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Renewable Energy Integration into Cloud & IoT-Based Smart Agriculture

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Abstract: *The increasing demand for sustainable agriculture and resource utilization accelerates the incorporation of renewable energy systems with cloud-connected IoT solutions. Here is a solar- powered IoT-based smart agriculture system, which aims to automate environmental monitoring and irrigation using NodeMCU ESP8266. The proposed model contributes to temperature and humidity sensing, PIR-based field activity monitoring, and automatic actuation of the water pump based on soil and climatic conditions. Real-time data acquisition and device control can be enabled using the Blynk IoT cloud platform for ensuring remote accessibility for continuous supervision. A solar panel with battery storage ensures disturbance-free power supply in rural and off-grid areas, enhancing the reliability and sustainability of the system. Experimental results represent stable sensor communication, responsive pump actuation, and efficient renewable energy use. This system presents how the integration of IoT, cloud computing, and renewable energy enables precision agriculture, limits water wastage, and offers practical eco-friendly farming solutions.*

Key Words: *Smart Agriculture, IoT, Renewable Energy, Cloud Computing, NodeMCU (ESP8266), Blynk IoT, Temperature and Humidity Monitoring, PIR Sensor, Automated Irrigation, Solar Panel.*

I. INTRODUCTION

Farming's changing fast. People care more about eco-friendly food. Resources are scarce, and the weather's all over the place, so farmers need to figure things out. Just walking around the field to check on things like temperature or soil isn't cutting it. You really need to know what's happening right away to decide fast. Now, with IoT and cloud stuff, there's a fix. Sensors can watch the farm all the time. You can see what's up and make changes from anywhere. Also, if these sensors run on solar power, mainly where there's not much electricity, they'll keep going no matter what happens. Good for the earth and useful. This project is all about making a smart farm setup with these ideas. We're using a NodeMCU ESP8266 board to watch for temperature, moisture, and all that. It also turns on watering pumps automatically, and it sends updates to the Blynk IoT thing, so you can watch the farm live. It saves water, cuts down on work, and helps farmers manage bigger, greener farms.

II.LITERATURE SURVEY

Lately, smart farming has really taken off, and a lot of that comes down to IoT, cloud tech, and renewable energy coming together to make things run smoother and greener. The old way-just checking temperature, humidity, and soil moisture by hand-never gave consistent results. Farmers ended up wasting water, and researchers saw the need for better, automated systems. People have already shown that microcontrollers like the ESP8266 are great for this stuff: connecting to Wi-Fi easily, not using much power, and working with lots of different sensors means you can keep an eye on the environment in real time. There is also research showing that if you hook up solar panels and a battery, these IoT systems keep running even out in the middle of nowhere where power might be spotty. On top of that, cloud dashboards and mobile apps are making things easier for farmers. Now, they can get alerts and tweak irrigation settings without even leaving the house. They've even thrown in features like relay-controlled pumps and PIR sensors to let them know what's happening in the field for giving farmers smarter ways to make decisions. But here's the thing-most existing setups don't pull all those elements together. Usually, they leave out fully combining renewable energy, cloud communication, and multiple types of sensors into one smooth package. Here's where this project steps in. Using solar power, NodeMCU for sensing, and Blynk for IoT connectivity, we're going to build a smart farming system that finally pulls everything together in one package.

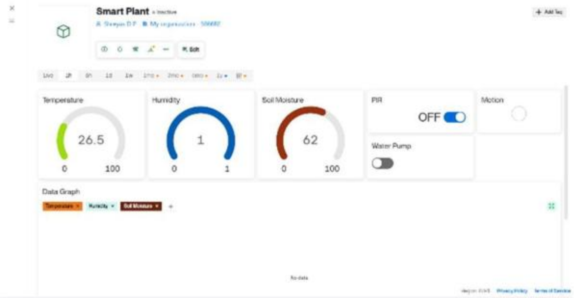

Figure 1: User Authentication Interface.

The real-time monitoring screen of the Blynk IoT application, displaying sensor readings and controls for the Smart Plant system.

