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Design of solar-powered automatic plant watering based on Internet of Things

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Abstract

Traditional manual watering practices, which pose challenges for optimal plant growth and resource management, are inefficient and labor-intensive. This study addresses these concerns by presenting a solar-powered, Internet of Things (IoT)-based automatic plant watering system. Utilizing NodeMCU ESP8266 and soil moisture sensors, the system autonomously monitors soil conditions, triggering irrigation only when moisture falls below a predefined threshold. This eliminates dependence on manual intervention, minimizing both water waste and labor burdens. Solar panels provide a sustainable energy source, eliminating dependence on grid power and reducing environmental impact. WiFi connectivity enables remote monitoring by transmitting sensor data to Blynk, a user-friendly IoT platform. Testing demonstrated accurate soil moisture sensing (3.1% error) and effective automated watering based on predefined thresholds. For example, the system automatically watered plants for 4 minutes and 13 seconds after humidity dropped to 37%, stopping once the target moisture level of 71% was reached. Notably, the solar panel successfully powered the system, providing sufficient voltage (12.08 V) and current (1.08 A) for the water pump. This study showcases the feasibility and effectiveness of a sustainable, IoT-based automatic plant watering system for optimized irrigation and environmental stewardship. Future research could optimize watering algorithms for diverse plant types and environmental conditions, explore wider agricultural applications, and further solidify this technology's contribution to responsible water management.

Keyword

Solar power, Automatic plant watering, Internet of Things

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Introduction

The significance of water in agriculture, particularly in horticulture, cannot be overstated. Plant survival and optimal growth are contingent upon adequate water availability, necessitating regular and meticulous irrigation practices [1]. Insufficient watering triggers wilting and ultimately leads to plant death [2]. Conversely, overwatering can induce root rot and have equally detrimental consequences [3]. Consistent water supply, tailored to specific plant needs, fosters healthy growth, fruit production, and overall plant well-being. For instance, chili plants thrive in soil with an average air temperature of 15-35 °C and a humidity level of 60-80% [4][5].

Traditional plant watering, primarily manual in nature [6], can be time-consuming and inconsistent, potentially leading to under- or over-watering. An automated irrigation system presents a solution to this challenge [7][8][9]. This system aims to provide timely and tailored watering based on pre-programmed schedules and real-time weather data, ensuring optimal plant health and minimizing resource waste.

A growing body of research in agricultural science is dedicated to the development of intelligent irrigation systems. In several notable examples, researchers have addressed the challenges of water scarcity and inefficient traditional irrigation methods through innovative technological solutions. For instance, [10] proposed an embedded irrigation system utilizing wireless sensor networks (WSNs) to optimize water usage and boost crop yields. This system deploys sensor nodes throughout fields to monitor crucial environmental parameters like soil moisture, temperature, and humidity. Similarly, [11] constructed an automated plant monitoring and watering system leveraging Raspberry Pi and Internet of Things (IoT) technology. Their system incorporates sensors for detecting soil moisture, temperature, and humidity, while the Raspberry Pi controls the water pump based on pre-defined rules. This approach not only minimizes water waste and improves plant health, but also facilitates remote monitoring via a web interface. [12] presents another noteworthy example, an Arduino-controlled automatic watering system specifically designed for greenhouses. This system utilizes a soil moisture sensor to trigger irrigation automatically when necessary, ensuring water delivery aligns with the specific needs of the plants. This sensor-driven approach prioritizes plant health, conserves water, and reduces maintenance requirements. The trend of Arduino-based automation continues in [13], where the authors demonstrate an automated plant watering system employing an Arduino Uno, a soil moisture sensor, a water pump, and a relay. This system constantly monitors soil moisture, triggering irrigation only when levels dip below a predetermined threshold. Finally, [14] showcases an intriguing and potentially valuable automatic plant irrigation control system developed using an Arduino microcontroller and a GSM module. This system leverages sensors to monitor both soil moisture and temperature, automatically triggering irrigation based on predefined thresholds. The inclusion of a GSM module enables remote monitoring and control of the system via SMS, making it particularly advantageous for farmers or gardeners who are not always physically present on-site. [15] concludes this overview with an Arduino-based automatic plant watering system utilizing a soil moisture sensor and a water pump. This system directly addresses the drawbacks of manual watering and promotes water resource optimization. Its simplicity and affordability make it ideal for home hobbyists or small-scale applications.

