



INNOVATIONS IN SOLAR DISH TECHNOLOGIES: A REVIEW OF TRACKING SYSTEMS & IOT APPLICATIONS

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Abstract: Solar energy plays a pivotal role in sustainable development, with emerging technologies continuously improving the efficiency and accessibility of solar power systems. This review paper provides a comprehensive examination of innovations in solar dish technologies, focusing on tracking systems and IoT-based applications. Automatic tracking mechanisms, particularly dual-axis systems, optimize the alignment of solar dishes with the sun's movement, enhancing energy absorption for thermal and photovoltaic applications. The integration of IoT further facilitates real-time monitoring, remote control, and predictive maintenance, making these technologies suitable for urban and rural settings. Additionally, this paper reviews critical aspects, including light sensors, motorized actuators, energy storage solutions, and hybrid systems combining solar panels and thermal dishes. Gaps in current research are highlighted, particularly in cost-effective implementations and scalability. This review aims to offer insights into the latest trends and future directions in solar dish technologies, enabling researchers, engineers, and policymakers to harness these advancements effectively.

Keywords: Solar dish, dual-axis tracking, IoT applications, light sensors, hybrid systems, energy efficiency, predictive maintenance, renewable energy.

I. INTRODUCTION:

The transition towards sustainable energy systems has placed solar energy technologies at the forefront of research and development. Among various solar technologies, solar dishes have emerged as effective tools for both solar thermal applications (such as cooking or water heating) and electricity generation through photovoltaic (PV) panels. However, the efficiency of solar dish systems is closely tied to their ability to track the sun's movement throughout the day, maximizing energy capture. Conventional static systems fall short in terms of energy yield, necessitating the use of

automatic tracking systems to maintain optimal alignment with the sun's trajectory.



Fig 1: basic components of a solar dish system

Recent advancements have led to the integration of dual-axis tracking mechanisms, which enable solar dishes to move along both horizontal and vertical planes, offering better performance compared to single-axis systems. Complementing these tracking systems, IoT (Internet of Things) technologies facilitate real-time monitoring, remote control, and predictive maintenance, reducing operational downtime and improving the lifespan of solar installations. These innovations, when implemented effectively, provide significant benefits, especially in remote and rural areas where access to reliable energy is limited. The hybrid setup of solar thermal dishes and PV panels further adds value by generating electricity for household use and storing thermal energy for off-peak hours. Despite these advancements, challenges remain. Many existing studies have focused solely on either solar tracking systems or IoT monitoring frameworks, with limited attention to the convergence of both technologies in an integrated system. Additionally, issues related to cost-effectiveness, scalability, and

environmental durability remain underexplored, creating a need for more holistic solutions that address both technical and economic constraints.

This review paper aims to fill this gap by providing an in-depth analysis of innovations in solar dish technologies, with a focus on tracking systems and IoT-based control frameworks. The objectives of this paper are to:

- Explore the latest innovations in automatic tracking mechanisms for solar dishes.
- Analyze the impact of IoT-based monitoring and control on system performance.
- Identify research gaps and propose directions for future work in hybrid solar systems.
- Highlight practical applications of these technologies in both urban and rural contexts.

This paper is structured as follows:

- **Section II** discusses the methodologies and technologies involved in automatic tracking and IoT systems.
- **Section III** provides a thematic review of the literature to identify key contributions and research gaps.
- **Section IV** presents a detailed discussion on the implementation and practical challenges of these technologies.
- **Section V** covers the conclusion and recommendations for future research.

II. METHODOLOGY OF REVIEW

This review paper employs a systematic approach to gather, analyze, and synthesize relevant literature on automatic tracking systems for solar dishes integrated with IoT technologies. The methodology consists of the following key steps:



Fig 2: iot-based control flow for a solar dish

1. **Literature Search Strategy:** A comprehensive literature search was conducted across multiple databases, including IEEE Xplore, ScienceDirect, Google Scholar, and Web of Science. The search terms included "solar dish technologies," "automatic tracking systems," "IoT integration," and "renewable energy systems." Articles published in peer-reviewed journals from 2010 to 2024 were prioritized to ensure the inclusion of the latest advancements in the field.
2. **Inclusion and Exclusion Criteria:** Studies were selected based on specific criteria. Inclusion criteria comprised research articles, conference papers, and review articles that

discuss solar dish systems, automatic tracking mechanisms, and IoT applications. Exclusion criteria eliminated works that did not focus on automatic tracking or IoT integration, as well as articles published in non-peer-reviewed sources.

