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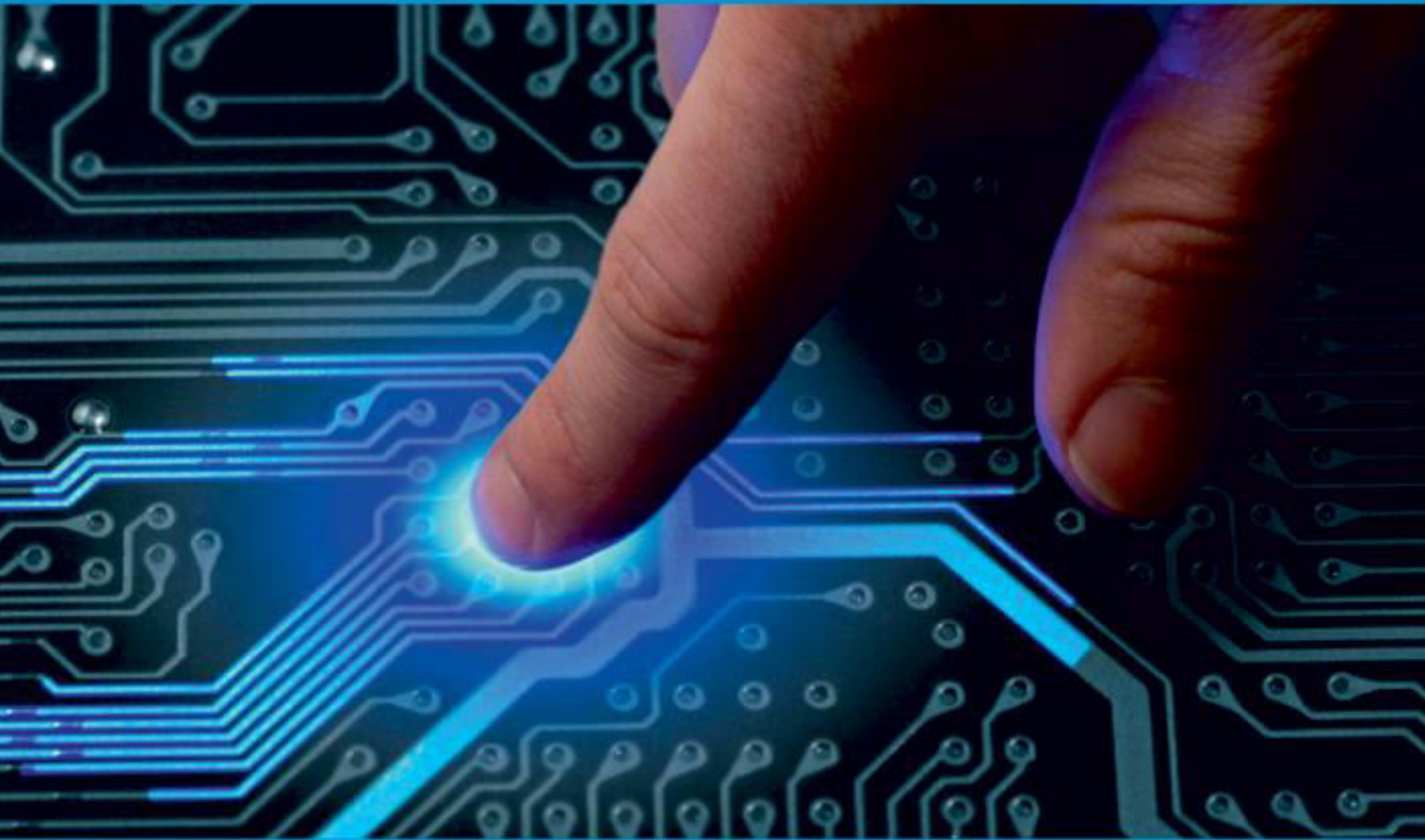

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Leveraging IOT and Cloud Computing for Smart Agriculture: Enhancing Irrigation and Resource Management

