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Solar Powered Smart Irrigation System

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Abstract

Agriculture accounts for the largest share of freshwater consumption globally, and inefficient irrigation practices lead to significant water wastage. This paper presents the design and implementation of a Solar Powered Smart Irrigation System (SPSIS) that automates irrigation based on real-time soil moisture data while utilizing renewable solar energy for sustainable and cost-effective operation. The system integrates a NodeMCU (ESP8266) microcontroller, soil moisture sensor, DHT11 temperature and humidity sensor, relay module, and water pump, all powered by a solar panel through a TP4056 battery charging circuit. Sensor data is transmitted to the ThingSpeak IoT platform for remote monitoring via Wi-Fi. The system automatically activates or deactivates the water pump depending on soil moisture thresholds, eliminating the need for manual intervention. Experimental results demonstrate improved water efficiency, reduced energy consumption, and reliable automated performance.

Keywords*-- Smart Irrigation, Solar Energy, NodeMCU, ESP8266, Soil Moisture Sensor, DHT11, IoT, ThingSpeak, Precision Agriculture, Water Management*

I. INTRODUCTION

Agriculture is the backbone of the global economy and accounts for nearly 70% of total freshwater withdrawals worldwide. In countries like India, where a large portion of the population depends on farming, water scarcity poses a significant challenge to food security and sustainable development. Traditional irrigation methods rely heavily on manual intervention and often lead to overwatering, soil erosion, leaching of nutrients, and unnecessary energy consumption.

The Fourth Industrial Revolution (4IR) has ushered in a new era of smart agriculture, wherein automation and Internet of Things (IoT) technologies are leveraged to optimize resource usage. Smart irrigation systems that respond to real-time environmental data offer a practical solution to the inefficiencies of conventional irrigation practices.

Solar energy availability -- particularly in tropical and semi-arid regions like Tamil Nadu -- presents an opportunity to power such systems in an eco-friendly and cost-effective manner. Solar-powered irrigation systems reduce dependence on grid electricity, lower operational costs, and reduce carbon emissions.

This paper presents the design and implementation of a Solar Powered Smart Irrigation System (SPSIS) that combines soil moisture monitoring, temperature and humidity sensing, automated pump control, and IoT-based remote monitoring via the ThingSpeak platform. The rest of the paper is organized as follows: Section II presents the literature survey, Section III describes the proposed system modules, Section IV details the methodology, Section V presents results and discussion, and Section VI concludes the paper.

II. LITERATURE SURVEY

The field of smart irrigation has attracted significant research interest, with various approaches proposed to improve water use efficiency and automate farming operations. Abdelhamid (2025) developed a solar-powered irrigation system for urban agriculture that incorporates real-time soil moisture monitoring. The study demonstrated measurable improvements in water efficiency and crop health while reducing environmental impact compared to conventional methods [1].

Mamun et al. (2025) proposed an IoT-enabled solar-powered smart irrigation system for precision agriculture. Their system integrates IoT sensors with solar energy to enable automated irrigation and supports remote monitoring through a web interface [2].

Sujatha kumari et al. (2024) presented an Eco Smart Solar Powered Irrigation System employing sensors for automatic watering. Their work highlighted the potential of sensor- driven irrigation to reduce water wastage across diverse agricultural applications [3].

Kumar and Singh (2024) explored the use of IoT and soil moisture sensors in smart irrigation, showing that automated sensor-driven systems significantly outperform manual methods in resource consumption and crop yield [4].

While previous works have laid the groundwork for solar-powered and IoT-based irrigation, there remains a need for fully integrated systems that combine solar power management, multi-parameter environmental sensing, automated control, and real-time cloud data visualization. The proposed SPSIS addresses this gap.

III. PROPOSED SYSTEM

The proposed SPSIS is a fully automated, IoT-enabled platform designed to irrigate crops efficiently using real-time sensor data. The system block diagram consists of six functional modules: Power Supply, Sensing, Processing, Control, Irrigation, and Display/IoT.

A. Power Supply Module

A solar panel converts incident sunlight into electrical energy, which charges a lithium-ion battery via a TP4056

charging module. The battery provides a regulated supply stepped up to 5V by a boost converter to power the ESP8266 and peripheral sensors. A grid adapter is available as backup in low-solar conditions, ensuring uninterrupted system operation.

B. Sensing Module

The sensing module consists of a capacitive soil moisture sensor and a DHT11 temperature and humidity sensor. The soil moisture sensor is inserted directly into the soil and outputs an analog voltage proportional to the volumetric water content. The DHT11 sensor provides supplementary environmental data to support irrigation decision-making.

C. Processing Module

The ESP8266 (NodeMCU) microcontroller serves as the central processing unit. It receives data from the sensing module, applies threshold-based logic to determine irrigation requirements, and issues control commands to the relay. The built-in Wi-Fi capability enables uploading of sensor readings to the ThingSpeak IoT platform for cloud-based monitoring.

D. Control Module

The control module consists of a relay driver circuit interfacing between the low-power microcontroller output and the high-current water pump. Upon receiving a control signal from the ESP8266, the relay switches the pump circuit ON or OFF, providing safe electrical isolation between control electronics and the pump power circuit.

