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Challenges and Recent Developments in Solar Tracking Strategies (STS) for Concentrated Solar Parabolic Dish

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ABSTRACT

This contribution presents an overview of control strategies for Parabolic Dish Concentrated Solar Power (PD-CSP) sun tracker technologies from the literature on different commercial dish systems. This paper also highlights the practical challenges in designing sun trackers for CSP applications. Solar radiation undergoes seasonal changes and transients from the cloud that is exceptionally challenging to manipulate. This paper may provide control engineers with technical information on high-precision solar dynamic tracking and optical accuracy by emphasizing the features, advantages, and limitations of different control techniques and algorithms. Implementation of efficient control strategies addresses concerns in amending dynamics and nonlinearities, thus improving the system responses and extending the operational timeline of CSP plants, which results in a reduced cost per kWh produced.

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1. INTRODUCTION

One of the fundamental inputs to economic activity is energy. Since the 20th century, fossil fuel consumption has increased proportionally on the global population and economic growth. However, this also corresponds to the continuing deterioration of natural resources as the need arises. Thus, there is an urgent need to develop initiatives on increasing economic development while conserving natural assets. To Facilitate this, we need to catalyze policies and investment on innovation for sustainable growth and the rise of new economic opportunities. In this context, the energy sector presents a challenging case on reducing our dependence on fossil fuels, as it contributes to 84% of the global greenhouse gas emissions in 2009. [1]

Solar energy technology emerged as a potential global approach to deal with climate change, energy conservation, environmental enhancement, and pollution reduction. Two main technologies in solar energy are being utilized to convert it into electrical energy, photovoltaic, and thermal technology. To date, photovoltaic technology efficiency has reached more than 20% while thermal technologies are in the range of 40-60% [1]. Between the two, thermal technology showed great potential in meeting up the world's power demand and expected to provide 12% of global energy demand by 2015 [2]. Solar thermal technology is catching up with competitive pricing with conventional fossil fuel due to some technological development and improved operation.

Solar Thermal technologies collect and concentrate sunlight to produce high-temperature heat to produce steam converting it into a mechanical action in a turbine that generates electricity. There are four (4) main technologies under Solar Thermal and these are: (1) Linear Fresnel, (2) parabolic trough reflector, (3) central tower receiver, and (4) parabolic dish. Great attention was given to parabolic trough as it deployed successful commercial applications and accounted for the 90% capacity of the currently installed solar thermal power plants. Thus, minimal interest left for other technology, particularly on the solar parabolic dish. Yet among the technologies, the solar parabolic dish concentrators are the most efficient and high concentration ratios [3], [4] and suitable for a micro-scale power production in remote areas and small communities with capacities in the range of 10-100kW [4], [5].

In the last 30 years, attempts on improving the efficiency of the solar parabolic dish concentrators in terms of architectural integration of these systems for a more dynamic and modular implementation [6]. To achieve the best results, however, these authors suggest that the collector must be correctly positioned to reflect the maximum amount of direct solar radiation [7], [8]. This is why the solar tracking system (STS) plays a significant part in the solar thermal energy systems control system. This left researchers the impression that the development and implementation of advanced control strategies are likely the way to improve and implement a commercial, standalone solar parabolic dish.

This paper covers several important topics on sun-tracking systems, actuating systems, electronic control processes and strategies, and some commercial deployment of the system. This is evidence that unresolved needs and designs can be identified from the control strategies. This paper is arranged in two parts: (1) Practical Design challenges in Solar Tracking System (STS) and (2) Recent Advancements in Solar Tracking Control Strategies.

2. PRACTICAL DESIGN CHALLENGES IN SOLAR TRACKING SYSTEM (STS)

Concentrated Solar Power (CSP) systems generate electricity directly commensurate with the amount of solar energy collected. To achieve a large amount of solar energy, scientists and engineers have investigated the efficiency of the CSP. Literature reveals that there are three ways to maximize the efficacy of CSP systems have been found: (1) to advance the power efficiency; (2) is the application of control algorithms and power transmission strategies; and (3) is to use the tracking system for full solar power [9]. This paper aims to explore both the second and third methods for solar parabolic dish concentrators. Along with the different control strategies and tracking systems studied and developed, the volatility of CSP power generation produces erratic variations in solar irradiance and power production as factors to be discussed. This section includes challenges in solar harvesting and its effects on CSP power generation.

