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Smart Iot-Based Solar Powered Refrigerator For Farmers

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Abstract- Post-harvest losses in fruits and vegetables due to improper storage remain a major challenge for rural farmers, especially in off-grid areas with unreliable electricity. This research presents a Smart IoT-Based Solar Powered Refrigerator designed to provide sustainable cold storage using solar energy and intelligent monitoring. The system integrates an ESP32 microcontroller, DS18B20 temperature sensors, an MQ-6 gas sensor, Peltier cooling modules, and a solar charging unit with battery backup. Real-time monitoring is achieved through a locally hosted IoT dashboard and LCD interface. The system automatically regulates cooling, monitors spoilage gases, and manages battery health, significantly reducing losses and enhancing produce shelf life. This paper discusses the system design, implementation, results, and feasibility for rural agricultural deployment.

Keywords: IoT monitoring, Solar refrigeration, ESP32, Peltier cooling, Agricultural storage, Battery management, MQ-6 sensing, Smart farming**.**

I. Introduction

The agricultural sector suffers major economic setbacks due to spoilage of perishable produce. In developing regions, 20–40% of harvested fruits and vegetables deteriorate before reaching consumers due to lack of cold storage. Traditional refrigerators require consistent electricity, making them unsuitable for farmers in rural, off-grid areas.

Recent advancements in renewable energy and IoT technologies enable the development of decentralized, intelligent, and low-power cooling systems. This research introduces a solar-powered, IoT-enabled refrigerator tailored for farmers. The system provides smart monitoring of temperature, gas levels, battery health, and cooling status through sensors integrated with an ESP32 microcontroller.

The goal of this work is to build an efficient, cost-effective, and practical solution for rural cold storage, bridging the gap between agricultural needs and technological feasibility.

II. Literature Survey

This study presents the design, development, and evaluation of an IoT-based solar powered cold storage system tailored for small-scale agricultural applications. The system utilizes photovoltaic panels to generate renewable energy, coupled with an IoT enabled monitoring setup for real-time control of temperature and humidity.

1. Performance tests conducted with apples, cucumbers, and tomatoes indicated significant improvements in shelf life and quality compared to ambient storage. The system maintained internal temperatures between 3–5°C while reducing spoilage, ensuring food safety and quality. This work demonstrates the feasibility of decentralized, sustainable cold storage solutions for small farmers, potentially reducing post-harvest losses and improving farm income. This paper presents a techno-economic framework for smart cold-storage management tailored to smallholder agricultural communities.

2. The system integrates photovoltaic (PV)-powered refrigeration, phase-change material (PCM)based thermal buffering, IoT monitoring and control, controlled-atmosphere (CA) regulation, and a digital marketplace to address post-harvest losses, limited market access, and low-income generation. A 200-liter prototype was deployed for 30 days in a peri-urban cluster near Dharwad, India. The system demonstrated a return on investment (ROI) of approximately 2.05 times within three years, highlighting its economic viability. The integration of renewable energy, thermal buffering, and IoT monitoring ensures energy-efficient operation, while the digital marketplace facilitates direct-to-market sales, enhancing farmers' income.

3. The system utilizes locally available materials to ensure sustainability, affordability, and ease of maintenance. Key electrical parameters such as voltage, current, power consumption, and efficiency metrics were analyzed to optimize energy utilization and system performance. The findings indicate that the system operates efficiently under varying solar irradiance conditions, providing a reliable solution for preserving perishable goods in remote areas. The study underscores the importance of utilizing indigenous resources and designs to create cost-effective and sustainable refrigeration systems for rural communities.

4. This paper presents the design of a dual-powered automated Peltier effect cooler that transfers heat via the thermoelectric effect. The system is powered by both solar energy and mains electricity, ensuring continuous operation even during periods of low sunlight. The IoT integration allows for remote monitoring and control of the refrigeration unit, providing real-time data on temperature and system status. The compact and portable design makes it suitable for small-scale farmers and rural households, offering a sustainable solution for preserving perishable items. Performance evaluations demonstrate the system's effectiveness in maintaining desired temperatures, thereby reducing spoilage and extending the shelf life of stored produce.

