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Iot Rainwater Harvesting System with Solar

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1. Product Description

The IoT Rainwater Harvesting System with Solar is an innovative prototype that integrates traditional rainwater harvesting with smart technologies to create a green, fully autonomous water management solution. Unlike conventional systems that depend heavily on manual monitoring and grid electricity, this system leverages IoT sensors, solar power, and a mobile application to provide an efficient, sustainable, and low-cost alternative. Rainwater is collected from rooftop catchments, filtered, and stored in tanks for reuse in irrigation and domestic applications. A solar-powered pump, controlled by an Arduino UNO microcontroller and a NodeMCU ESP8266 Wi-Fi module, manages water distribution. The ultrasonic sensor for monitoring tank water levels, the soil moisture sensor for detecting dryness and triggering irrigation, and the rain sensor for detecting rainfall to prevent unnecessary pumping to ensure intelligent automation. All sensor data is transmitted in real time to a Firebase Realtime Database and displayed on a mobile application developed with Flutter. Through the app, users can monitor tank levels, soil conditions, and rainfall, switch between automatic and manual pump operation, and receive alerts on low water levels, rain detection, or system anomalies. The system operates entirely on solar energy, stored in a 12V battery via a solar charge controller, making it reliable for rural, off-grid, and disaster-prone areas. As a low-cost, scalable prototype built with open-source technologies, this system demonstrates the potential of smart water management to be both sustainable and affordable.

2. Innovation Objectives

This project aims to bridge the gap between traditional rainwater harvesting systems and intelligent technologies by achieving several key objectives. First, it promotes sustainable water management by harvesting, treating, and storing rainwater for non-potable uses such as irrigation, cleaning, and flushing, thereby reducing dependence on municipal water supplies. Second, it emphasizes renewable energy integration through the exclusive use of solar power, lowering electricity costs and enabling off-grid deployment. Third, it incorporates IoT-based smart automation, where real-time monitoring and sensor-driven decision-making regulate water usage and optimize irrigation schedules. To enhance usability, the project focuses on user-centric accessibility by providing a mobile application that offers real-time updates, historical performance tracking, pump control, and instant alerts. Affordability and expandability are also core objectives, with the system designed as a low-cost, modular prototype using Arduino and ESP8266 hardware, scalable for larger tanks, additional sensors, or future AI-driven predictive irrigation. Finally, the project aligns with global sustainability agendas by directly contributing to SDG 6 (Clean Water and Sanitation) and SDG 7 (Affordable and Clean Energy), while indirectly supporting SDG 12 (Responsible Consumption and Production).

3. Problem Statement

Water scarcity is one of the most pressing global challenges, driven by climate change, population growth, and uncontrolled consumption. In Malaysia, this paradox is especially evident: despite receiving abundant rainfall, much of it is wasted due to inefficient collection and storage systems. On average, a Malaysian consumes over 200 liters of water daily, yet during dry spells and rationing periods, supply remains uncertain. Traditional rainwater harvesting systems face several limitations, including the absence of real-time monitoring, which prevents users from tracking water levels or soil conditions; manual pump operation, which is inconvenient and error-prone; reliance on grid electricity, which increases costs and restricts use in rural or off-grid areas; and low efficiency, as water is often wasted by irrigating during rainfall or when soil is already saturated. These shortcomings highlight the urgent need for a smart, automated, and eco-friendly solution that enables optimal rainwater utilization at low cost and minimal environmental impact. The proposed system directly addresses these gaps by integrating IoT automation, solar-powered autonomy, and mobile app based control to deliver an efficient and sustainable water management approach.

4. Authenticity / Novelty

The uniqueness of the IoT Rainwater Harvesting System with Solar lies in its integration of renewable energy, IoT-based automation, and low-cost scalability, setting it apart from both traditional rainwater systems and existing smart irrigation solutions. The system is entirely self-sustaining, powered by solar energy and managed through IoT sensors, enabling continuous operation without dependence on municipal services.