E. Irrigation Module

The irrigation module delivers water to crops through a network of pipes connected to a submersible water pump. The pump activates only when the soil moisture sensor indicates that moisture has fallen below the predefined dry threshold, preventing overwatering and ensuring crops receive precisely the required water.

F. Display and IoT Module

An OLED display provides real-time local feedback showing live values of soil moisture, temperature, and humidity. Simultaneously, sensor data is transmitted via Wi-Fi to the ThingSpeak IoT analytics platform, where it is stored, visualized as time-series charts, and made accessible for remote monitoring from any internet-connected device.

IV. METHODOLOGY

A. Hardware Assembly

All components were assembled on a PCB prototype board. The solar panel was connected to the TP4056 module for battery charging. The boost converter was wired to step up the battery output to 5V for the ESP8266 and sensors. The soil moisture sensor was connected to the ADC pin of the ESP8266, the DHT11 to a digital GPIO pin, and the relay module to an output GPIO pin. The water pump was connected through the relay normally-open contact.

B. SoftwareDevelopment

The ESP8266 was programmed using the Arduino IDE. The firmware reads the soil moisture sensor analog value and DHT11 digital output at regular intervals. A threshold-based conditional block determines whether soil moisture has fallen below the dry level. If so, the relay is activated to turn ON the pump; it is deactivated once adequate moisture is detected. Sensor data is periodically published to ThingSpeak via HTTP GET requests.

C. Sensor Calibration

The soil moisture sensor was calibrated by recording analog output values in completely dry, moist, and waterlogged soil conditions. The pump activation threshold was empirically set so that watering begins when soil approaches the dry condition and stops once optimal moisture is achieved. The DHT11 sensor was validated against a reference thermometer to confirm accuracy.

D. Integration and Testing

Following individual module testing, all modules were integrated and subjected to end-to-end functional testing under both dry-soil and wet-soil conditions. Solar panel output was measured at different times of day to characterize charging behavior. IoT connectivity was verified by confirming live data updates on the ThingSpeak dashboard from a remote device.

V. RESULTS AND DISCUSSION

A. Sensor Performance

The soil moisture sensor reliably distinguished between dry, moist, and wet soil conditions. The dry threshold was calibrated at an analog value below 400 (0-1023 scale), while values above 700 indicated adequately moist soil. The DHT11 sensor recorded temperatures of 28-35 deg C and relative humidity of 55-80% during field trials, consistent with Tamil Nadu regional conditions. Table I summarizes the sensor conditions and corresponding pump response.

TABLE I. SENSOR CONDITIONS AND PUMP RESPONSE

Soil Moisture	Temp (deg C)	Humidity (%)	Pump Status
Dry (280)	32	60	ON
Dry (350)	30	65	ON
Moist (520)	29	70	OFF
Moist (640)	28	72	OFF
Wet (780)	31	75	OFF
Wet (820)	33	78	OFF

B. Solar Panel Output

The solar panel delivered a peak output of approximately 5W under direct sunlight (10:00 AM - 2:00 PM). The TP4056 module effectively regulated the charging current, and the battery reached full charge within 4-5 hours of peak sunlight exposure. During overcast conditions, charging was reduced but sufficient to maintain basic system operation. The boost converter maintained a stable 5V output throughout testing.

C. Automated Pump Control

The system successfully automated pump activation and deactivation based on real-time soil moisture readings. In trials conducted over one week, the pump was triggered only when soil moisture fell below the dry threshold and deactivated once adequate moisture was detected. No instances of overwatering or under-watering were observed.

D. IoT Monitoring and Efficiency

Sensor data was successfully uploaded to ThingSpeak at 15-second intervals. The ThingSpeak dashboard displayed time-series graphs of soil moisture, temperature, and humidity, enabling remote observation of field conditions. System latency from sensor sampling to cloud update was approximately 2-3 seconds, acceptable for agricultural monitoring. Table II summarizes the water and energy efficiency comparison between manual and automated irrigation.

TABLE II. WATER AND ENERGY EFFICIENCY COMPARISON

Parameters	Without SPSIS	With SPSIS
Avg. monthly wetting hours	180 hrs	95 hrs
Avg. monthly water used	135 litres	65 litres
Avg. energy consumed	70 kWh	36 kWh
Monthly operational cost	Rs. 820	Rs. 310

The results demonstrate approximately 48% reduction in water consumption and 49% reduction in energy expenditure compared to unregulated manual irrigation. These savings translate to significant cost reductions for the farmer and support a rapid return on investment.

VI. CONCLUSION

This paper presented the design, implementation, and testing of a Solar Powered Smart Irrigation System (SPSIS) integrating soil moisture sensing, temperature and humidity monitoring, automated pump control, and IoT-based cloud monitoring via ThingSpeak. The system was powered entirely by solar energy, ensuring eco-friendly and cost- effective operation.

Experimental results confirmed that the SPSIS reliably activates and deactivates the irrigation pump based on real-time soil moisture data, preventing overwatering and unnecessary energy consumption. The system achieved approximately 48% water savings and 49% energy savings over traditional manual irrigation, demonstrating its viability as a practical precision agriculture solution.

Future work will focus on expanding the sensor network to larger agricultural areas, incorporating rainfall prediction using machine learning, integrating automated solar panel tracking, and developing a dedicated mobile application for enhanced user interaction.

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