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ABSTRACT: Rising food demand, scarce water supplies, and the effects of climate change are just a few of the major issues facing the agriculture sector. These problems are frequently not adequately addressed by conventional farming methods, underscoring the need for sophisticated, technology-based solutions. In order to enhance agricultural methods, sustainability, and resource efficiency, this study presents an Internet of Things (IoT)-driven smart agriculture architecture that integrates cloud computing and renewable energy. The system combines Arduino and ESP8266 microcontrollers with state-of-the-art sensors, including TMP36 for temperature, PIR for motion, and gas sensors. These elements make it possible to continuously monitor vital environmental parameters like temperature, humidity, soil moisture, and levels of dangerous gases. The gathered data is transferred to the Thing Speak cloud platform for MATLAB analysis, yielding useful insights to improve irrigation accuracy and efficiently manage resources. The system is feasible for isolated or water-limited areas without access to traditional electricity thanks to its solar-powered configuration. Scalability and operational reliability are improved with the NI Compact RIO controller and affordable Wireless Sensor Networks (WSNs). The technology maximizes agricultural output and reduces water waste by optimizing irrigation schedules through the use of weather predictions and big data analytics. When compared to conventional approaches, tests on a real-world prototype revealed water savings of up to 70%. Additionally, using renewable energy promotes environmentally responsible farming methods by reducing expenses and carbon emissions. In order to solve important global issues like food security, climate resilience, and water management, this study presents a reproducible paradigm for modernizing agriculture. The findings highlight how IoT-based solutions can revolutionize the shift from traditional farming to scalable, adaptive, and sustainable agriculture Solutions.

KEYWORDS: Smart agriculture powered by the Internet of Things (IoT), cloud computing, renewable energy, resource optimization, precision irrigation, wireless sensor networks (WSN), Thing Speak cloud platform, Temperature sensor (TMP36), motion sensor (PIR), gas sensor, Arduino, ESP8266 microcontroller, MATLAB data analysis, Big data analytics, sustainability, water saving, soil moisture monitoring, and environmental monitoring.

I. INTRODUCTION

Human society has been built on the agricultural sector, which has shaped the world economy, the supply of food, and socioeconomic advancement. It is important for maintaining livelihoods, feeding populations, and promoting economic stability. In order to meet the increasing demands of a growing population, agriculture has evolved throughout millennia from traditional ways to creative ones. Climate change, depleting water supplies, and rising food demand are some of the major issues facing the industry today. The urge to increase food production despite scarce land and water exacerbates these problems. Food production must rise by 70% in order to meet the world's projected 9.7 billion people by 2050 (FAO, 2017), which calls for the use of cutting-edge technologies to ensure future food supplies.

In order to increase production and sustainability, the agricultural industry is presently undergoing a significant transition through the integration of new technologies like machine learning, precision farming, and the Internet of Things. These developments come after the Green Revolution's notable successes, which raised yields by using high-

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yielding crop types and synthetic inputs. However, these techniques led to problems including resource depletion, drug dependency, and environmental devastation. These problems are intended to be addressed by the move toward sustainable agriculture (SA), which encourages methods that increase output while protecting the environment for coming generations. SA is becoming more well-known throughout the world, particularly in areas like Morocco where agricultural plays a significant role in the economy and will account for 10.3% of GDP in 2022.

However, to guarantee effective farming and resource management, problems like water scarcity, soil erosion, and extreme weather necessitate creative solutions like smart technologies.

Technological Innovations: IoT and Smart Agriculture

The use of IoT in agriculture represents a pivotal step towards efficient and sustainable farming. IoT enables real-time monitoring of environmental and crop conditions, allowing farmers to make informed decisions. Sensors monitor soil moisture, temperature, humidity, and light intensity, with data transmitted to cloud-based systems for analysis and remote access. This technology enables farmers to optimize processes and enhance productivity.

Automation in farming is also made possible by IoT. For instance, automated irrigation systems minimize waste while guaranteeing that crops receive enough water by using sensor data to apply water at the right times and amounts. Furthermore, sensors for temperature and humidity can forecast disease or insect outbreaks, allowing for preventative action. Motion sensors protect infrastructure and crops by detecting animals or attackers.

Better resource management is another benefit of IoT. Water scarcity challenges in places like Morocco, where irrigation uses 75-87% of total water resources, are addressed by IoT-enabled water monitoring, which drastically lowers water use. Farmers can improve irrigation schedules and save water by using real-time data. In order to reduce the negative environmental effects of farming operations, IoT systems also incorporate renewable energy sources like wind turbines and solar panels.

By evaluating sensor data and producing useful insights, machine learning (ML) expands the potential of the Internet of Things. Machine learning algorithms are able to predict crop yields, suggest when to plant and harvest, and identify early indicators of pests or illnesses. Farmers may minimize environmental effects, cut expenses, and maximize productivity with these data-driven strategies. IoT, cloud computing, and machine learning give farmers strong tools to modernize agriculture.

1. Opportunities and Difficulties in Smart Agriculture:

Despite its advantages, smart agriculture faces several challenges. Small-scale farmers' access is restricted by the high cost of IoT devices like sensors and drones, particularly in poor countries. Farmers who are not familiar with these innovations face extra challenges because integrating new technologies frequently calls for knowledge and training.

