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ORIGINAL

# Design and implementation of an IoT monitoring system for the optimization of solar stills for water desalination

## Diseño e implementación de un sistema de monitoreo IoT para la optimización de destiladores solares en la desalinización de agua

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**ABSTRACT**

The project "Design and Implementation of an IoT Monitoring System for the Optimization of Solar Distillers in Water Desalination" sought to improve the efficiency of desalination in La Guajira, a region with critical water scarcity. The objective was to develop an IoT system to optimize solar stills, offering a sustainable solution. A prototype solar still with IoT monitoring was built. The study included the creation of circuits to integrate sensors and an HTML dashboard to visualize real-time variables, such as internal and external temperatures, humidity, and water level in the basin, facilitating the calculation of efficiency. The IoT monitoring system proved to be effective in increasing efficiency and providing valuable data for design decisions, marking a step towards water autonomy.

**Keywords:** Solar Desalination; Internet of Things (IoT); Solar Still Efficiency; Remote Monitoring.

**RESUMEN**

El proyecto "Diseño e Implementación de un Sistema de Monitoreo IoT para la Optimización de Destiladores Solares en la Desalinización de Agua" buscó mejorar la eficiencia de la desalinización en La Guajira, una región con escasez crítica de agua. El objetivo fue desarrollar un sistema IoT para optimizar destiladores solares, ofreciendo una solución sustentable. Se construyó un prototipo de destilador solar con monitoreo IoT. El estudio incluyó la creación de circuitos para integrar sensores y un dashboard en HTML para visualizar variables en tiempo real, como temperaturas interna y externa, humedad, y nivel de agua en la cuenca, facilitando el cálculo de eficiencia. El sistema de monitoreo IoT demostró ser efectivo para aumentar la eficiencia y proporcionando datos valiosos para decisiones de diseño, marcando un avance hacia la autonomía hídrica.

**Palabras clave:** Desalinización Solar; Internet de las Cosas (Iot); Eficiencia en Destiladores Solares; Monitorización Remota.

## INTRODUCTION

In the Department of La Guajira, the critical shortage of drinking water is a major challenge, exacerbated by adverse weather conditions and limitations in water infrastructure. In response to this situation, the project "Design and Implementation of an IoT Monitoring System for the Optimization of Solar Distillers in Water Desalination" set out to monitor the main variables of solar desalination processes through Internet of Things (IoT) technology as a starting point for obtaining more efficient solutions. This approach seeks not only to increase the availability of drinking water but also to ensure the sustainability and scalability of future solutions.

Solar desalination, taking advantage of the abundant solar radiation in La Guajira, is presented as a viable strategy to address the water crisis. However, traditional methods have faced significant limitations regarding efficiency and adaptability. IoT-based systems for monitoring and controlling solar stills introduce an unprecedented ability to optimize operational conditions in real-time, adjusting processes according to environmental variations and region-specific needs (Benghanem et al., 2021; Gil et al., 2019).

A prototype solar still equipped with an IoT monitoring system was designed and experimentally evaluated to address these challenges. This system was configured to record multiple critical variables, such as internal and external distiller temperatures, humidity, and water level, whose fluctuations directly impact the efficiency of the desalination process (Alshehri et al., 2021; Muñoz et al., 2020). Integrating specific sensors and creating schematic circuits adapted for this purpose were crucial to the project's success. In addition, a user-friendly interface was also developed, and a dashboard was programmed in HTML, allowing real-time visualization of all relevant metrics. This tool facilitates constant monitoring and provides valuable data for decision-making and continuous system improvement.

This tool facilitates constant monitoring and provides valuable data for decision-making and continuous system improvement, ensuring that each adjustment effectively contributes to optimizing desalinated water production.

The results have demonstrated that implementing IoT technologies can significantly increase the efficiency of solar stills. This breakthrough is a testament to the potential of IoT technology in environmental engineering applications. However, it also represents an essential step towards self-sufficiency and sustainability in water management in La Guajira, marking a path towards innovative and lasting solutions in the context of the global water crisis.

This study provides a framework for future research and development in the field of solar desalination, highlighting the importance of integrating new technologies to address our era's environmental and social challenges. Through the detailed exploration of the possibilities offered by the IoT, this work contributes to redefining water management strategies in arid regions, aiming towards greater operational efficiency and reduced environmental impact.

## METHOD

Developing IoT monitoring systems for optimizing solar stills requires a rigorous methodology integrating experimental design, systems engineering, and data analysis. This multidisciplinary approach is essential to ensure the findings' accuracy, relevance, and applicability, especially in water-scarce contexts such as La Guajira, where solar distillation technology represents a vital solution.