A customized Flutter–Firebase mobile application enhances accessibility by providing real-time visualization of sensor data, role-based permissions, and remote pump control—features rarely found in small-scale harvesting solutions. Its automated irrigation logic ensures that the pump activates only when soil moisture falls below a threshold and no rainfall is detected, thereby conserving water and improving efficiency. Designed with affordability in mind, the prototype uses readily available components such as Arduino UNO, ESP8266, and low-cost sensors, making it suitable for households and small farmers, while its modular design allows for future upgrades such as AI-driven predictive watering and advanced filtration. Furthermore, the project directly contributes to sustainability by promoting water conservation and renewable energy adoption, aligning with global efforts to combat climate change and resource scarcity. This combination of automation, solar power, and affordability not only provides technical novelty but also carries significant social impact, with potential applications across urban residences, rural farms, and community-scale initiatives.

5. Implementation Level

a) Analysis of Hardware Requirements

The successful integration of all the main parts includes the Arduino UNO, sensors, relay, pump, solar panel, charge controller, and battery. The system uses solar energy to run independently of the power grid, accomplishing its stated sustainability goal. To verify real-world functionality, the prototype was set up with a scaled-up storage tank and irrigation system.

b) Develop the Prototype System

At the development level, the system incorporated relay control, pump automation, and sensor inputs, all programmed through the Arduino IDE. A mobile application was developed using Flutter and Dart, providing functionalities such as manual and automatic pump control, water level monitoring, and user authentication through a secure login system. Additionally, the integration of Firebase Realtime Database ensured seamless synchronization, enabling sub-second updates between sensors and mobile devices for precise and responsive system performance.

c) Integrate with the Firebase

At the Firebase implementation level, the database was structured around three primary entities: User Records, Sensor Data, and System Logs. This structure enabled efficient organization of information while supporting both real-time monitoring and the preservation of historical records, thereby confirming reliable data flow between the IoT hardware and cloud services. Furthermore, Firebase Authentication ensured role-based and secure system access, strengthening the overall reliability and security of the application.

d) Deployment and Testing of Prototype

At the deployment and testing level, the system achieved a fully functional prototype that was successfully tested under outdoor conditions. The solar-powered water pump effectively delivered irrigation cycles triggered by water level and soil moisture readings, demonstrating the reliability of its automated operation. The mobile application was packaged into an Android APK and deployed for end-user testing, ensuring accessibility and ease of use. End-to-end functionality was validated, confirming smooth operation across all stages such as from sensor detection to database updates, user notifications, and pump control.