5. This study introduces a solar photovoltaic (PV)-driven micro cold storage (MCS) system, specifically engineered for seamless integration with electric vehicles (EVs) to effectively mitigate post-harvest losses in perishable agricultural commodities. The system employs thermoelectric modules powered by solar energy to maintain optimal storage temperatures during transportation. The integration with EVs ensures that the cold storage system operates continuously without the need for external power sources, making it suitable for off-grid applications. Experimental results indicate that the system successfully maintains temperatures within the desired range, preserving the quality and shelf life of the produce. This innovative approach offers a sustainable solution for the transportation and storage of perishable goods, reducing food waste and enhancing food security.

6. Solar refrigeration systems (SRS) offer a crucial solution for reducing fruit and vegetable (F&V) loss and addressing energy and environmental challenges. Recent developments in SRS have focused on improving efficiency, scalability, and integration with renewable energy sources. Innovations include the use of phase change materials (PCMs) for thermal storage, advanced control systems for temperature regulation, and hybrid systems combining solar energy with other renewable sources. These advancements aim to enhance the performance and reliability of SRS, making them more accessible and effective for smallholder farmers.

7. This study analyzes the operational efficiency of a solar-powered VISI cooler with a DC compressor-based refrigeration system, adding and omitting phase change materials (PCM). The experimental findings demonstrate that incorporating PCM significantly enhances energy efficiency by reducing average power consumption from 48 to 40 W. The use of PCM allows for better thermal storage and regulation, reducing the reliance on solar energy during periods of low sunlight. The study also examines the impact of various operating parameters on system performance, providing insights into optimizing solar powered refrigeration systems for agricultural applications. The results suggest that integrating PCM can lead to more sustainable and cost-effective cold storage solutions for perishable produce.

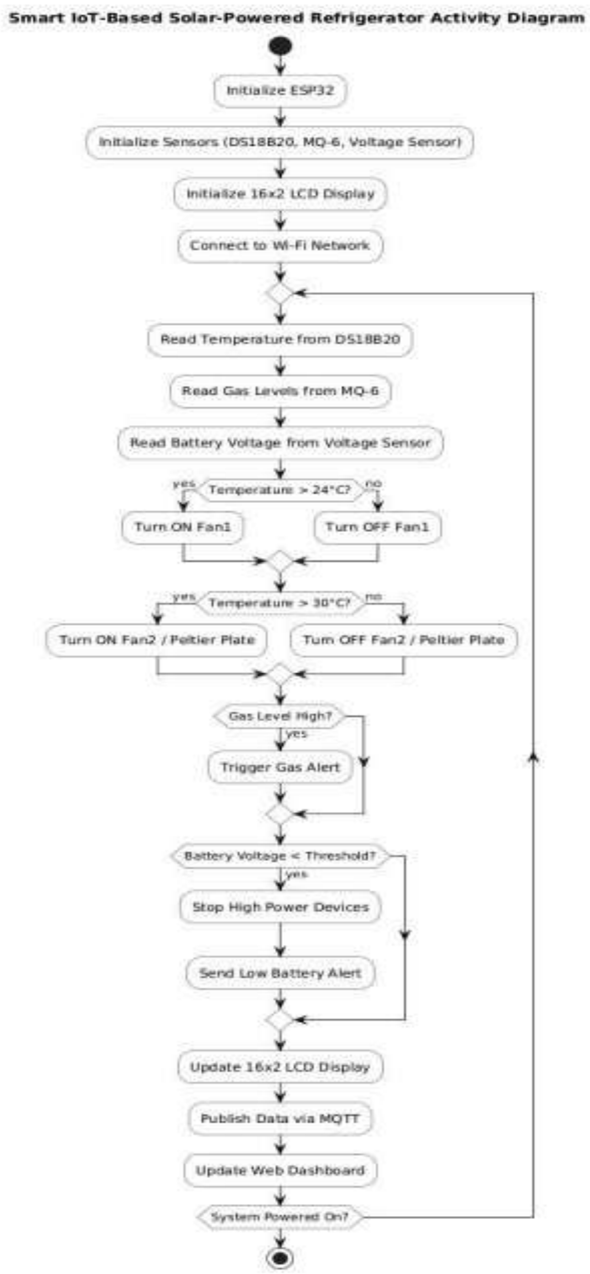
8. This paper presents the design and performance evaluation of a solar refrigerated storage system developed in India. The system utilizes solar energy and evaporative cooling to maintain optimal temperatures for storing agricultural produce. The design incorporates locally available materials to reduce costs and ensure sustainability. Performance tests indicate that the system effectively maintains temperatures within the desired range, preserving the quality and shelf life of stored produce. The study highlights the potential of solar-powered refrigeration systems in addressing the challenges of post-harvest losses and food security in rural areas.