2.1 Cloud Disruptions

The sky and the clouds, in particular, is the CSP's heel of Achilles. Cloud transients can significantly affect control systems for the solar tracker and power plant substation. During the regular period, solar radiation changes continuously with moving clouds. In their planned lifespan of more than 30 years, solar power plant central receivers experience over ten thousand start-ups and shutdowns. Also, they undergo ~~a~~ quick metal receiver temperature changes of over 25,000 [2]. These changes are 25 to 50 times more than any traditional power station. Metal temperatures increase in start-ups and shutdowns from ambient to over 700 °C on regular days [3]. Solar irradiation of intermittent clouds may be decreased by 5 percent per second, contributing to a shift in metal temperature by 600 ° C per minute at receptor elevated flux points [4]. These factors induce substantial thermal stress in products, reduce the plant's life, and maintenance costs.

2.2 Costs and complexity

Given the cost of tracking systems in terms of initial and energy costs, ~~cost for~~ CSP STS is between 30-40 % higher than for fixed systems [5]. The tracking device is primarily responsible for 20% of the CSP plant's running and repair costs [6]. It is also important to reduce the valuation of solar trackers as much as possible to prove the economic viability of the CSP scheme. With a view to an independent off-grid low-cost infrastructure, the United Nations Mechanism for Climate Change communicates its engagement in empowering rural populations by encouraging the development of stand-alone CSP dish technologies. However, considering many emerging countries' social contexts and technical strengths, simplicity and sustainability would be considered as critical factors. Prinsloo [7] demonstrated a stand-alone Parabolic solar dish device in some rural areas of African Villages, striving for simple implementation and compact architecture by implementing an effective automated positioner operated device to generate a potential 12 kW of solar harvesting at noon of full sunshine. The research further suggests improving the structural feature STS of the parabolic solar dish concept for its modular implementation. In the analysis performed by Alexandru and Tatu [8], higher costs will still arise in the engine and traveling joint monitoring system. This technology still proves commercial efficiency and service. High investment costs are needed for a stable support system and axis tracking mechanism [9]. The framework can be cost-effective with the advancement of computer and control system technology [10].

2.3 Environmental conditions of the Field

In addition to the complexity of mechanical structural motion and balance, a Solar Tracking Unit's design option must live up to the area's harsh conditions. Environmental factors such as air temperatures, temperature changes, deposits of soil dust (especially mirrors), strong winds, snow, rain/raining, and lightning, create operational challenges. Considering the design robustness, these effects should be taken into account since some solar generation systems can be deployed where the maintenance crews are not readily available. Components of solar concentrate should be handled to corrosion, whereas components of stainless steel are selected for critical subcomponents.

To protect against humidity and dusty conditions, control electronics must be housed in a watertight and correctly-ground enclosure. When used outdoors in severe weather conditions, all modules should instead have an IP level of at least IP55 to stay secure. The IP number indicates how much protection is provided from entry into mechanical/electric locks of physical objects, pollutants, or water [11]. In the language of IPxy, IP codes show how solid foreign objects are covered against the invasion. The y is the protection standard against moisture/water proximity. Many manufacturers of concentrated solar collection and solar control systems do not consider on-site assembly as practical. Due to the mathematical precision required for assembling structural components, the concentration of solar housing systems is challenging to assemble in remote rural areas. Many parabolic concentrator assemblies would require technical expertise to navigate and coordinate optically.

The cable trusses may also be tensioned, and the mechanism is coordinated optically by an industrial crane or mechanical hoist in most cases. They are also inaccessible or mobile to remote rural or mountain areas. In specific mountain regions, snowfall during the winter season is often subject to extreme fluctuations in temperatures. Because of potential snow and ice deposits, the solar tracking platform's design needs to compensate for extra gravity. Materials with a wide range of working temperatures must, however, be selected.

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2.4 High Wind Conditions

Solar trackers move the payload towards the sun throughout the day; thus, its mechanical drives should make easy and active transitions of the STS and lock its position to the sun regardless of any deviations in the environment. In design and development, understanding the wind loads can help optimize energy production per unit cost. Wind load on STS may be the most challenging design calculation in developing the product since the tracker parts simultaneously move in various directions. The current STS design supports the collector at the single-axis; however, the design should support gravity and wind load. The need to consider forces acting and their moments should be observed practically in the design process [19].