Another challenge is connectivity. The transfer of real-time data to cloud systems is hampered by the unreliability of internet in many rural regions. Even while certain locations have better access thanks to 4G and 5G networks, many areas are still underserved.

IoT systems produce vast amounts of data, which necessitate effective tools for interpretation, making data management another difficulty. To maximize IoT insights, farmers require software that is easily available and easy to use.

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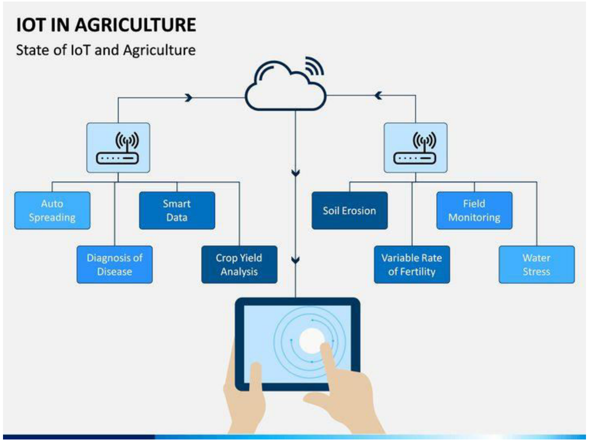

Figure 1: IoT Integration Flow Chart for Agriculture

By using IoT devices and cloud networks to optimize agricultural operations, the accompanying flow chart demonstrates how IoT and smart agriculture systems enable better water management and sustainable farming.

II. RELATED WORK

Agriculture has been significantly impacted by recent technology developments, especially in the areas of water management, energy efficiency, and productivity increase through the use of cloud computing, renewable energy, and the Internet of Things. In order to produce farming systems that are more sustainable and efficient, a number of academics have created creative solutions that combine these technologies.

A middleware method was created by Qiu et al. (2017) to gather data from several sensors. Their study concentrated on combining various data sources and enhancing processing effectiveness using heuristic techniques, which proved crucial for handling diverse sensor data in large-scale agricultural systems.

Wali et al. (2018) used Arduino and Raspberry Pi to create an affordable data collecting system. Through the integration of digital and analog sensors, amplifiers, and Python scripts, they demonstrated how this system may reduce operating costs and maximize energy use in agricultural situations.

An IoT-based continuous health monitoring system that can be used in agriculture for crop health evaluation was presented by Banerjee et al. (2018). Their method, which combined sensors and machine learning, produced predictions based on real-time data that aid in improving agricultural techniques.

A digital speedometer with a mobile notification system for cyclists was proposed by Kondamu et al. (2020), demonstrating sensor-based solutions that have applications in agriculture, specifically in real-time monitoring and well-informed decision-making.

IoT-enabled power systems that made use of renewable energy sources, such as solar, wind, and hydro, were investigated by Singh et al. (2020). In order to support IoT devices in remote agricultural settings and improve sustainability, their findings highlighted the importance of integrating clean energy.

In their study of new smart water technologies, Gupta et al. concentrated on the Internet of Things' potential to address agricultural water scarcity. They emphasized that real-time water monitoring is a useful technique for enhancing irrigation efficiency and water consumption efficiency. Damas et al. proved the advantages of technology-driven solutions by demonstrating an automated irrigation system that can cut water usage by up to 60%.

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The AGRI2L system was created by Kadar et al. to track water levels and find leaks. In line with IoT-driven advancements in smart farming, their low-cost, real-time method improved the management of water resources.

Larios et al. looked into the potential of combining biology with IoT to reduce irrigation water loss. Their strategy, which was based on chemical sensors, offered a practical means of ensuring sustainable practices and water conservation.

Macaroni et al. divided smart irrigation systems into categories such ICT for management and evapotranspiration-based estimate. Their research provided a thorough summary of developments in precision irrigation and its uses.

In order to maximize water use, Giusti et al. created a fuzzy logic-based irrigation control system that makes use of predictive soil moisture models. When compared to conventional methods, their results showed better water conservation.

Wireless Sensor Networks (WSNs) were used by Zhu et al. to introduce agricultural environmental monitoring systems. Their solution demonstrated flexibility in remote locations, allowing for precise and instantaneous data collection in situations where traditional methods are less successful.

Dasgupta et al. developed a unified model that offered real-time agricultural advice by combining IoT, WSN, and AI technologies. Precision agriculture has advanced thanks to their deep learning-enabled drone crop recognition system, which achieved high accuracy and enhanced agricultural decisions.