Inefficiencies in conventional irrigation practices often result in inconsistent water delivery, hindering crop yields and wasting precious resources. This study aims to design a solar-powered automatic plant watering system based on the Internet of

Things (IoT). By empowering users with real-time remote control over irrigation schedules, the system ensures optimal water delivery for diverse plant types, regardless of changing weather conditions. Leveraging the power of the IoT, users can monitor and adjust watering needs via smartphone, maximizing water efficiency compared to conventional methods. This not only minimizes energy consumption but also contributes to environmental responsibility. Our system's adaptability caters to the unique requirements of various plant life, while its reliance on solar panels eliminates dependence on the grid and reduces environmental impact. This study not only proposes a solution for sustainable agriculture but also promotes crop resilience. By meticulously nurturing each plant with the right amount of water, we can usher in a future of flourishing agricultural yields.

Methods

This solar-powered drip irrigation system, equipped with a multi-functional sensor measuring both soil moisture and solar panel voltage, optimizes plant watering with exceptional precision. Connected to the Internet of Things (IoT) network, it delivers real-time data, facilitating remote control of irrigation schedules and enabling data-driven insights for maximizing water efficiency.

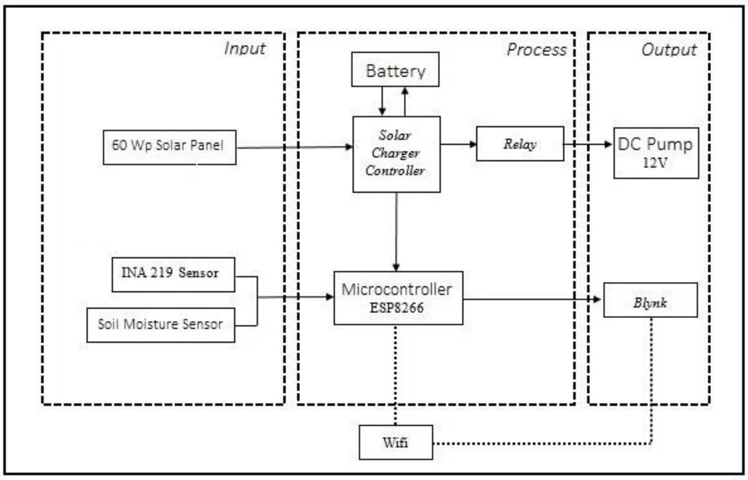


Figure 1. Block diagram of a solar-powered automatic plant watering system

The architecture of a solar-powered automatic plant watering system utilizing the Internet of Things (IoT) depicted in Figure 1 and Figure 2. The system relies on several key components: a central processing unit (CPU) built around the ESP8266 microcontroller, a Wi-Fi module for internet connectivity, a soil moisture sensor for real-time feedback, a solar charge controller for power management, and a 12 V DC pump for water delivery. The ESP8266 microcontroller functions as the system's brains, processing data from the soil moisture sensor and orchestrating operations. Leveraging this information, the CPU dynamically adjusts watering schedules based on pre-defined plant requirements and real-time environmental conditions, further customizable through a dedicated mobile application. This data-driven approach optimizes water usage and promotes optimal plant growth while allowing for remote monitoring and control through real-time updates on soil moisture and photovoltaic (PV) output. Powering the system is a 60 Wp solar panel that converts solar energy into electricity, stored in a 12 V/5 Ah battery for continuous operation. A dedicated solar charge controller regulates battery charging and manages power supply to the battery and pump.