3. RECENT ADVANCEMENTS IN SOLAR TRACKING CONTROL STRATEGIES

In 1975, McFee[12] presented the first automatic STS, for which the author can calculate the distribution of flux density and received power in the central solar receiver systems. A few years later, Semma and Imamru [13] used a microprocessor to change the solar collector's position in the thermal collector. The rapid growth of control system technology following the advent of Industry 4.0 has opened the way for studies to improve the use of STS to increase power efficiency and reduce costs of the CSP. Improved efficiency, accuracy, and stability can be obtained through continuous surveillance of all solar energy incidents. The CSP tracking strategies are classified in various forms. In terms of their mobility, CSP STS are classified as: (1) the one-axis tracked by a single rotating pivot point, and (2) the dual-axis tracked by two pivot points in two separate directions, following the sun's track. These types can also be categorized in terms of their control strategies: (1) open-loop, (2) closed-loop, and (3) Hybrid. These methods may also be categorized as active or passive trackers. The rest of this section describes recent developments, approaches, and algorithms for each category. Table 1 summarizes recent advances in sun-tracking strategies.

3.1 Open-loop Control Strategies

A strategy for open-loop control follows its implant instructions (i.e., algorithms and astronomical equations) faithfully to track and target solar energy. It uses information such as the sun vector and the sun's direction, measured at any time, to shift a parabola into the sun's center without reactions [14]. Figure 1 demonstrates the typical configuration of this system. This strategy is straightforward and inexpensive to implement but will need extensive configuration to match the algorithm. The passive open-loop tracking device has many error sources such as time, subscales, site latitude and longitude, varying astigmatisms, a cosine effect, processor precision, refraction atmosphere, structural and mechanical tolerances and tolerances for installation [15]. Moreover, it makes the control system more complex and less reliable, since it does not track the output data.

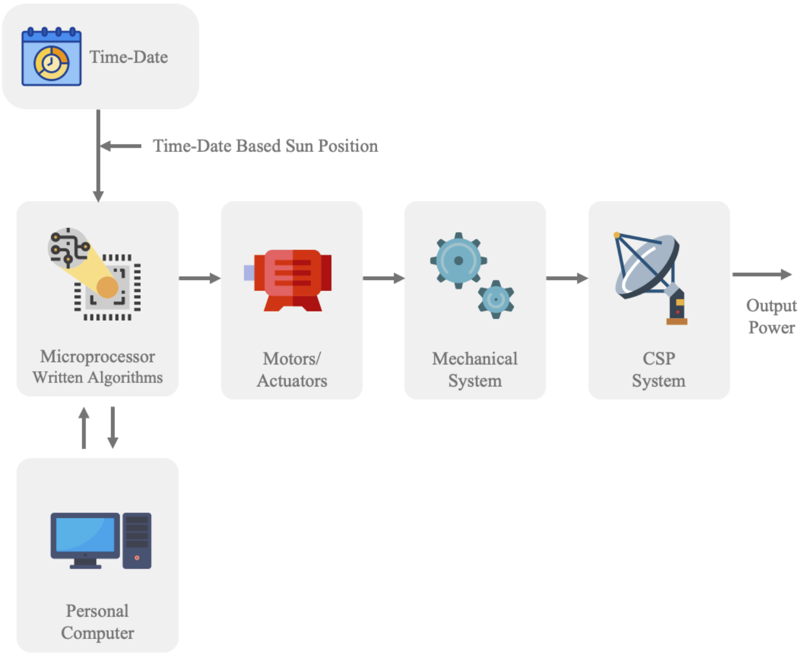

Figure 1. Generic configuration of an open-loop solar tracking system.

Several studies have been conducted that involve algorithms, regardless of the input factor, enhancing sun-tracking precision. These open-loop algorithms started when McCluney (1983) implemented an early-research guide to a solar-irradiation geometry model.

In 1983, a microcontroller-based dual-axis solar tracking device for astronomical sun coordinates was implemented by Al-Naima and Yaghobian [17]. Comparative tests have shown that their approach has provided a far better tracking performance than a conventional sensor unit with a tracking error less than 1o. Several years later, Blanco-Muriel *et al.* [18] developed a new algorithm using a simple algorithm in a low-cost microprocessor that allows determining true solar vector with an accuracy of 0.5 minutes of arc for the period of 1999-2015. For azimuth and zenith, the algorithm was 15% and 22% better than those from past algorithms (called the algorithm).

Beshears *et al.*[19], released a successful hybrid illumination tracker in 2003. Instead of sensing the relative sun is wearing with the optical sensors by calculating the sun's celestial bearing to the earth, the sun is determined by latitude, longitude, date, and time zone. The following year, a two-axis electromechanical sun tracker programmed based on solar angle analysis and motor speed calculations through PLC was introduced by Abdallah and Nijmeh [20]

The said system was able to increase energy accumulation by around 41.34% over a fixed 32° surface. Similarly, Reda and Andreas [21] proposed a straightforward build of an open-loop solar algorithm using the aforementioned key input variables: ecliptic longitude, mean latitude, Date equinox, only ascending right and declining with the following correction parameters: longitude nutrition, obliquity nutrition, ecliptic obliquity, and precise geometry decline. Many of these parameters are used in algorithms to compensate for reliable errors in performance management. It achieved greater accuracy of less than 0.0003° error on its solar zenith and azimuth angles.