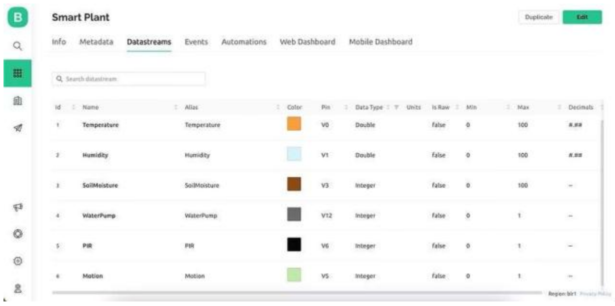

Figure 2: Blynk Data Stream Configuration.

The setup interface in the Blynk IoT platform showing the creation and mapping of data streams for sensor inputs and device controls, forming the foundation for real-time monitoring and automation.

III.METHODOLOGY

The development of the solar-powered IoT Smart Agriculture system took place in steps, from hardware interfacing to automated irrigation and cloud-based monitoring. First, the DHT11 temperature and humidity sensor, soil moisture sensor, PIR motion sensor, and voltage module were interfaced with NodeMCU ESP8266. Every sensor was first tested individually for stable readings, and their outputs had to be calibrated and converted to obtain meaningful values. This system operates in open farm conditions; therefore, a small 6V solar panel, together with an 18650 lithium-ion battery and basic protection circuitry, provides uninterrupted power during fluctuating sunlight hours.

Once the hardware layer was stable, the next focus was on communication and data handling. All sensor readings were normalized and mapped to appropriate ranges prior to sending via Wi-Fi to the Blynk IoT cloud. Separate virtual pins handled temperature, humidity, soil moisture, PIR status, and pump control to make the data better visualizable and manageable.

A relay module was integrated for irrigation, which drives the 3–6V submersible water pump. NodeMCU checks the value of soil moisture and compares that with the threshold set on the Blynk app. Based on this, the pump can run automatically; although users can also switch it on or off manually from the dashboard. In parallel, PIR readings are updated to indicate motion around the plant area.

All of these operations, namely sensor sampling, data transmission, decision-making, and relay actuation, are managed by an Arduino-based modular firmware. As such, this structure ensures the system remains responsive, energy-efficient, and easy to maintain. Combining the use of renewable energy with IoT automation creates a reliable and workable final setup for smart farming.

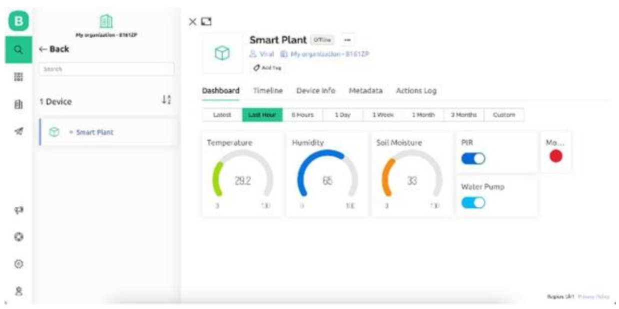

Figure 3: Blynk Dashboard Monitoring Interface.

Main device dashboard in the Blynk IoT platform showing real-time sensor readings and control widgets for temperature, humidity, soil moisture, PIR status, and water pump activation.

IV.RESULTS AND DISCUSSION

The integrated IoT-based Smart Agriculture system showed stable and reliable performance throughout the testing phase in terms of all sensing and automation modules. Temperature and humidity readings from the DHT11 sensor were responsive to varying environmental conditions, while the soil moisture sensor presented clear, distinguishable changes with respect to dry and semi-moist conditions, versus fully watered soil. This confirmed its suitability in automated irrigation decisions. It also performed accurately in detecting human or animal movement within its range and updated the motion status on the Blynk dashboard, with very negligible delay. Real-time transmission of sensor values through NodeMCU to the Blynk cloud was smooth, with continuous updating of current readings of all sensors on the dashboard supported via gauges, switches, and timeline graph widgets without noticeable communication latency.

Beyond raw sensing accuracy, the automation functionality played a crucial role when assessing system effectiveness. The water pump, controlled via relay, immediately acted on changes in soil moisture thresholds configured on the Blynk interface, hence validating both the programmed decision logic and the reliability of remote actuation. If programmed to do so, the system would execute an automated irrigation cycle every time the moisture level fell below the threshold that was set for it, while manual override commands performed through the dashboard were executed in real time. Finally, the solar panel and battery subsystem showed robust performance by keeping the NodeMCU and sensors running smoothly even with fluctuating light intensity. The logged data within the Blynk platform showed historical trends for all sensors, thus affording a valuable opportunity to review what had happened in the environment concerning past conditions and irrigation events with time-stamped accuracy.