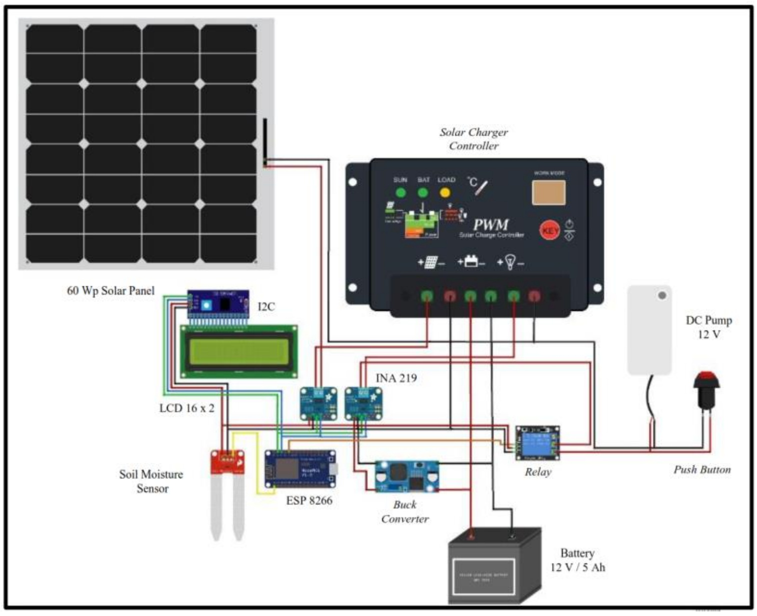
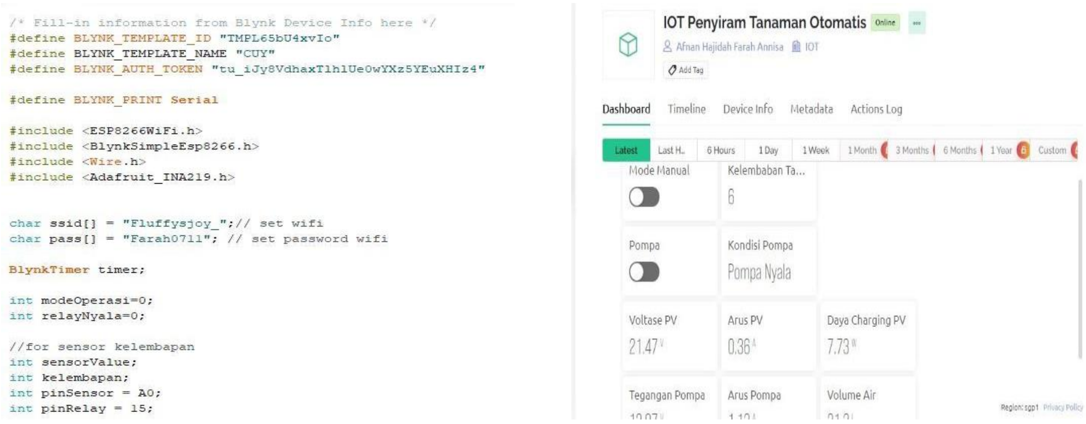


Figure 2. Wiring diagram of a solar-powered automatic plant watering system

Figure 3. Prototype of a solar-powered automatic plant watering system

This section details the prototype design of the solar-powered automatic plant watering system, illustrated in Figure 3. At its core resides a custom printed circuit board (PCB) designed with Altium software. This PCB consolidates key circuit components, such as the INA219 current sensor, soil moisture sensor, relay, and buck converter, optimizing assembly and reducing wiring complexity. The Arduino Uno microcontroller, LCD 12C display, and water pump are housed within the system enclosure. Power acquisition and management are accomplished through a multi-layered approach. The solar panel charges a 12 V/5 Ah battery via a solar charge controller (SCC), with an INA219 sensor in series for real-time monitoring of voltage, current, and power outputs. This battery serves as the primary power source, feeding the water pump through a parallel connection with a manual push-button switch for emergency override. The SCC also supplies power to a relay, automatically activating the pump when soil moisture, measured by a dedicated sensor, dips below 40% and deactivating it upon exceeding 70%. Data processing and communication capabilities are facilitated by an ESP8266 microcontroller. This "brain" of the system receives sensor data and transmits it to the Blynk platform, enabling remote monitoring and control through IoT protocols. Additionally, a conveniently located 16x2 LCD display provides real-time measurements directly on the system. Notably, a buck converter efficiently steps down the 12 V battery voltage to 5 V, catering to the specific power requirements of the soil moisture sensor.

