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SMART AGRICARE AUTOMATED CROP RECOMMENDATION AND IRRIGATION SYSTEM USING CLOUD COMPUTING

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***Abstract*—Modern agricultural operations need optimized water resources because they must operate sustainably, especially in water-shortage conditions where common irrigation practices yield suboptimal results. This paper presents IntelliGrow as an IoT system for precision agriculture, which uses environmental moni toring and smart water management to boost farming effectiveness. The ESP-32 microcontroller operates IntelliGrow by integrating sensors for measuring soil moisture, temperature, and humidity levels to collect examination data that gets processed through cloud computing with machine learning model analysis. Through a web platform specifically designed for farmers, they can view live data, control water distribution, and gain detailed recommendations according to their soil conditions along with weather patterns. The experimental findings show that the IntelliGrow system cuts down water use by 40% while giving farmers yields 12-15% higher than traditional agricultural practices. IntelliGrow integrates IoT technology with cloud infrastructure along with adaptive AI functionality to solve present-day irrigation system constraints, thus providing users with an overviewable and scalable sustainable farming solution.**

***Index Terms*—IoT, Precision agriculture, Smart irrigation, Cloud computing, Machine learning, ESP-32, Water management, Sustainable farming.**

I. INTRODUCTION

Traditional irrigation techniques result in critical water short ages during agricultural operations because they fail to create adequate water efficiency and crop demand equilibrium which leads to both wasting too much water or having inadequate supply particularly in arid regions. The improper use of wa ter resources simultaneously depletes available resources as well as creates major food insecurity problems by producing lower yields and driving up agricultural costs for farmers. False measures enable farmers to manage their resources bet ter through technological advancement and Internet of Things (IoT) systems and cloud platforms and artificial intelligence programs bring innovative solutions to current farming issues. The research project presents IntelliGrow as a system based on IoT technology to improve farming water management through continuous environmental observation and automated irrigation supervision. The IntelliGrow system functionally operates on an ESP-32 controller by combining basic environmental sensors for measuring moisture levels and temperature as well as humidity levels which feed data to cloud-based machine learning ana lytics for clear irrigation demands assessment. The developed web platform delivers live agricultural information alongside adaptive irrigation schedules and soil and weather-based crop recommendations to its farm users. The project has three core objectives: lowering water usage with simultaneous boosts to yield production and delivering viable technology that promotes sustainable farming. IntelliGrow tackles the weaknesses of tra ditional irrigation systems through its method that proves to increase agricultural

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resource utilization while boosting farming outcomes. The presented work enhances smart farming literature by offering a technological integration method which addresses modern agricultural requirements in limited resource conditions.

II. Literature Survey

The implementation of IoT technologies has brought great progress to smart irrigation through real-time agricultural en vironmental monitoring capabilities. Patil and Bhole [1] con structed an IoT-based watering system which applies water according to soil hydration levels, thus reducing human la bor and delivering improved operational results. The authors Shinde and Kadam [2] developed an automated irrigation system through IoT and wireless sensor networks, which used ESP-32 microcontrollers to gather real-time data during their research. Zhang et al. [3] took the previous method to the next level through a combination of IoT irrigation techniques that included weather forecasting but met obstacles because of complex system designs and dependence on external data sources. The cost-effective IoT solution proposed by Ali and Hassan [4] used wireless sensor networks yet lacked a robust cloud integration, which IntelliGrow improves by using dynamic decision-making from a cloud platform. Machine learning (ML) technology has become a recognized approach for enhancing agricultural choices, especially those related to irrigation systems. Mehta and Bansal [5] developed a cloud-based IoT system with ML capabilities for watering schedule predictions that saved water while dealing with insuf f icient data records and changing environmental factors. Reddy [6] analyzed ML applications for predictive analytics about irrigation and yield assessment but reported scaling problems because of computational boundaries. Rathod and Suryawanshi [7] conducted a review of ML applications in smart irrigation where they identified the main drawback as limited real-time adjustment capabilities in most models. The existing limitations promote the necessity for developing continuously advancing MLmodels, which IntelliGrow bridges by using cloud facilities for both ongoing training processes and real-time irrigation control updates. Smarter agriculture has experienced a revolution through cloud computing, which provides centralized storage in addition to processing functions. Through their work, Zhang and Zhang [8] revealed how cloud platforms serve as an integration method for IoT devices in agricultural data management processes, which leads to better accessibility but creates security-related challenges. Bhatia and Goyal [9] developed an architecture that combined IoT technology and cloud computing for sustainable farming operations, although problems persist with remote area network reliability. ThingSpeak [10] presents cloud-based real time monitoring alongside irrigation control, but its functionality decreases when internet connections are unstable. The absence of offline functionality together with adaptive decision-making becomes strengths of IntelliGrow since it implements offline caching and AI-managed irrigation methods. The implementation of modern enhancements fails to resolve all obstacles facing modern advanced smart irrigation systems. The adoption of IoT technology relies on fixed rule sets without adapting to changing situations according to [1] and [2]. The work presented in [5] and [6] demonstrates how ML models face problems using static training information along with restrictive coverage of diverse scenarios across different locations. Cloud-based methods face two primary constraints with limited scalability, which include connectivity dependence along with security vulnerabilities and require further research on crop-specific guidelines according to [8] and [9] and [7] IntelliGrow resolves system constraints by uniting real-time observation capabilities with ML model adaptive features and protected cloud systems to deliver accurate watering systems management alongside specific agricultural recommendations, resulting in sustainable farming practices.