Studies [22], [23] were then successfully conducted using the non-linear concept of analog optical compensation to show the sun sensor algorithm, where the incident sunlight illuminates a picture to signal inside the quadrants on the detector plane. The signal was proportionate with the light area and the angle of the incident. A variety of scientific equations have also been used to solve potential errors due to the non-linear shift of the projected image and shifts in the solar beam's incident angle. The proposed algorithm could have better accuracy of 0.2 ° over the whole view area (62° for both axes). Chong et al. [24] proposed an inventive general sun-tracking formula to accurately track the sun with a 2.99 mrad maximum error. The said system can effectively enhance efficiency, reducing the cost of high-concentration systems.

In 2012, Grena [25] proposed a new, simple open-loop algorithms to ensure high accuracy in the sun’s direction by uniform fractions of length, time, and distance. The algorithm tests the rotational axis of the earth’s ecliptic angle and inclination angle to calculate the exact location of the sun on the Elliptical Plane. Most of these algorithms indicate that the open-loop method's error are monitored between 0.0003° and 0.0027°. In 2013, Omara and Eltawil [26] designed and installed a solar-powered open-loop PLC control system for a dual-axis solar dish concentrator. The system rotates the collector at a constant rate of 15°/h, corresponding to the earth's rotational speed, and performed well when the wind velocity remained within a range of up to 2.0 m/s. The results show that their daily efficiency is 68%. Three years later, Skouri et al. [27] conducted a comparative study with a commercial tracker of the three sun-tracking systems. The tracker's total price is estimated to be about 1300 euros, based on efficiency and economic criteria, and its tracking error is less than 0.2°.

Yang et al. [28] developed a dual-axis open-looped concentrated STS without the additional power. Sunlight concentration was made possible using Fresnel lens module on Stirling Engine's heading head. The said STS uses solar PV for its power supply. During the experiment, the heating head reached a 900ºC. Recently, Shufat, Kurt, and Hancerlioğulları [29] designed a two-axis automatic parabolic dish tracking system that can raise the concentrated sun radiation by up to 40% compared to fixed systems. The designed tracker used Direct Normal Irradiation (DNI) and data of sun trajectory angles (azimuth and altitude) as a basis for the PLC programming. According to the present side, operating simulations were done via MATLAB/Simulink to identify tracking features to be applied during the site implementation.

In line with the results above, numerous single- and double-axis trailer algorithms are easy to see, most of which produce reasonably good results to decide the sun's location in open-loop controls. However, a lot of preconceptions and experiments will be needed during and before the design process. We also want to explore more flexible solutions. The designer wants faster systems and hence the closing control system to describe its dynamic behavior and current operating conditions.

3.2 Closed-Loop Control Strategies

Closed-loop ST primarily uses concept of control feedback in an open-loop system. In these systems, the inputs from solar sensors, camera images, or visually imported encoders are usually employed to trigger the drive's accuracy. This improves the overall accuracy of the solar panel's rotation, showing the its precise location in the air. In a closed-loop tracking solution, any variation between measured angles via an algorithm and synchronous positioning of the CSP can be observed and corrected. STS ensures that monitoring errors caused by wind effects, mechanical reverse effects, implementation mismatches, cumulative errors, or any other disorders in the parabolic dish's positioning can be remedied or avoided with this input. Figure 2 shows the generic structure of the solar tracker configuration.