### Experimental Design

The methodology adopted for this study began with selecting a solar distiller design based on the criteria of efficiency, simplicity, and cost-effectiveness. This selection was informed by previous studies that demonstrated the applicability of such systems in similar regions (Benghanem et al., 2022; Bisaga et al., 2017). The experimental design was oriented toward developing a functional prototype that would allow for incorporating and testing different monitoring configurations and components.

### Prototype Construction

Following the proposed design logic, a distiller prototype was constructed. The predominant material was glass due to its solar heat transmission and capture properties, which are essential for the efficiency of the distillation process (Burbano, 2014). The base and support structure were manufactured with materials resistant to corrosion and a saline environment, which are relevant characteristics for the system's durability in La Guajira.

### IoT integration

The core of the monitoring system was an ESP32 microcontroller, selected for its robustness, flexibility, and compatibility with various types of sensors. This choice was supported by references from similar studies where the ESP32 has been successfully employed in IoT applications (Alshehri et al., 2021). Sensors were integrated to measure critical parameters, such as ambient and internal temperature, humidity, and water level. These sensors were chosen based on their accuracy and stability, which are fundamental for monitoring critical processes (Benghanem et al., 2021; Bisaga et al., 2017). Data captured by the sensors were collected and transmitted through the ESP32, which is configured to operate as a node within an IoT network. The network infrastructure was designed to ensure uninterrupted and secure data transmission, a critical aspect of real-time monitoring.

### User Interface Development

The user interface was programmed in HTML and complemented with JavaScript and CSS style sheets, allowing a clear and accessible visualization of the collected data. This dashboard was developed with usability

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and intuitive interpretation of the data, allowing non-specialized users to understand and respond to sensor readings in real-time.

### Efficiency Evaluation

The efficiency of the distillation process was quantitatively evaluated by comparing the volume of desalinated water versus the volume of evaporated water. The mathematical formulation for this evaluation was adopted from relevant literature, which provides a standard for efficiency evaluation in distillation systems (Benghanem et al., 2021d; Daud et al., 2020).

## RESULTS AND DISCUSSION

The information gathered through an IoT monitoring system to optimize solar stills for water desalination provides a valuable opportunity to analyze potential improvements in the efficiency and design of these systems, especially in water-scarce regions such as the Department of La Guajira. As the first tests, two different configurations of the solar distillation process were implemented: one using a Fresnel lens and the other without. Efficiency metrics are crucial performance indicators calculated from the initial salt water volume, the distilled water obtained, and the evaporation loss. In the case of the distiller equipped with the Fresnel lens, the efficiency reached 60 %, while the distiller without the lens recorded an efficiency of 28,27 %, a figure within the range of conventional solar distillers (Abdenacer & Nafila, 2007; Essa et al., 2022; Sivakumar & Ganapathy Sundaram, 2013). These results in a remarkable improvement from the use of solar concentrating elements(Chakravarthy et al., 2022; Dellicompagni & Franco, 2019; Elashmawy, 2017; Sales, 2016; Singh & Tiwari, 2017b, 2017a), corroborating similar findings in the literature. The incorporation of IoT technologies enables finer control and data-driven decision-making, which can lead to iterative optimizations in the design of solar stills (Khechekhouche et al., 2021; Meukam et al., 2004; Yousefi et al., 2021).

**Table 1.** Solar distiller test with Fresnel lens application

| Time | Salt water (ml) | Distilled water (ml) | Water lost due to evaporation (ml) |
|---|---|---|---|
| Start (9:51am) | 1000 | 0 | 0 |
| Final (5:30pm) | 500 | 300 | 200 |

$$\text{Efficiency . } (\eta) = \frac{(\textit{Distilled water produced}) \times 100\%}{\textit{Evaporated water}}$$

For our case:

$$\eta = (\frac{300ml}{500ml}) \times 100\% = 60\%$$

**Table 2.** Solar still test without Fresnel lens application

| Time | Salt water (ml) | Distilled water (ml) | Evaporated Water<br>Evaporation loss (ml) |
|---|---|---|---|
| Start (10:00am) | 1000 | 0 | 0 |
| Final (5:30pm) | 855 | 41 | 104 |

$$\text{Efficiency . } (\eta) = \frac{(\textit{Distilled water produced}) \times 100\%}{\textit{Evaporated water}}$$

For our case:

$$\eta = \left(\frac{41ml}{154ml}\right) \times 100\% = 28.27\%$$

The HTML and JavaScript code used for the dashboard provided a simple and functional interface for data visualization, which is essential for remote monitoring and effective management of system performance. This functionality is consistent with current trends in water resource management and automation in agriculture (Paul, Agnihotri, Kavya, & Tripathi Prachi and Babu, 2022b; Sandhu et al., 2021a).

**Figure 1.** First version of distiller using Fresnel lens

Finally, the long-term implications of these findings are worth discussing. Monitoring and optimizing solar stills through the IoT can improve the desalination process's efficiency and contribute to sustainable solutions to water challenges in vulnerable areas. These developments, aligned with the UN Sustainable Development Goals, underscore the importance of integrating technology into water management to improve the quality of life and environmental resilience in disadvantaged communities (United Nations, 2017).