The Smart & Green system was created by Campos et al. using Internet of Things sensors to forecast soil moisture and maximize irrigation. Their innovation dramatically decreased water consumption, highlighting the potential of IoT in resource conservation.

An IoT-based irrigation and field monitoring system was put into place by Patil et al. Their solution provided real-time analysis by linking sensors to a cloud platform, which helped to modernize agriculture and improve decision-making.

WALL e SMART, an IoT and cloud platform for agricultural management, was presented by Roukh et al. Their system's ability to interpret real-time agricultural data effectively shows promise for increasing output and optimizing resources.

An Internet of Things system for greenhouse monitoring was presented by Kodandaramaiah et al. Their technique yielded actionable insights that could be implemented on farms of different sizes by gathering environmental data and storing it on cloud servers.

Using cloud computing, embedded technologies, and the Internet of Things, Morchid et al. created a smart irrigation system that allows for real-time monitoring. Their strategy demonstrated its efficacy in resource conservation by reducing water usage by 70%.

In conclusion, significant advancements in agricultural resource management have been fueled by the convergence of IoT, cloud computing, renewable energy, and machine learning. These studies demonstrate how these technologies can be used to maximize energy and water use, boost production, and advance sustainability. Building on this work, our study aims to develop an open-source, solar-powered, cloud-integrated Internet of Things platform that will solve existing constraints and provide small and medium-sized farms with scalable smart farming solutions.

III. METHODOLOGY

The goal of the project is to develop and deploy a smart irrigation system that makes use of cloud data processing, renewable energy sources, and Internet of Things (IoT) technology. By automating irrigation procedures based on real-time environmental data, the main objective is to improve water management in agriculture. IoT-based sensors, wireless connection, cloud integration, the use of renewable energy sources, and intelligent irrigation control are some of the main elements that make up the technique. The methodology is described in depth in the parts that follow.

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IoT Setup and Sensor Deployment:

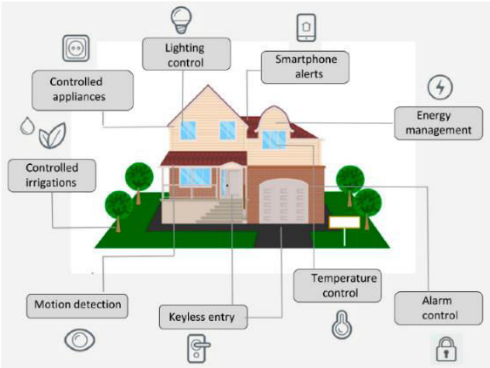

Fig. 2: Sensor deployment and IOT configuration

Various sensors are installed throughout the agricultural field in the first step. These sensors are essential for gathering data on temperature, soil moisture, and other environmental parameters that have a direct impact on irrigation requirements in real time.

Temperature Sensors:

Figure 3: Temperature sensor

Because TMP36 sensors are dependable and compatible with microcontrollers, they are utilized to measure the ambient temperature (Fig. 3). In order to adjust irrigation schedules to crop needs and seasonal conditions, temperature monitoring is helpful.

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Soil Moisture Sensors:

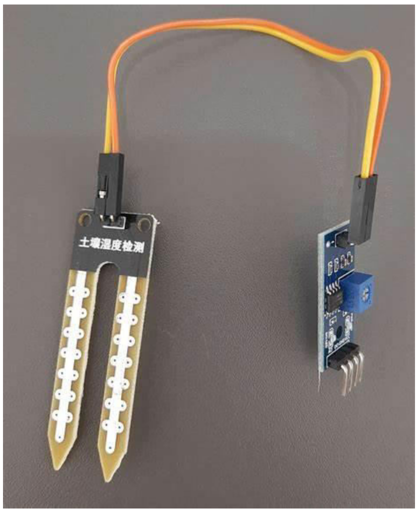

Figure 4: Sensor for Soil Moisture

The field's hydration levels are regularly monitored by soil moisture sensors placed throughout it. To maintain the ideal soil water content, irrigation is automatically started when the moisture level falls below a predetermined threshold.

Additional Environmental Sensors:

Fig. 5: Sensor configuration outside

To improve irrigation choices, more sensors are added, such as those for weather detection (humidity, rainfall, and air quality). Determining irrigation needs in real time requires the use of these environmental indicators.

An Arduino microcontroller, chosen for its compatibility and affordability, interfaces with the sensors. Sensor data is wirelessly communicated through the ESP module after being sent to the Arduino's Tx pin. The ESP module requires 3.3V and uses a voltage divider circuit for compatibility, but the Arduino is powered by a 5V source.