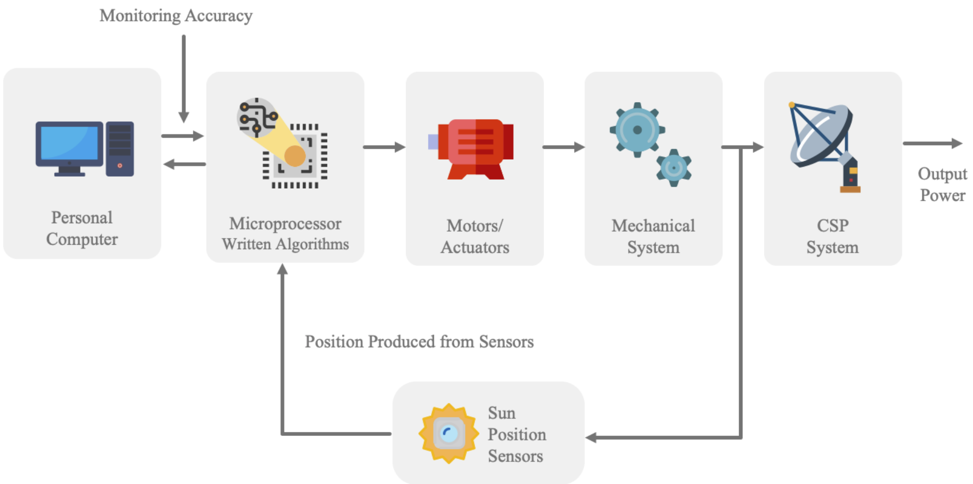

Figure 2. Generic configuration of a close-loop solar tracking system.

The configuration of the closed-loop to the solar tracker's control system dramatically improves the system's performance. For instance, the solar power station efficiency increased from 357 W to 500 W when a closed-looped tracker is installed [30]. At the same time, Maish [31] designed an inexpensive and straightforward STS with the aim of improving daily tracking precision below 0.1°. A neural network controller was used for the Solar tracker system developed by Brown and Stone [32] to manage the error model to retain error below 0.01°, which shows improved controller performance. To improve the parabolic concentrator's thermal performance, Khalifa and Al-Mutawalli [33] constructed a dual-axis tracker, with sun-tracking capability every 3-4 minutes the azimuthal axis and 4-5 minutes in the altitude axis. Two adjacent phototransistors are provided in each axis to create voltage difference, which drives the STS. The tracking system is expected to consume 0.5 hours of energy and increase solar energy by approximately 75% compared to a fixed collector of the same size. Yousef [34] has also demonstrated Fuzzy Logic on the desktop computer, interfacing card, sensor, data processing module, driving circuits, signals, and serial communication module for solar tracker deployment. His results revealed the robustness of the Fuzzy logic controller.

To trace solar altitudes with CSP systems, Falbel, Puig-Suari and Peczalski [35], have suggested an algorithm using an analog dual-axis module to track and obtain accurate results with an allowed error below 0.05 ° of the sun for its optical axis. Luque-Heredia et al. [36] proposed an accurate sun tracker using 1,000X micro-concentrator modules. It uses a suitable algorithm to absorb unexpected or variable time errors by automatically calibrating low-cost, sun-starter sensors running in extreme winds with direct solar radiation of 95%.

Roth, Georgiev, and Boudinov [37] introduced the solar tracker using an algorithm for tracking sunlight via a closed servo belt, with a pyrheliometer. In the 4-quadrant sensor center, a digital camera was installed on a computer to capture the projected real-time sun images by the heliostats [38]. Images are continually captured and compared with the sun's radiation perpendicular to the heliostat. Any difference will re-orientate the solar beam to 90° through servo motors. Aiuchi *et al.* [39] proposed two photosensor trackers to follow sunlight's reflected direction. The two image sensors were placed side-by-side in the system, partly illuminated by the solar system, on a box's base. Photosensor output signals were generated with an electrical signal based on the light's area to indicate the direction of reflected radiation, which were then used to adjust the mirror angle. Tracking Error of under 0.0006 rad, was achieved by the system.

Similarly, Alata, Al-Nimr, and Qaroush [40] demonstrated the design and simulation of step sun-tracking systems, which includes (1) a latitude tilt axis, (2) dual-axis equatorial, and (3) azimuth/altitude. For modeling and control architecture, Sugeno's first-order fuzzy inference method is used. The simulation results indicate that trackers and time-controlled systems with low energy consumption are capable of providing advantages. Lee *et al*. [15] investigated the development of the sun-post sensor and algorithm to use sunscreen imagery properly. However, when low irradiation occurs, either of them cannot maintain high precision. The solar position sensor based on image vision will fix the downside. The findings demonstrate that the Sun tracking device will solve cloud-based weather uncertainty and achieve a tracking precision of 0.04 °.

In 2016, Patil, Khandekar, and Patil [41] carried out an experimental study using Arduino with its five light-dependent resistors (LDR) to detect and collect the maximum solar energy using two-axis automatic solar trackers. The two DC engine permanent motors were developed with an algorithm to detect sunbeam in 20 minutes. Rahimoon *et al.* [42], just recently prototyped a low-cost Arduino automated control system for a 1.22 m diameter parabolic Stirling engine dish following an algorithm that was demonstrated. Although it is still in a prototype stage, it proved to be powerful since 210 W/m^2 at 21.6 °C could be achieved.