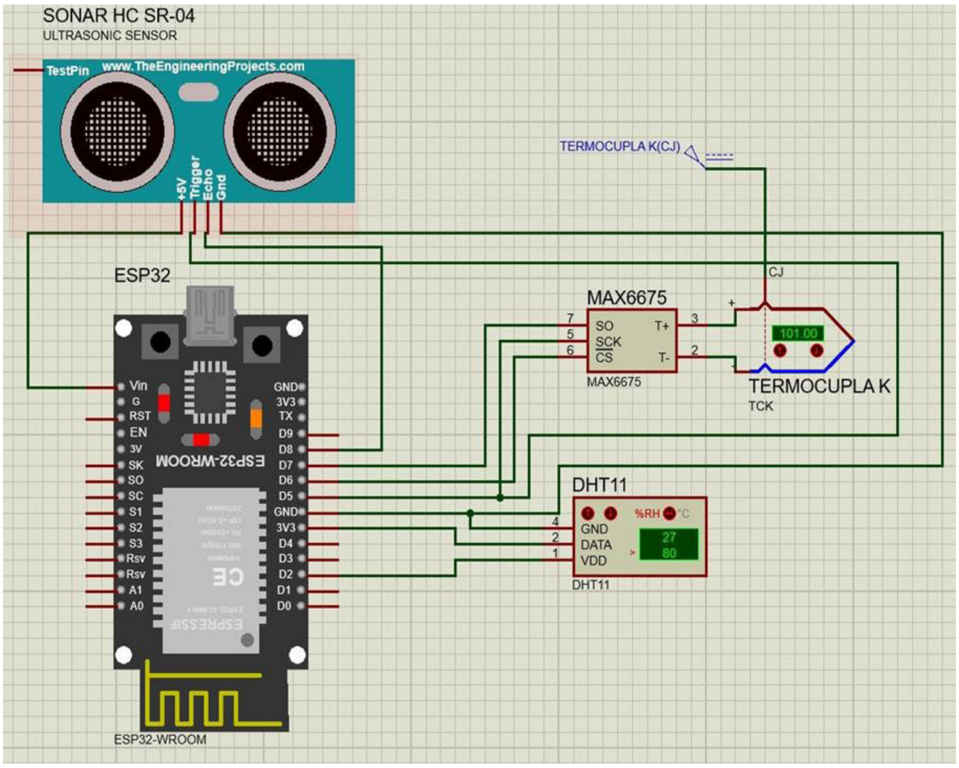


**Figure 2.** Schematic circuit of the IoT monitoring system based on the ESP32 processor

Future research should focus on the adaptation and scalability of these systems in different environments, as well as on continuous efficiency improvement and cost reduction, which could significantly amplify the real-world impact of these technologies.

