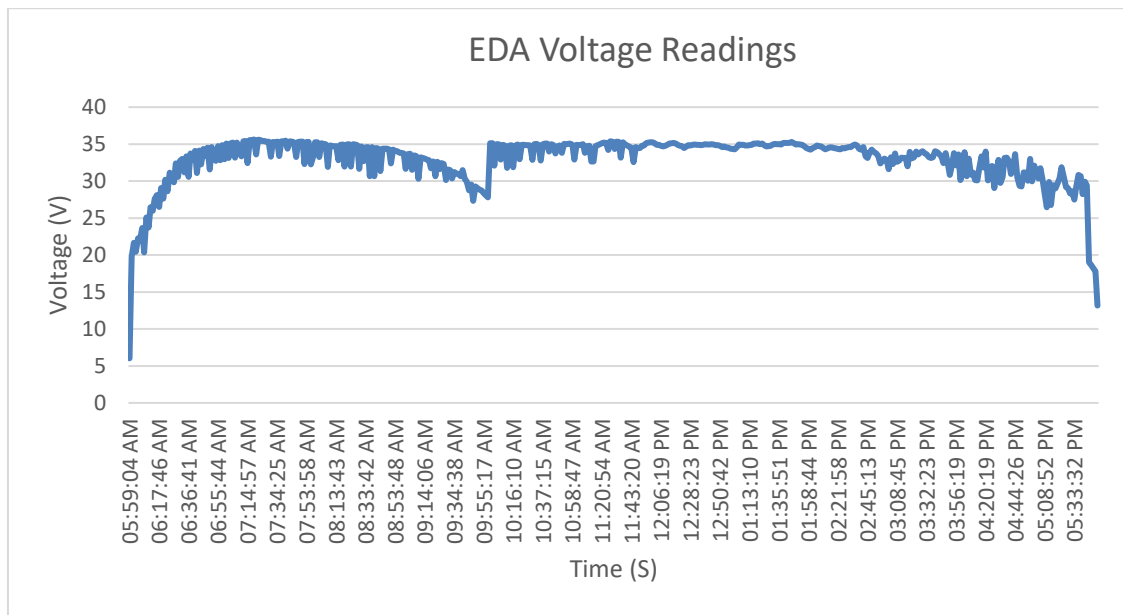


Fig. 4: The voltage reading for the Euclid distance algorithm.

V. CONCLUSION

The innovative application of the EDA in the development of a dual-axes solar tracking system demonstrated notably improvements in the effectiveness of solar energy collection. Employing this algorithm, the system was able to regularly and perfectly align its position in real-time to track the path of the sun all over the day. This also guaranteed the general sustainability of solar technologies and rise in energy production from the sun. This study clearly pointed out the great promise of the EDA in the development of a solar tracking system with dual-axes aid. This algorithm assisted in the advancement of solar energy harnessing throughout the day due to its accuracy and responsiveness. By permitting for the real-time variations subject to the sun's location, the incorporation of this algorithm increased energy output and enhanced the overall efficiency of solar energy systems. The data revealed that the dual-axes solar tracking system powered by the EDA produces more energy yield. This development supports not only the financial viability of solar energy projects, but also the broader objective of increasing the use of renewable energy. In addition, the merit of this study runs beyond solar tracking systems; the concepts of the EDA may be exploited in various spheres, requiring accurate spatial computations and optimization. Potential studies might probe how the merging of ML techniques can even increase the adaptability and efficiency of tracking systems, consequently initiating the path for more smart energy solutions. This study emphasized how innovative algorithmic methods facilitate the acceleration of renewable energy solutions.

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