Ruelas *et al*. [43], the following year, proposed a microcontroller-based sensor with a synchronous clock, a geo-location inertial measurement sensor, and an angle of incidence, tilt position, and sensor position. The sensor representation showed how the accuracy of 0.0426 ° and 0.986 percent uncertainty could be measured to achieve accuracy below 0.01 ° for a tracking error. The confirmation of this sensor has been identified, and the concentration error has been shown in Kipp & Zone SOLYS 2. Carballo *et al.* [44] new approach to the computer screen, low-cost hardware, and in-depth solar tracking systems training. The preliminary test performed successfully at the Solar Aleria Platform (PSA) showed great potential. New approaches offer STS' essential controlled variables, such as cloud transient forecasting, blocking and shadow detection, air damping, or concentrated solar radiation measurement, thus enhancing system and system control strategies per system. Examining these techniques and algorithms and extensive neural network training will be part of future work to further improve the results achieved while reducing calculation costs. Wardhana, Ashari, and Suryoatmojo [45] recently developed a closed-loop system for a two-stage parabolic dish concentrator utilizing figures from gyrosensors and thermocouples. The feedback controller applied fuzzy logic based on tuning up the optimization at Genetic Algorithm-simple additive weighting (GA-SAW) to maintain the optimal temperature condition on the absorber receiver. Results reveal better power output and heat flux increased up to 62.49%.

One downside to closed-loop STS control is the recovery from extended periods of cloud cover will be troublesome using the PLC system. Optical observation's solar vector may be challenging to establish in the absence of guidance from an astronomical algorithm. The case is valid if the sun has passed beyond the sun sensor/imaging camera's field of view or if the sun's direction is no longer in the optical device's field of view. An optical feedback approach can be used more effectively in hybrid-loop control strategies to solve this problem. In the following section, a hybrid open/closed-loop tracking control will be discussed to overcome closed-loop control limitations.

3.3 Hybrid-loop Control

Solar tracker Hybrid Loop refers to an open-circuit approach in tandem with a closed-loop approach, as shown in Figure 3. To overcome the disadvantages of the open-loop controller, error from tracking the sun's position is added to generate an accurate alignment, assembly, and precision scheduling. Two types of hybrid STS Controllers offer calibration and prevention approaches. Model-based calibration is based on ~~math~~ mathematical errors in the model. Multiple systematic sources of error can be identified. After an apparent day of the session, tracking errors are measured; the template parameters are calibrated—part of the calibration process to correct the accumulated error data into a best-fit model. From then on, the calibrated model will be used on a purely open-loop basis without additional feedback requirements for error-tracking. The sun position algorithm for error correction will be based on estimates based on past error tracking measurements and iterative estimates without an error-modeling process.

It is Safan, Shaaban and Abu El-Sebah [46] who implemented a multi-degree freedom-simplified Universal Intelligent PID (MDOF-SUI PID) sun-tracking process controller. Their study reveals that the maximum tracking error achieved was ±0.0067 °. In addition to active tracking by using an image processing algorithm and a commercial webcam as a sensing element, Chauhan *et al.* [47] proposed an innovative hybrid active-passive solar tracker System is provided using GPS tracking with the SG2 algorithm's help. Analysis of the pictures acquired by a webcam allows accurate data from the azimuth position and the sun's altitude to be collected. The system's core advantage is its high flexibility to operate under extreme conditions when the sun's position is not very clear due to weather conditions such as cloud cover. Depending on the location's spatial coordinates, the System can track the sun both in real-time, regardless of the space-time coordination, and passively. The information extracted from the Cam-GPS system is used to control the two servo motors, one for the azimuth and altitude axis of the solar tracker's dual mechanism, to achieve the optimal alignment of the payloads connected to the solar tracker to increase the power generation.