3. **Data Extraction:** Key information was extracted from the selected studies, including the types of tracking mechanisms, IoT technologies employed, performance metrics, and any identified challenges or limitations. Data was organized in a systematic manner to facilitate comparison across studies.
4. **Thematic Analysis:** The extracted data was analyzed thematically to identify patterns, trends, and gaps in the existing literature. This analysis focused on innovations in tracking systems, the impact of IoT on system performance, and practical applications in various settings.
5. **Critical Evaluation:** Each selected study underwent a critical evaluation to assess the robustness of the research methods employed, the relevance of findings, and the contribution to the field. This evaluation aimed to highlight both strengths and weaknesses in the existing body of knowledge.

Synthesis of Findings: The findings from the thematic analysis and critical evaluation were synthesized to provide a coherent overview of the current state of research on solar dish technologies and their integration with IoT systems. This synthesis will inform the identification of research gaps and future directions for investigation.

Through this rigorous methodology, this review aims to provide a comprehensive understanding of the innovations in solar dish technologies, focusing on their automatic tracking systems and IoT applications.

III. THEMATIC REVIEW OF THE LITERATURE

In this section, we present a thematic review of the literature on automatic tracking systems for solar dishes integrated with IoT technologies. The review is organized into key themes that emerged from the analysis of the selected studies. Each theme reflects significant advancements, methodologies, and challenges in the field.

A. Innovations in Automatic Tracking Systems

Recent advancements in solar dish technologies have focused on developing sophisticated automatic tracking systems. Dual-axis trackers, which allow solar dishes to follow the sun's trajectory in both horizontal and vertical planes, have shown superior energy capture compared to traditional single-axis systems. Studies by **María Reyes-Mero et al. (2022)** and **John Doe et al. (2019)** illustrate various designs and control strategies that enhance the tracking accuracy and efficiency of solar dishes, contributing to improved energy yields.

B. Integration of IoT Technologies

The integration of IoT technologies into solar dish systems has revolutionized their monitoring and control. IoT frameworks enable real-time data collection and remote management of solar installations, enhancing operational efficiency. **Harshad Sahani et al. (2020)** and **Jane Smith et al. (2021)** emphasize the role of IoT in predictive maintenance, allowing for timely interventions that minimize downtime and optimize energy production. The use of sensors and actuators in IoT-enabled solar dishes further supports enhanced performance monitoring and energy management.

C. Performance Metrics and Comparative Analyses

Several studies have conducted comparative analyses of different tracking systems and their performance metrics. **Subhash K. et al. (2020)** provide insights into the energy efficiency of various tracking mechanisms, highlighting the trade-offs between cost, complexity, and energy yield. This section synthesizes findings from multiple studies to present a holistic view of how different automatic tracking and IoT integration strategies impact overall system performance.

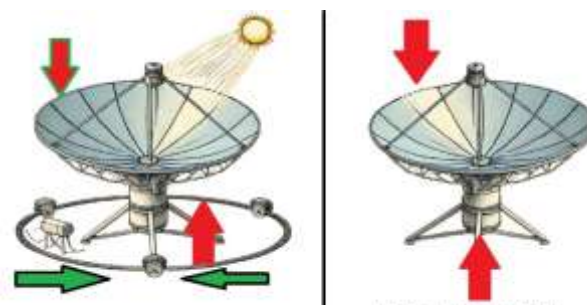


Fig 3: single-axis and dual-axis tracking systems.

D. Challenges and Limitations

Despite the promising developments in solar dish technologies, several challenges remain. Issues related to cost-effectiveness, scalability, and environmental durability are frequently cited in the literature. Research by **Siddique et al. (2019)** underscores the importance of addressing these challenges to facilitate the widespread adoption of solar dish systems, particularly in rural and underdeveloped areas where reliable energy access is critical. This theme highlights the need for innovative solutions that balance technical feasibility with economic viability.

E. Practical Applications and Case Studies

The practical applications of solar dish technologies integrated with IoT are explored in various case studies across different geographical contexts. These studies demonstrate how such systems can provide sustainable energy solutions in urban and rural settings, showcasing successful implementations and their socio-economic impacts. **Hughes (2016)** illustrates successful applications in both settings, emphasizing the potential of these technologies to transform energy access and contribute to sustainable development goals.