9. This paper investigates the tools and equipment used in applications of wireless sensors in IoT agriculture and the anticipated challenges faced when merging technology with conventional farming activities. The study explores various IoT based solutions for sustainable agriculture, including soil moisture monitoring, climate control, and pest detection. The integration of IoT technologies enables real time data collection and analysis, facilitating informed decision-making and resource optimization. The paper also discusses the challenges of implementing IoT solutions in traditional farming settings, such as infrastructure limitations, cost, and technical expertise.

10. This research work presents a new IoT-based precision agriculture system with multi-sensor technology to quantify important soil parameters: pH, moisture, temperature, and NPK level. A case study on Kottayam rubber plantations proved the efficiency of the system in detecting site-specific nutrient deficiencies and enhancing crop suitability estimation. This paper fills the existing gap for integrating low-cost IoT-based monitoring with

actionable feedback and mobile access. The system's real time data collection and analysis capabilities enable precise irrigation and fertilization, leading to improved crop yield and resource efficiency.

III. PROPOSED SYSTEM



Working of the Proposed System

The overall workflow of the system begins with the solar panel generating energy, which is regulated by the charge controller and stored in the battery. The ESP32 microcontroller continuously monitors temperature, gas levels, and battery voltage using the connected sensors. Based on the sensor data, the ESP32 activates the fans to maintain optimal temperature, triggers alerts in case of high gas concentration, and manages energy usage to prevent battery depletion. Real-time data is displayed on the 16x2 LCD display for local monitoring and hosted on a web dashboard for remote access. The integration of renewable energy, intelligent sensors, IoT connectivity, and real-time monitoring ensures the system operates efficiently, sustainably, and reliably, addressing the key challenges faced by farmers in storing perishable produce.

The block diagram effectively highlights the interconnections between power management, sensing, control, and monitoring subsystems. It demonstrates how solar energy, battery storage, temperature and gas sensors, microcontroller logic, fan actuation, local display, and IoT interfaces work together to create a comprehensive refrigeration solution. Each component complements the others, forming a synergistic system that addresses energy constraints, spoilage prevention, and operational efficiency in agricultural storage applications.

The overall working cycle of the system can be summarized as a loop:

- Start & System Initialization
- Continuous Monitoring Loop
- Temperature Control Logic
- Gas Detection Logic
- Battery Voltage Monitoring Logic
- Data Display & Communication
- Loop Continuation
- System Stop Condition

Because this loop runs continuously, the system reacts quickly to changes such as sudden increase in load, cloudy weather, or nearing battery depletion. In this way, the proposed system not only supplies power but also keeps the user informed, protects the battery from harmful operating conditions, and provides useful data for future maintenance and optimization of the solar setup.

Hardware components

- **ESP32 MICROCONTROLLER**
- **DS18B20 TEMPERATURE SENSOR**
- **MQ-6 GAS SENSOR**
- **PELTIER PLATE / THERMOELECTRIC COOLER**
- **SOLAR PANEL (PHOTOVOLTAIC MODULE)**
- **RECHARGEABLE BATTERY (12V, 8AH)**
- **VOLTAGE SENSOR**
- **CHARGE CONTROLLER (20A MPPT/PWM)**

Software Components

- **Arduino IDE –** Programming ESP32 and uploading code.
- **MQTT Protocol** – Communication for remote monitoring and battery charging.
- **ESP32 Web Server (Local Hosting)** – Display live data on a local website.
- **Libraries:**

  1. OneWire.h – For DS18B20 sensor

  2. DallasTemperature.h – For DS18B20 sensor

  3.PubSubClient.h – For MQTT communication

  4. LiquidCrystal.h – For 16x2 LCD display

Using this software, the IoT-enabled solar-powered refrigerator becomes a smart, autonomous system. It combines automation, remote monitoring, real-time alerts, and energy efficiency, making it highly suitable for farmers in remote locations. Farmers gain control and visibility over the refrigeration system, ensuring their produce remains fresh while optimizing solar energy usage and battery management.