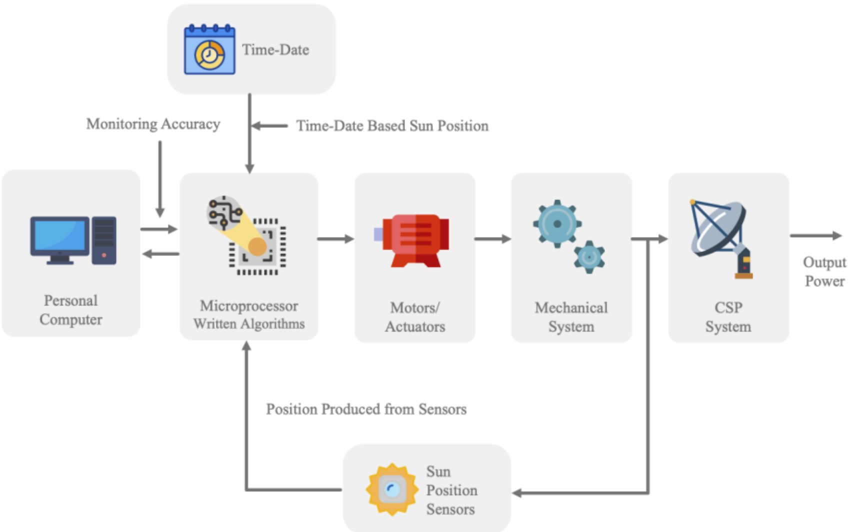

Figure 3. Generic Configuration of a Hybrid-Loop Solar Tracking System.

4. CONCLUSION

This paper presented practical design challenges and recent developments related to tracking strategies of CSP Parabolic Dish technologies. Many solar thermal systems have been developed for various applications in solar algorithms over recent years. The CSP systems, which monitor changes and track the sun's movement throughout the day, generate far greater solar power than their traditional stabilized counterparts and collect far greater energy during the day.

This paper analyzes tested algorithms, and sun sensors developed over the last 30 years for sun tracking strategies. Algorithms used for STS are categorized as open-looped, closed-looped, or hybrid in general. Each method was reviewed with control and computer principles. Also, efficiency, and comparative benefits and limits have been evaluated. This analysis verified the applicability of the STS to the Parabolic Solar Dish. The study should, in the future, focus more on computer vision and artificial intelligence.

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Table 1: Recent Advancements in Parabolic Dish Tracking Strategies

References	Degree of Freedom	Control Module	Description of Investigated Strategy	Performance and Significant Gains
Open Loop Control Strategies				
Al-Naima &Yaghobian, 1990 [23]	Dual-axis	Microcontroller	Improved tracking capabilities using the astronomical coordinates of the sun.	Tracking error lesser than 1°
Blanco-Muriel et al., 2001[24]	-	Low-Cost Microprocessor	Determines the actual solar vector for 1999–2015 with 0.5 minutes of arc.	Azimuth and Zenith is 15% and 22% better than previous Algorithms.
Beshears et al., 2003[25]	-	Soltrak Microcontroller	The sun's position is determined by calculating the sun's celestial bearing to the earth, the sun is determined by latitude, longitude, date and time zone.	Average Error on X-Tilt, Y-Tilt and prim-to-sec distance is +0.089°, -0.209° and -1.55 mm respectively.
Abdallah & Nijmeh, 2004 [26]	Dual-axis	PLC	The control programming algorithm is based on on solar angle analysis and motor speed calculations through PLC	Increased energy accumulation by around 41.34% over a fixed 32° surface.
Reda & Andreas, 2004 [27]	-		The solar zenith and azimuth angles measurement process from 2000 to 6000 was progressively established. The incidence angle of the surface tiled with any horizontal or vertical angle was also calculated.	Tracking error lesser than 0.0003°
Chen et al., 2006 [27]	-		Used a novel optical vernier measuring principle that is accurate and has large FOV.	In the whole FOV (visual field), the precision is ±64 º better than 0.02º (arc approx. 1 minute).
Grena, 2008 [29]	-		The algorithm tests the rotational axis of the Earth's ecliptic angle and inclination angle to calculate the exact location of the Sun on the Eclical Plane.	The tracking errors are between 0.0003 ° and 0.0027 °.
Chong et al., 2009 [31]	Dual-axis		The computer program uses the three unknown angles of orientation to be measured in practice, not precisely by the instruments, i.e., φ, λ, and ζ.	There has been a maximum point error of 2.99 mrad, which is below the 4.13 mrad encoder resolution limit.
Omara & Eltawil, 2013[30]	Two-Axis	PLC	Used a special approach to the position of the sun in relation to a solar collector tracking device.	Its daily average efficiency is 68%.
Skouri et al., 2016 [8]	-		They developed an algorithm focusing on solar tracker performance and cost-effectiveness. The algorithm uses time and geographic parameters to determine sun angles as a time angle and	Tracking error is inferior to 0.2°.