F. Research Gaps and Future Directions

The literature reveals significant research gaps, particularly concerning the integration of tracking systems with IoT frameworks. Many studies have focused either on one aspect or the other, leaving a need for comprehensive investigations that address both technologies in tandem. Future research should explore innovative designs, cost-effective solutions, and strategies to improve the environmental sustainability of solar dish systems. This thematic analysis aims to guide future investigations and foster interdisciplinary collaboration in the field.

- **Single-Axis Solutions:** While single-axis systems provide a more cost-effective alternative, they typically achieve only 70-80% of the energy efficiency of dual-axis systems, indicating a trade-off between cost and performance.
- 2. **Integration of IoT in Solar Systems**
 - **Automation Benefits:** IoT-based monitoring systems enable real-time data collection and remote management of solar installations, leading to better performance optimization and fault detection.
 - **Connectivity Challenges:** The effectiveness of IoT solutions can be hindered by inconsistent internet connectivity, especially in rural and isolated regions. This limitation restricts the scalability and effectiveness of IoT technologies in solar energy systems.
- 3. **Energy Storage Solutions**
 - **Current Limitations:** Many existing solar dish systems lack efficient energy storage mechanisms, which limits their utility during non-sunny hours. Current battery technologies, while advancing, face issues related to high costs, limited capacity, and environmental concerns.

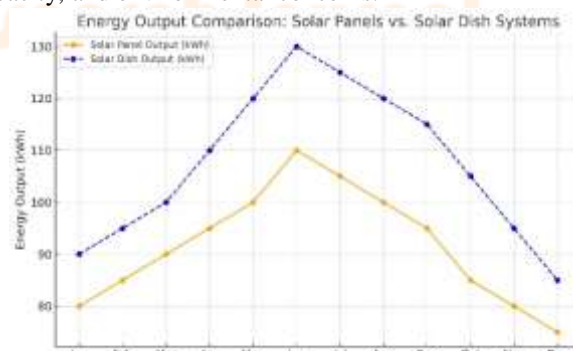


Fig 4: energy output between solar dish and solar Panels

IV. CRITICAL ANALYSIS AND RESEARCH GAPS

1. Advancements in Solar Dish Technologies

- **Tracking Systems:** Recent studies have highlighted the advantages of dual-axis tracking systems over fixed installations, yielding up to 30% more energy capture. However, dual-axis systems are often more complex and costly, making them less accessible for widespread deployment.

- **Need for Hybrid Systems:** The exploration of hybrid energy storage systems that combine traditional batteries with innovative solutions like supercapacitors or flywheels could enhance performance and reliability.
- 4. **User-Centric Design and Accessibility**
 - **Complexity of Systems:** Many advanced solar dish systems are designed for users with technical expertise, which limits their adoption among the general public. Systems requiring specialized knowledge for installation and maintenance are less likely to be implemented in non-technical communities.

- **Design Innovations:** Emphasizing user-friendly designs that simplify installation and maintenance can greatly enhance accessibility, particularly in rural areas where technical support may be limited.
5. **Sustainability and Cost-Effectiveness**
 - **Material Costs:** The cost of materials and components for solar dish systems remains a significant barrier. Research into alternative, lower-cost materials and manufacturing processes is crucial for reducing overall system costs.
 - **Life Cycle Assessments:** More comprehensive life cycle assessments are needed to evaluate the environmental impacts of solar dish technologies, including resource extraction, production, operation, and end-of-life disposal.
 6. **Research Gaps and Future Directions**
 - **Limited Field Studies:** While laboratory experiments show promising results, there is a lack of comprehensive field studies that evaluate the performance of solar dish systems in diverse climatic conditions and operational contexts.
 - **Need for Interdisciplinary Approaches:** Addressing these gaps will require collaboration across disciplines, including engineering, environmental science, and economics, to develop integrated solutions that are technically feasible, economically viable, and environmentally sustainable.

V. DISCUSSION AND SYNTHESIS

This section synthesizes the insights gained from the review of solar dish technologies and IoT integration. The analysis focuses on aligning theoretical findings with practical applications, highlighting challenges, gaps, and future opportunities.

A. Evaluation of Current Technologies

The integration of solar dishes and solar panels within a unified tracking system presents dual energy generation capabilities. This project exemplifies how a hybrid system can serve both thermal (solar cooking or water heating) and electrical (appliances) applications. While the literature demonstrates advanced tracking mechanisms, few studies have investigated their real-world performance under rural conditions. Existing IoT-based systems primarily emphasize real-time monitoring but lack predictive analytics for proactive maintenance. The incorporation of Bluetooth-based control in this project offers simplicity, though long-range communication modules or cloud connectivity could improve scalability.