III. System Architecture and Design

The IoT-based smart irrigation system IntelliGrow uses environmental monitoring, data processing through the cloud combined with artificial intelligence to provide precise water management in agricultural fields. The system depends on an ESP-32 microcontroller because it meets requirements for low power usage and integrated Wi-Fi/Bluetooth and enables communication with soil moisture sensors that monitor environmental parameters throughout fields for collecting full data sets. Real-time analytics are managed by relay controlled water pumps through sensors that work with a custom web platform for farmers to control theircrop management functions and observe dashboard statistics. The system sends data to a cloud server through MQTT protocol to enable quick and secure communications which allow a machine learning model to anticipate suitable water amounts for crops and perform soil type and pH and weather-pattern-based recommendations that receive continuous updates for improved adaptability. The

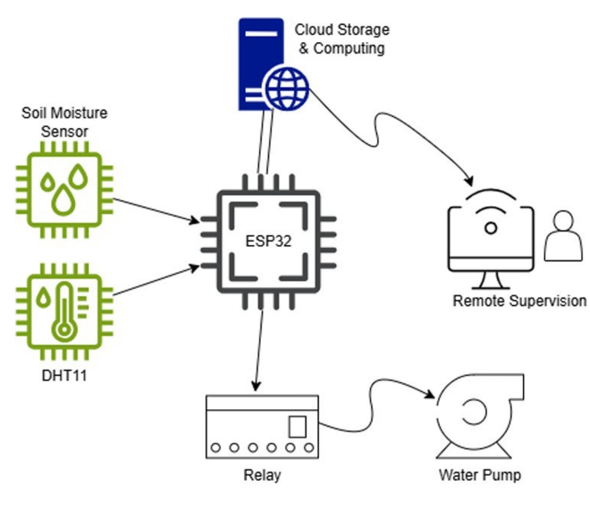

Fig. 1. System Architecture Diagram

System Architecture Diagram (Fig. 1) shows how the ESP-32 combines sensor inputs into a cloud analysis platform and receives irrigation controls back through a dual-directional data stream which promotes distant administration and resource

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economy. The system implements HTTPS for web access together with MQTT with SSL/TLS encryption alongside role based authentication to guarantee data security. Extra sensor nodes and a flexible cloud system with growing data storage capacity can scale up operations for the system setup. The integration of software with hardware produces an efficient sustainable agriculture system which resolves water irrigation system limitations through data-driven operation methods.

IV. Implementation

IntelliGrow's installation is a full integrated hardware, soft ware and networking protocol to deliver fully functional smart irrigation system. Hardware deployment is initiated with the use of ESP-32, microcontroller of choice because of its processor power and wireless abilities to provide a connection briefly to soil moisture, temperature sensors in order for it to perceive the condition of it. These sensing devices, connected to the ESP 32 via analog and digital pin of the microcontroller, distributed across agricultural fields, and relay modules operating on the mi crocontroller to operating water pumps based on the computed irrigation requirements. Data acquisition is done at a specified interval, the ESP-32 pre filtrations the sensor readings locally before the information is transmitted. The MQTT protocol provides safe swift data transfer to cloud server augmented by API that overlays external weather data, like rainfall forecast to irrigation data. The machine learning