			angle of decay. Solar information is then used in the horizontal plane to recognize diffuse and direct radiation elements.	
Yang et al., 2017 [33]	-		The sun was tracked by a constant angle tracking method. Photovoltaic and photothermal devices can be combined with more solar energy.	The temperature of the heating head reached around 900 °C under a cloudless environment.
Shufat et al., 2019 [34]	-	PLC	Simulations were carried out with high efficiency using azimuth and altitude data for the DNI values of Kufra city in Libya.	The operating DNI is equivalent to 80% to 90% of the total sun DNI.
Closed Loop Control Strategies				
Liu et al., 2010 [53]	Dual-Axis	SolarTrak	It consists of two counter-sensors on every axis, a limit switch, and the angle reference sensor for reference to fixed hardware's internal counter location.	Accuracies of better than ± 0.1 have been achieved.
Brown & Stone, 1993 [37]	-	Microcontroller	Using a neural network controller, the error model is managed and the neural network controller performs better.	Tracking error lesser than 1°
Khalifa & Al-Mutawalli, 1998 [38]	-	-	Two identical subunits and two adjacent phototransistors with a differential voltage are used to track the sun to detect the sun's location.	The tracking system was said to have a power consumption of 0.5 Whr and increase solar energy by around 75% compared to a fixed collector of the same sizes.
Yousef, 1999 [39]	-	-	Fuzzy Logic was shown for implementing Solar Tracker on personal computers, interfaces, sensors, data acquisition modules, circuits, and signal conditioning circuits.	It achieved positive results that revealed the Fuzzy logic controller's robustness.
Luque-Heredia et al., 2003 [41]	-	-	Includes a control unit that relies on an adaptive algorithm to absorb unexpected or time-variate errors by self-calibrating low-cost, sun-starter sensors.	Remained in high-wind operations accounting for 95% of the direct solar radiation available.
Roth et al., 2004 [42]	Dual-Axis	-	Calculated direct solar radiation with a pyrheliometer. The axes' speeds are relatively low, but the system's design ensures a long time without costly maintenance.	The demonstrated tracker illustrates the practical working of a cost-effective and uncomplicated mechanism adapted for use in more effective systems such as solar cell panels.
Aiuchi et al., 2004 [44]	-	-	Two photosensor trackers monitored the reflected path of solar radiation. Both image sensors were mounted side by side at the base of the box, partially illuminated by the device's sunlight.	Tracking error of less than 0.0343775°
Alata et al., 2005 [45]	-	-	The controller was developed with a flashy logic platform, and the input and output signal were generated with a squarely less subtractive cluster algorithm.	The robust logic was demonstrated, and the results were satisfactory.

Lee et al., 2009 [21]	-	-	Four-quadrant sensors and bar-shadow photosensors have been used to track the location of the sun over recent years. Nevertheless, in low irradiation conditions, neither can achieve high accuracy. This downside will be addressed by the Solar position sensor based on the image.	Tracking accuracy of 0.04°.
Ruelas et al., 2013 [48]	-	-	The proposed sensor consists of a real-time clock microcontroller, geo-location inertial measuring sensor, sunlight incident angle, tilt position, and sensor position.	The sensor characterization showed how the precision of 0.0426 ° and uncertainty of 0.986 percent could be calculated to achieve a precision under 0.01 °
Patil et al., 2016 [46]	-	Arduino	Experimental study using Arduino with its five light-dependent resistors (LDR) to detect and collect the maximum solar energy using two-axis automatic solar trackers.	Able to detect sunbeam in 20 minutes.
Rahimoon et al., 2019 [47]	-	Arduino	A low-cost Arduino automated control system for a 1.22 m diameter parabolic Stirling engine.	It proved to be powerful since 210 W / m^2 at 21.6 °C could be achieved.
Carballo et al., 2019 [49]	-	-	A new approach to computer-screen, low-cost hardware, and profound training solar tracking systems	Provided essential variables in controlling the sun tracking system, such as the cloud movement forecasts, blocking and shadow detection, air damping, or concentrated solar radiation measurement, thus enhancing system and system control strategies per system
Wardhana et al., 2020 [50]	-	-	A new Fuzzy Logic system based on Dual Parabolic Dish Concentrator Optimization Tuning for Genetic Algorithm-simple additive weighting (DS-SAW).	In this investigation, the acquired fuzzy controller's result was 0.497 seconds on average, and the average increase was 0.277 seconds faster than the standard PID controller.
Hybrid Loop Control Strategies				
Safan et al., 2017 [51]	-	-	A hybrid control strategy has been implemented, and the sun tracking process has included the multi-degree reformed MDOF-SUI PID controller.	Achieved a maximum tracking error of ±0.0068 °.
Chauhan et al., 2018) [52]	-	-	Innovative hybrid active-passive solar tracker system with GPS tracking using SG2, the quick implementation of the popular SPA, combined with active tracking with image processing algorithms and a commercial webcam.	The system can monitor the sun both in real-time, irrespective of space-time synchronization and passively per spatial location coordinates.