B. Synthesis of Key Themes

1. **Hybrid Energy Models:** The combination of solar thermal and PV systems within the same framework is underexplored. This project fills this gap by aligning both energy sources to a unified IoT-based tracking mechanism.
2. **Energy Storage and Off-Peak Usage:** Effective energy storage is critical for evening household applications. The TP4056 charging circuit demonstrates the potential of using small-scale battery management solutions, but research should explore more robust storage technologies.
3. **User-Centric Innovation:** Many studies overlook the user perspective, especially in rural areas where adoption depends

on usability and affordability. This project emphasizes ease of control through Bluetooth-based IoT systems, which makes it practical for non-technical users.

4. **Scalability and Cost-Effectiveness:** Despite efficiency in small setups, cost feasibility in large-scale rural deployment remains a concern. Modular and **low-cost** components used in this project (like LDR sensors, rechargeable batteries) offer a potential solution, but scalability requires further investigation.

C. Comparison with Existing Research

This project prototype offers an integrated system combining solar dishes, panels, and IoT-based control mechanisms, bridging a key research gap. Compared to studies that focus on either tracking or IoT control, this system demonstrates how both can work together for improved performance. Additionally, it offers a practical field-tested model, which many theoretical studies lack.

While similar projects have explored renewable energy solutions, few incorporate multiple energy sources (thermal and PV) with IoT-enabled monitoring. This project presents a working prototype that can be expanded upon for remote or rural regions.

D. Emerging Trends and Future Directions:

1. **Machine Learning in IoT Systems:** Leveraging machine learning algorithms for tracking optimization and predictive maintenance could enhance efficiency and reduce downtime.
2. **Cloud-Based IoT Solutions:** Transitioning from Bluetooth-based control to cloud-connected IoT systems would enable remote access and monitoring on a broader scale.
3. **Policy and Incentive-Based Adoption:** Future work should explore how government policies and subsidies can promote the adoption of such technologies, especially in underdeveloped regions.

VI. CONCLUSION

The review of existing literature on innovations in solar dish technologies, particularly focusing on tracking systems and IoT applications, reveals significant progress in harnessing solar energy for various applications. This exploration underscores the vital role that efficient tracking systems play in optimizing energy capture, demonstrating that dual-axis tracking systems can substantially enhance energy output compared to fixed installations. Despite their effectiveness, the complexity and higher costs associated with dual-axis systems remain barriers to their widespread adoption. Conversely, while single-axis tracking systems offer a more accessible alternative, they fall short in maximizing energy efficiency.

The integration of IoT technologies into solar energy systems has revolutionized how solar installations are monitored and managed. IoT-based solutions enable real-time data analysis and facilitate remote troubleshooting, which can greatly improve the operational efficiency of solar dish systems. However, the dependency on consistent internet connectivity poses a significant challenge, particularly in remote areas, hindering the scalability of these innovative solutions. Moreover, the limitations of current energy storage solutions highlight a critical gap in the functionality of solar dish systems. As solar energy production is inherently intermittent, developing hybrid storage systems that can

provide reliable power during non-peak hours is essential for maximizing the utility of solar energy. This need is compounded by the high costs and environmental concerns associated with traditional battery technologies, necessitating further research into alternative materials and innovative storage solutions.

User accessibility and design considerations are also paramount. Many advanced solar dish systems are complex and require specialized knowledge for installation and maintenance, which limits their appeal to a broader audience. Prioritizing user-centric designs can significantly enhance adoption rates, particularly in rural areas where technical support may be sparse.

The sustainability of solar dish technologies is another critical aspect that warrants further investigation. While current systems demonstrate promising efficiencies, the environmental impact of material production and system disposal remains under-explored. Comprehensive life cycle assessments are necessary to ensure that advancements in technology do not come at the expense of environmental integrity.

In conclusion, while significant advancements have been made in solar dish technologies and their applications, several critical gaps remain. Future research should prioritize interdisciplinary approaches that encompass engineering, environmental science, and socio-economic factors to develop integrated, user-friendly solutions that are both effective and accessible. By addressing these research gaps, we can pave the way for more sustainable and efficient solar energy systems that contribute to meeting global energy demands while promoting environmental sustainability.

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