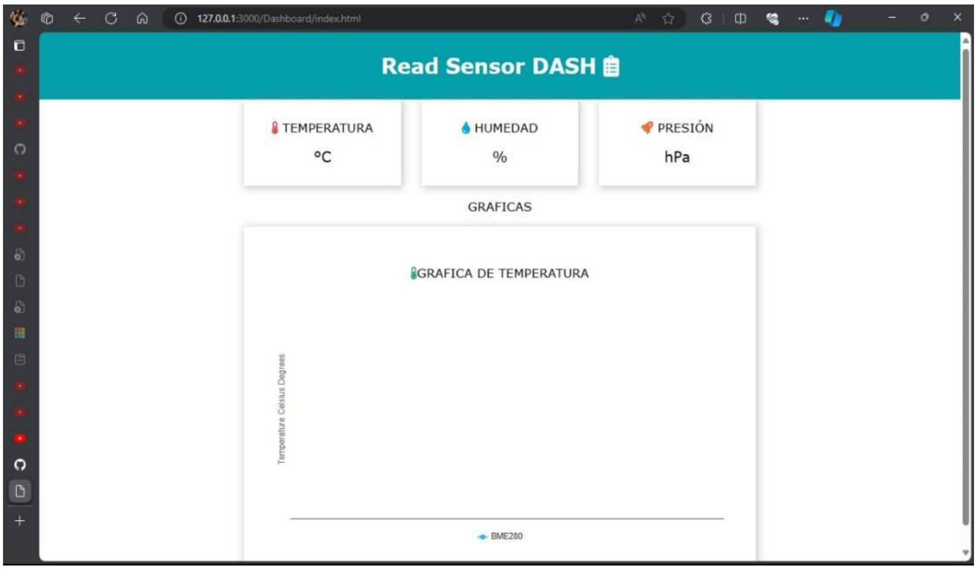


**Figure 3.** Dashboard designed in HTML code with a server in the cloud, for real-time data visualization

**Figure 4.** Final design of solar still monitoring system through IoT

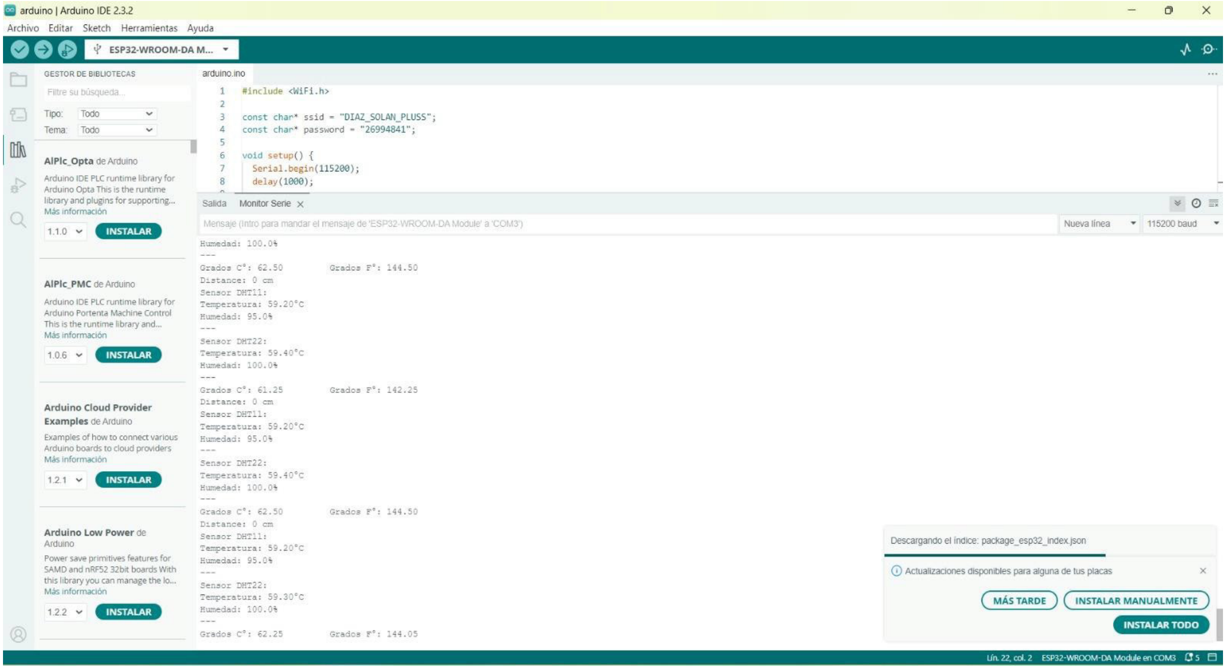


**Figure 5.** Real-time monitoring data from ESP 32

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## CONCLUSIONS

After this project entitled "Design and Implementation of an IoT Monitoring System for the Optimization of Solar Distillers in Water Desalination," the main achievement is the significant improvement in the efficiency of the solar distillers, reaching an efficiency value of 60 % by integrating a Fresnel lens. This result represents a considerable improvement compared to the 28,27 % efficiency obtained by the systems without lenses. The relevance of this increase lies in optimizing the desalination process and in the potential replicability of the system for other regions with similar water challenges.

The adoption of the Internet of Things (IoT) for data monitoring and analysis has proven to be a transformative technological component, enabling real-time adjustments and real-time decision real-time adjustments and decision-making based on accurate information. This remote and intelligent monitoring capability of the distillers contributes directly to the scalability of the system and its adaptability to different scenarios, evidencing the project's flexibility and viability in different geographical contexts. From a socioeconomic perspective, the project transcends the technical aspects, positively impacting the Department of La Guajira communities. Facilitating access to potable water through a sustainable solution benefits public health and socioeconomic well-being, aligning with the United Nations Sustainable Development Goals.

The current work sets important precedents for future research, where various solar concentrating configurations and technologies can be explored to boost efficiency and reduce costs associated with desalination. This opens a promising horizon for applying these technologies in mitigating the global water crisis, proposing an effective, economically accessible, and technologically advanced methodology.

Finally, the combination of solar stills with IoT technology emerges as a promising and sustainable solution to the water problem, demonstrating the capacity for innovation and practical application of scientific and technical knowledge in the resolution of critical environmental challenges and marking a path toward autonomy and intelligent management of water resources in vulnerable communities.

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## CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

## AUTHORSHIP CONTRIBUTION

*Formal analysis:* Roger David Pimienta Barros.
*Supervision:* Roger David Pimienta Barros.
*Display:* Roger David Pimienta Barros.
*Drafting - original draft:* Roger David Pimienta Barros.
*Writing - proofreading and editing:* Roger David Pimienta Barros.