Figure 4: Mobile Output Interface in Blynk.

Mobile Output Interface in Blynk. Mobile view of the Blynk IoT application showing current sensor data and control widgets of the Smart Plant system for easy monitoring of conditions and pump control using just your smartphone...

Qualitative observations through the dashboard showed that the system could effectively capture meaningful patterns in the environment. Temperature and humidity graphs obviously reflected the natural variations of the testing intervals, while soil moisture data suddenly rose during pump activations followed by gradual decrease when the soil dried out, showing proper irrigation control. The motion indicators from the PIR sensor also captured the events of motion correspondingly, validating that the system is useful not only for environmental monitoring but also for basic security awareness. Altogether, these confirm the correct functioning of the system as a cloud-integrated agricultural assistant, demonstrating an important capability-it did not just collect values of sensors, instead analyzed conditions, acted upon those autonomously, and maintained continuous functioning with support through renewable energy, which is an important requirement for any next-generation smart farming solution.

Other practical merits of the system include the fact that it works seamlessly on virtually any device a user might prefer. Be it someone logging in from a laptop, an Android phone, or an iPhone, the interface of Blynk remains consistent and user-friendly. That makes it very convenient to check sensor readings, review past data, or control the water pump from wherever you are, without being restricted to a particular platform or operating system.

V.APPLICATIONS

This smart agriculture system isn't just some flashy tech; it actually gets the job done in the field. Now, precision irrigation is where this system really shines. The system checks soil moisture in real time and keeps an eye on the weather, so that you know exactly when and how much to water. No more guesswork, no more wasted water, and crops are bound to come out healthier. The PIR sensor is nothing special but does a great job in terms of security, spotting anyone or anything that gets too close to the farm area. The data points connect via the Blynk IoT platform, meaning there is no need to stand right at the field to keep track of everything or to switch the water pump on/off-you may take your phone and perform all that from any other place. Solar power plays a significant role, especially in rural places where electric power may not be that stable. Parts are affordable. Since all of these tie into the cloud, it is a great teaching tool for IoT, renewable energy, and automation. At the end of the day, this setup's flexible, easy to upgrade, and doesn't draw much power—a solid pick if you want to modernize your farm without making things complicated.

VI.FUTURE WORK

The system works well right now, but there's plenty of room to make it smarter and more flexible for real- world farming. A big step in that direction might be to add more sensors-think soil pH, rainfall, or light intensity. With those, you get a fuller picture of what's happening in the field, which means better decisions. The irrigation side could use a boost, too: instead of just flipping on when certain numbers hit, machine learning models can look at past data and actually predict when crops need water.

Power's always a concern, especially when the sun isn't playing nice. Upgrading to bigger solar panels or using MPPT charging helps the system keep running, even on cloudy stretches. On the tech side, automatic notifications-like texts or emails-would let users know right away if something's off in the field. And if you throw in GPS tagging and connect multiple nodes, the system scales up easily for bigger or spread-out farms.

It's also worth creating a web dashboard to work alongside the Blynk app. That way, you get better visuals, more ways to access the data, and a setup that grows with whatever new needs pop up in smart farming.

VII.CONCLUSION

So, here's where things stand: the project succeeded at pulling off exactly what it set out to do-a smart agriculture setting running on renewable energy, keeping track of events in real time, and even going so far as to automatically water the crops. By hooking up sensors for temperature, humidity, soil moisture, and motion to a NodeMCU ESP8266 and feeding the data into the Blynk IoT cloud, we got a steady stream of accurate readings and seamless automation, regardless of the conditions we threw at it. The solar panel and battery kept everything running without a hitch, and that alone proves this type of setup is totally viable in places without easy access to power. What really shines is how sensors, remote cloud access, and relay-controlled pumps came together seamlessly to minimize manual work and make water use much smarter. We hit every goal, and honestly, this just shows affordable IoT gadgets, powered sustainably and managed through easy-to-use dashboards, really can handle the demands of modern precision farming. It's scalable, straightforward, and ready for real-world use.

Acknowledgement

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