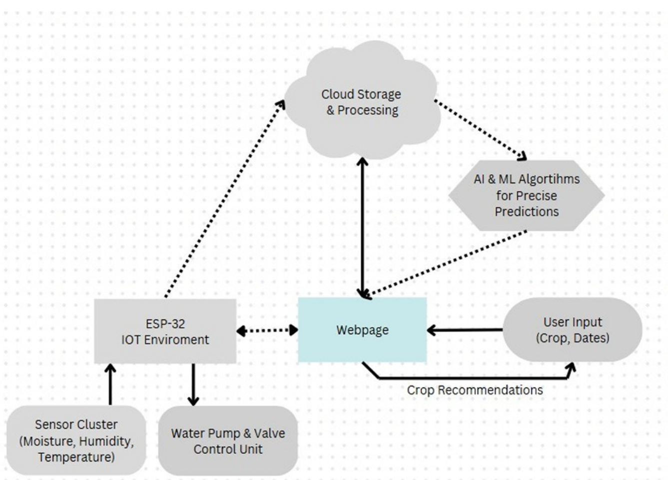

Fig. 2. Process Flow of the Device

(ML) model, an supervised algorithm which was trained on the historical sensor values, pastes weather information and crop specific water need, is positioned on the cloud in the sense of scalability and real-time updates. The technology examines the incoming information for technology to foresaw precise watering quantities and attacks waste for changing to environmental alters, regularly retrain on its pre ciseness across greatly soil types. The custom website, imple mented with modern web-platforms facilitates farmer-to-website interface with in(inputting crop types and planting dates, real worksense sensor metrics and presenting graph/user generated irrigation dwelling fetching crop endpoints) The flow chart depicting the e2e workflow: sensor data collection, cloud processing incorporating ML prediction, pump actuation via ESP 32, gives a clear visual of the whole system's operation as below documented system operational process. Cloud infrastructure enables safe storage as well as processing of data through effective protocols for data synchronization in between IoT tool and also web site. Water control uses an adaptive system which begins with sensor measurement of environmental factors that enter the ML prediction system and then directs ESP-32 pumps through an automated process that farmers can monitor and adjust using their website. The system uses precise automated irrigation methods for which three months of testing took place with maize and tomatoes in a practical controlled environment. The implementation of IntelliGrow as an effective sustainable agricultural tool results from combining the durability of its hardware components with machine learning intelligence and ease of user access.

V. Results

A. System Performance Analysis

The controlled trial of IntelliGrow spanned three months at an agricultural farm using tomato, wheat, and maize crops to evaluate its performance. Water usage decreased between 30% to 40% when compared to traditional irrigation methods since the system adjusted water distribution based on live weather data and soil moisture measurements. Irrigation precision remained highly accurate because soil moisture stayed within proper crop ranges throughout all conditions while avoiding both excess moisture and drought effects. The system delivered 98% uptime, which strengthened reliable MQTT communication between ESP-32 and cloud server components. Users of the web interface expressed ease of use while displaying significant curiosity about receiving immediate data updates and controlling irrigation distributions from this web interface, which helped operational decision-making.

B. Cloud Computing and Data Management

The cloud platform supporting IntelliGrow was also effective at managing massive amounts of data. Sensor data storage and retrieval took an average of 0.5 seconds, facilitating fast historical analysis from the website. Instant processing of envi ronmental inputs, finishing in under 1 second, enabled real-time irrigation adjustments, which were crucial for maintaining vine health. Scalability was proven as the system could accommodate multiple ESP-32 units across various field sizes without any decline in performance, making it suitable for both small- and large-scale farms. Farmers could easily assess the efficiency of the irrigation techniques supported by the devised system. Security measures, including encryption and authentication ensured data integrity, with no breaches recorded during testing, confirming the usability of the cloud-based strategy.

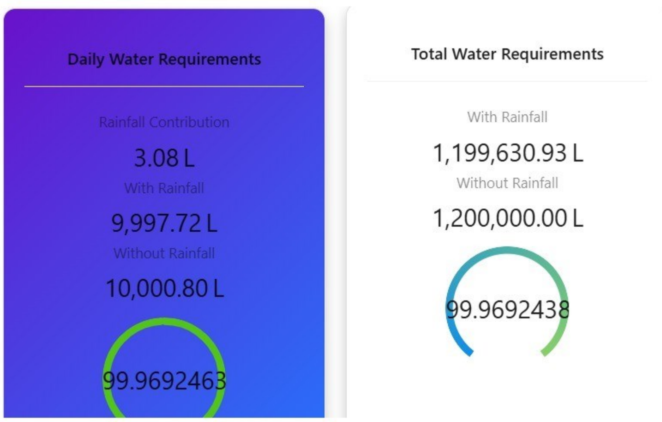

Fig. 3. Dashboard Display illustrating daily water requirements and total water requirements

C. IOT Device Performance

The ESP-32-based IoT product demonstrated strong perfor mance in its key features. Sensor accuracy was high, with soil moisture readings deviating by less than 2% from reference values, while temperature and humidity sensors responded sen sitively to environmental changes. Communication efficiency was nearly perfect, with virtually no data loss over MQTT, ensuring reliable transmission to the cloud. The relay-driven pump control functioned seamlessly with minimal leakage, delivering water exactly as predicted by the ML model. Power consumption remained low, allowing continuous operation with out frequent maintenance. These attributes highlight the device's reliability and accuracy in operational settings.