The automatic plant watering system software development utilizes the Arduino IDE platform, as illustrated in Figure 4(a). The core program, built upon existing sensor libraries, seamlessly integrates data readings from the INA219 current sensor and the humidity sensor. This enables real-time monitoring of power consumption and environmental conditions. Secure communication with the Blynk platform for remote access is established through dedicated libraries and configuration protocols, ensuring encrypted data transmission via template IDs and authorization tokens. WiFi connectivity for the ESP8266 microcontroller is readily established by specifying network credentials. Calibration routines implemented for both sensors guarantee data accuracy, promoting reliable decision-making. Synchronization between sensor readings and the Blynk dashboard is achieved through Blynk. VirtualWrite functions within each program loop, facilitating intuitive real-time data visualization as depicted in Figure 4(b). Notably, the system incorporates intelligent pump control based on soil moisture readings, enabling both manual and automatic operation. Automatic watering activates when soil moisture falls below 40% and deactivates when it surpasses 70%, promoting optimal plant hydration with minimal water waste.



(a) (b)

Figure 4. (a) Part of the initialization code in the Arduino IDE for a solar-powered automatic plant watering system; (b) Real-time visualization of an IoT-based solar-powered watering system

Results and Discussion

The accuracy of the humidity sensor was evaluated by comparing its readings to those of a standard soil moisture measuring instrument. This calibration process aimed to quantify the discrepancy between the sensor's data and a reliable reference. Table 1 presents the calibration results obtained under three distinct soil conditions. Analysis of the data revealed a high degree of accuracy for the sensor, with an average error of 3.1%, corresponding to approximately 96.9% agreement with the standard measurements.

Table 1. Calibration results of the humidity sensor

No	Soil Conditions	Soil Moisture Sensor (%)	Soil Tester (%)	Error (%)
1	Dry	19	20	5
2	Moist	60	62	3,2
3	Wet	80	81	1,2
Average		53	54	3,1

Table 2. Field test results

No	Time	Soil Moisture (%)	Lux	Solar Panel Voltage (V)	Solar Panel Current (A)	Pump Mode	DC Pump Voltage (V)	DC Pump Current (A)	Pump Condition
1	07:00	46	10146	19.86	0.33	Manual	12.08	1.12	On
2	07:05	78	10152	20.35	0.36	Manual	0	0	Off
3	12:50	52	29052	21.47	0.68	Automatic	0	0	Off
4	16:07	37	13672	20.65	0.58	Automatic	12.07	1.08	On
5	16:11	71	13567	20.45	0.48	Automatic	0	0	Off


(a)


(b)


(c)

Figure 5. (a) Preliminary evaluation of the equipment; (b) Drip irrigation installed on agricultural land; (c) Testing of equipment on agricultural land

Figure 5 presents an initial assessment of the drip irrigation system installed on agricultural land, including both equipment performance and field operation results. Detailed data is available in Table 2. At 7:00 AM, manual irrigation was necessary as soil moisture (46%) fell below the automatic watering threshold. Five minutes of watering raised the moisture content to 78%. Concurrent solar panel measurements under 10146 lux of sunlight revealed a voltage of 19.86 V, effectively charging the battery and powering the DC pump (12.08 V, 1.12 A). Despite automatic watering being initiated at 12:50 PM, the pump remained inactive due to insufficient soil moisture (52%). However, increased sunlight intensity (29052 lux) at 16:07 PM boosted the solar panel voltage to 21.47 V. A subsequent decrease in soil moisture to 37% at 16:07 PM triggered the automatic irrigation system, activating the pump for four minutes and thirteen seconds until the desired moisture level of 71% was reached, successfully meeting plant needs.

To ensure optimal water management for 60 chili plants, a drip irrigation system with a pre-set soil moisture threshold of 71% was deployed. During equipment testing, a water pump with a 5 L/min flow rate automatically delivered water for 4 minutes and 13 seconds, resulting in a volume of 21.1 liters. This amount aligns with the system's design to provide sufficient water while minimizing waste, as verified by the accurate soil moisture readings from the integrated sensor. Compared to traditional watering schedules, this system offers precise control and adaptability to environmental conditions. Further testing will explore the long-term efficiency and optimize watering schedules for different growth stages of the chili plants.