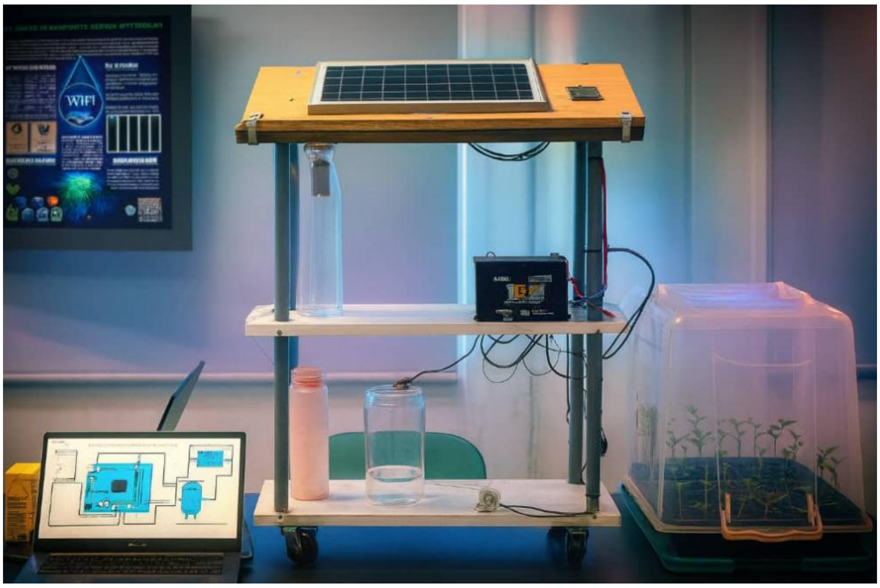

Figure 1 : Deployment of Prototype

6. Uses and Applications

Despite being primarily designed for agricultural plant irrigation, the IoT Smart Rainwater Harvesting System with Solar has versatile applications across multiple sectors. By integrating rainwater collection, renewable solar energy, and Internet of Things technology, the system delivers an economical, efficient, and sustainable approach to water management. In agriculture, the system serves as a smart irrigation solution for crops and plants. The soil moisture sensor and automated pump control ensure that crops receive water only when necessary, preventing waste and improving efficiency. By harvesting rainwater, farmers can strengthen resilience during dry seasons and lower costs by reducing reliance on external water sources. The solar-powered pump is particularly advantageous in rural and off-grid farming areas, while real-time monitoring enhances sustainability by conserving water and minimizing losses. Beyond agriculture, the system can be adapted for domestic use, making it ideal for landscaping, lawn care, and home gardening with programmable watering schedules. The harvested rainwater can also be repurposed for non-potable household tasks such as cleaning, toilet flushing, and car washing. The mobile application further enhances convenience by allowing users to monitor system performance in real time and receive notifications for timely interventions. At the community and environmental level, the system contributes to sustainable urban living by supporting rooftop gardens and urban agriculture, particularly in high-density areas where treated water is costly. Moreover, it aligns directly with Sustainable Development Goals (SDG 6: Clean Water and Sanitation, and SDG 7: Affordable and Clean Energy) by reducing dependency on freshwater grids and non-renewable electricity. In doing so, it not only mitigates environmental impact but also promotes the widespread adoption of renewable energy and sustainable resource management.

Impact

Integration of IoT and Renewable Energy

- This project integrates solar energy and IoT automation, making it completely autonomous and sustainable, in contrast to conventional systems that rely on manual labor or grid electricity.

Smart Monitoring and Control

- IoT sensors allow for real-time monitoring of rainfall, soil moisture, and water levels, facilitating precise water management and cutting down on waste.
- Users can remotely monitor and control pump operation from any location at any time with a mobile application created with Flutter and Firebase.

Automated Irrigation System

- In order to guarantee that plants receive water at the appropriate time and quantity, the system automatically turns on the pump based on sensor feedback.
- Precision agriculture benefits greatly from this innovation, which increases crop yield and lessens farmer labor.

Low-cost, Scalable Prototype

- Small-scale farmers can now use the prototype because it was constructed with inexpensive parts (sensors, ESP8266, and Arduino UNO).
- Future additions like larger tanks, AI-based predictive irrigation, and sophisticated filtration are made possible by the design's modularity.

Project Impact

Agricultural Impact

- Gives farmers a sustainable irrigation option, particularly in off-grid and rural areas.
- Lowers farming costs by reducing reliance on municipal electricity and water supplies.
- Promotes smallholders' adoption of smart farming technologies, which will boost their output and efficiency.

Environmental Impact

- Encourages water conservation by collecting rainfall and reducing waste with automation controlled by the Internet of Things.
- Helps protect freshwater resources by lowering the amount of treated water used for irrigation.
- Reduces carbon emissions by promoting the use of renewable energy sources by using solar panels rather than traditional electricity.

Social and Community Impact

- Offers a cost-effective way to encourage sustainable living that can be implemented by homes, schools, and community farms.
- Encourages creativity in environmental preservation and increases awareness of green technologies.
- Aligns with the Sustainable Development Goals (SDGs) of the UN and supports Malaysia's long-term plans for sustainable development.

8. Achievements

The project was successfully developed, tested, and showcased at the Final Year Project Showcase at Universiti Selangor (UNISEL), receiving positive feedback for its innovation and practicality.