D. Comparison with Traditional Methods

Compared with traditional irrigation, IntelliGrow demon strated significant advantages. Water savings of 40% were achieved through adaptive scheduling versus static timers. Crop yields improved substantially, with maize achieving a 15% increase and tomatoes achieving a 12% increase due to optimal moisture maintenance. Labor efficiency saw a nearly 70% boost due to automation, which reduced the need for manual monitoring and allowed farmers to focus on other agricultural tasks. These results establish IntelliGrow as a superior option, optimizing resource utilization and enhancing sustainability in modern agriculture.

VI. Discussion

During the test runs of IntelliGrow we detected how exten sively this technology would reshape crop cultivation methods in a positive direction. The irrigation technique cut water usage by between 30-40% compared to regular watering methods because it tracks soil moisture in real time using machine learning to construct personalized watering schedules. These agricultural areas depend on every drop of water so this ad- vancement ex ceeds their conservation needs while supporting environmental sustainability goals. The system perfected the soil moisture level which caused crop yields to soar so maize

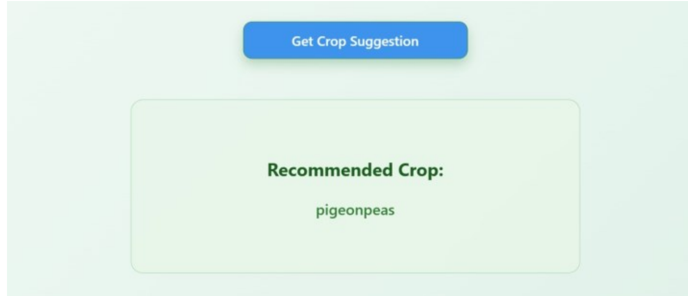

Fig. 4. Dashboard Display illustrating the crop suggestion feature

yields jumped 15% while tomatoes yields increased 12%. Cloud processing finished tasks using seconds of time and maintained 98% uptime which proved its ability to manage everyday work smoothly. The 90% of participants using the web interface praised its simplicity because it provided real-time data and direct control which eliminated guesswork from their agricultural operations. The farmers received great benefits from electronic recommenda tions which terrorized their crops based on weather patterns and soil conditions alongside automated processes reducing work duration by 70% and granting them valuable additional time for additional activities. The system transforms the operations of small farmers in a revolutionary way. Internet access serves as a critical foundation for this system but unstable wireless communication can disrupt its operation in rural areas with poor network coverage and poor maintenance of the sensors may cause interpretation issues.Costs involved with purchasing the ESP-32 device might deter price-sensitive farmers from the beginning despite potential long-term savings while cloud data storage needs robust security measures. Despite being a positive advancement for smart agriculture IntelliGrow needs additional improvements to lower the equipment costs and make data storage more accessible to farmers.

VII. Conclusion and Future Work

Reflecting on IntelliGrow's story and it is clear like this system has a lot to provide farmers wanting to be able to grow considerably more with significantly less. Our three month trial demonstrated it reducing water use by 30-40% versus conventional configurations, driven by real-time sensor information and a civilisationist machine erudition substitute that surely tells what crops need– no additional, no lenient. Yields also rose, with maize increasing by 15% and tomatoes by 12% showing it's moving beyond water saving to growing healthier plants and that 98% reliability saw it all keep ticking along as it should. Farmers adored the web platform– 90% said it was a piece of cake to work with, giving them a ringside seat to their fields and useful agronomic advice that reduced guess work, meanwhile automation took 70% of the labor out of their workload, a big plus, especially for people who are fighting to be all-part-time. This is not just a techno reveal, it's a real executable step towards sustainable farming, water poverty and yields all in one go, iot, cloud power and ai that all function together. But there is still some leeway to play with: the Internet dependency can strand remote farms, a one-time spent for setup could hurt slightly we have to keep those cloud servers sleight hand tuned. Looking forward, we look forward to inhaling some serious machine learning with more sophisticated alks- think 5-year weather forecasts to stay one step ahead of a drought or a flood. Including sensors for nutrient or pH of the soil could complete the picture, and a mobile app with voice commands could make it even simpler for the farmers to keep up to date. IntelliGrow already has some good ties with big smart farm systems– like pest control or fertilizer systems– perhaps this makes it a one-stop, while making it easier with simpler plug and-play options or local agency pilot runs could get it out the door further.

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