Conclusion

This study successfully developed and tested an IoT-based, solar-powered plant watering system that leverages ESP8266 microcontrollers and soil moisture sensors for precise water management. Test results confirmed its effectiveness: the system accurately reads sensor data, automatically activates watering based on customizable thresholds, and efficiently delivers water to achieve target moisture levels. In one scenario, a 4-minute, 13-second watering cycle using 21.1 liters maintained optimal moisture for chili plants. Beyond functionality, this system offers unique advantages: minimizing water waste compared to traditional methods, eliminating dependence on grid electricity, and providing a cost-effective solution for farmers and communities. Further research will optimize watering algorithms for diverse plant types and environments, while exploring wider agricultural applications. This technology holds significant potential to revolutionize sustainable water management in agriculture.

References

[1] K. Chartzoulakis and M. Bertaki, "Sustainable water management in agriculture under climate change," *Agric. Agric. Sci. Procedia*, vol. 4, pp. 88–98, 2015.

[2] D. Lee *et al.*, "The rice Os NAC 6 transcription factor orchestrates multiple molecular mechanisms involving root structural adaptions and nicotianamine biosynthesis for drought tolerance," *Plant Biotechnol. J.*, vol. 15, no. 6, pp. 754–764, 2017.

[3] A. González-Briones, Y. Mezquita, J. A. Castellanos-Garzón, J. Prieto, and J. M. Corchado, "Intelligent multi-agent system for water reduction in automotive irrigation processes," *Procedia Comput. Sci.*, vol. 151, pp. 971–976, 2019.

[4] K. Pramanik, J. Pradhan, P. P. Mohopatra, C. Jena, and K. L. Acharya, "Impact of temperature: an important climate changing factor on vegetable crops," *Agric. For. Curr. trends, Perspect. Immortal Publ. Vijayawada*, pp. 105–134, 2020.

[5] D. R. Aryanto, D. M. Subrata, R. O. Khastini, R. Arafiyah, and I. Saraswati, "Monitoring System of Humidity Environmental on Chilli Red Green House Aeroponic System," in *2nd and 3rd International Conference on Food Security Innovation (ICFSI 2018-2019)*, Atlantis Press, 2021, pp. 163–166.

[6] R. Syam, W. H. Piarah, and B. Jaelani, "Controlling smart green house using fuzzy logic method," *Int. J. Smart Mater. Mechatronics*, vol. 2, no. 2, 2015.

[7] R. Hussain, J. L. Sahgal, M. R. Anshulgangwar, and M. D. Riyaj, "Control of irrigation automatically by using wireless sensor network," *Int. J. Soft Comput. Eng.*, vol. 3, no. 1, pp. 324–328, 2013.

[8] C. Kamienski *et al.*, "Smart water management platform: IoT-based precision irrigation for

agriculture," *Sensors*, vol. 19, no. 2, p. 276, 2019.
[9] B. B. Sinha and R. Dhanalakshmi, "Recent advancements and challenges of Internet of Things in smart agriculture: A survey," *Futur. Gener. Comput. Syst.*, vol. 126, pp. 169–184, 2022.
[10] N. Gandhi and S. Himabindu, "Design of embedded irrigation system by using WSN.," *Int. J. Res. Appl. Sci. Eng. Technol.*, vol. 4, no. 4, pp. 1012–1018, 2016.
[11] U. B. Mahadevaswamy, "Automatic IoT based plant monitoring and watering system using Raspberry Pi," *Int. J. Eng. Manuf.*, vol. 8, no. 6, p. 55, 2018.
[12] M. Mediawan, M. Yusro, and J. Bintoro, "Automatic Watering System in Plant House-Using Arduino," in *IOP Conference Series: Materials Science and Engineering*, IOP Publishing, 2018, p. 12220.
[13] K. T. Tun, H. M. Oo, and C. T. Nwe, "Automatic plant watering system using arduino," *Int. J. All Res. Writings*, vol. 2, no. 3, pp. 178–186, 2019.
[14] S. Akwu, U. I. Bature, K. I. Jahun, M. A. Baba, and A. Y. Nasir, "Automatic plant irrigation control system using arduino and gsm module," *Int. J. Eng. Manuf.*, vol. 10, no. 3, p. 12, 2020.
[15] N. Singh, S. Srivastava, S. Mukhtar, and R. M. Upadhyay, "Arduino Based Automatic Plant Watering/Irrigation System," *Int. J. Eng. Appl. Sci. Technol.*, vol. 4, no. 12, pp. 273–276, 2020.