Circuit Diagram

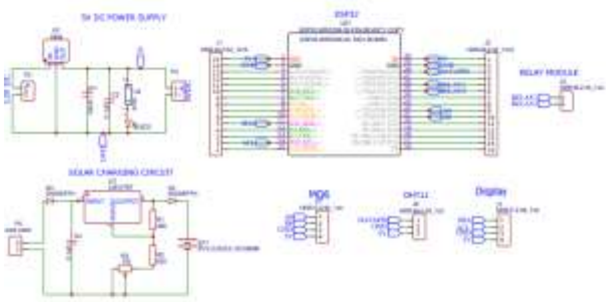


Figure 3.1: Circuit diagram

IV. RESULTS AND EVALUATION

The Smart IoT-Based Solar Powered Refrigerator for Farmers successfully provides a reliable cooling system using solar energy, making it suitable for rural areas with poor electricity supply. The system uses the ESP32 microcontroller to continuously read the temperature, gas level, battery voltage, and fan status. Based on this information, it automatically controls the fans to maintain the correct cooling conditions inside the refrigerator. For example, Fan 1 turns on when the temperature goes above 24°C, and Fan 2 turns on when the temperature rises above 30°C, helping to keep fruits and vegetables fresh for a longer time. The MQ-6 gas sensor detects any harmful gases released during spoilage, and if the gas level becomes unsafe, the system immediately alerts the user.
The results of the system are shown clearly on a 16×2 LCD display, where the farmer can see real-time temperature, gas status, and fan operation. Along with this, the ESP32 also hosts a local website, where users can check live data such as internal temperature, battery voltage, solar panel output, gas concentration, and overall system performance.

Figure 4.1: Smart IoT Solar-Powered Refrigerator Dashboard

This image shows a clean, modern dashboard interface that monitors a solar-powered IoT refrigerator system. It displays key metrics such as temperature, humidity, battery level, and gas level, helping users track the system's performance in real time.

Figure 4.2: Peltier Cooling and Solar Power Monitoring Panel

This image displays a dual-panel interface showing the status of a Peltier cooling system and a solar power system, including module activity and voltage levels. It highlights smart features such as temperature-based control logic, eco-friendly solar operation, and automatic power protection.

Figure 4.3: Activated Peltier Module 1 And Module 2

This image showcases a unified dashboard presenting real-time data on refrigerator temperature, humidity, battery level, and gas level, along with the operational status of the Activated Peltier Module 1 And Module 2 and solar power systems. It provides a clear overview of system performance for efficient, solar-powered refrigeration management.

V. CONCLUSION

The Smart IoT-Based Solar-Powered Refrigerator for Farmers provides an efficient, autonomous, and cost-effective solution for preserving perishable agricultural produce. By combining solar energy, IoT technologies, and sensor-based automation, the system ensures optimal storage conditions, energy conservation, and real-time monitoring. The integration of ESP32 microcontroller, DS18B20 temperature sensor, MQ-6 gas sensor, voltage sensor, Peltier plate, fans, LCD, and local web dashboard allows farmers to monitor and control the system effectively, even in remote areas.

This project demonstrates how renewable energy and IoT can improve agricultural productivity, reduce post-harvest losses, and support sustainable farming practices. Despite limitations such as weather dependency and small-scale capacity, the system offers significant advantages for rural farmers. With future enhancements like cloud integration, mobile applications, and AI-based predictive control, the project can be scaled to provide smart, energy-efficient refrigeration solutions for larger communities and commercial agricultural storage.

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