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Wireless Communication and Data Transmission:

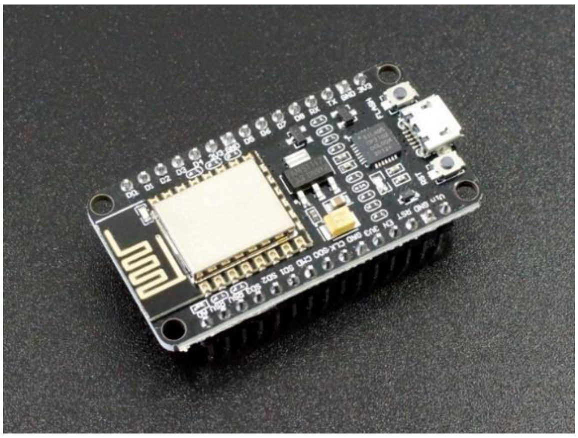

Figure 6: ESP module

To send data wirelessly to the cloud, the ESP module (ESP8266 or ESP32) is required. Because wireless communication does not require physical connections, the system is scalable and adaptable.

The system uses ZigBee for local networks and GPRS for long-distance communication in wide areas. Robust data transmission across various agricultural setups is ensured by these complimentary protocols.

Processing and Storing Data in the Cloud:

The Thing Speak cloud platform stores and processes sensor data that is transmitted by the ESP module. Features including data storage, analysis, and visualization are included in Thing Speak. Data from several sensors placed around the field is handled via a dedicated channel for smart agriculture.

Thing Speak makes MATLAB-based analysis possible, turning gathered data into graphs and useful insights. Temperature and moisture trends in the soil are shown over time. Predictive irrigation changes depending on rainfall probability are made possible by integration with external weather forecasting services such as Open Weather Map.

The system manages sizable datasets gathered from external sources and sensors by utilizing Big Data principles. Real-time analysis and decision-making assess variables including soil moisture content and weather predictions to improve irrigation schedules.

Intelligent Irrigation Control System:

The system's capacity to intelligently regulate irrigation schedules is its key component. The following steps are part of the process:

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Soil Moisture Monitoring:

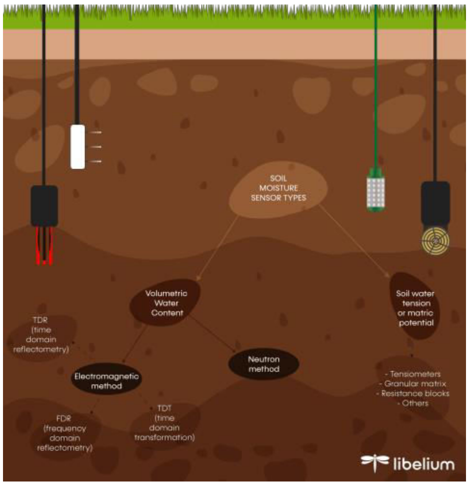

Fig. 7: Soil Monitoring Configuration

Using sensor data collected across the field, the Soil Moisture Average (SMA) is continually computed. To reflect current soil conditions, this average is updated on a regular basis.

Weather Forecast Integration:

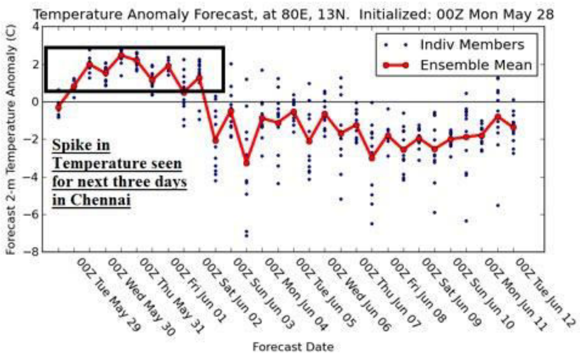

Figure 8: Analysis of Weather Forecasts

The method looks at rainfall probability projections if SMA drops below a predetermined minimal threshold. Irrigation thresholds are changed to avoid overwatering if there is an 80% likelihood of rain within three hours.

Irrigation Activation:

The system turns on irrigation if there is little chance of rainfall and SMA stays low. In order to reduce waste and guarantee adequate hydration, water is provided for a predetermined amount of time or until the soil moisture level reaches the intended maximum threshold.

Dynamic Adjustments:

Schedules for irrigation adjust dynamically to the situation, maximizing water use for changing crop needs and weather patterns.

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Renewable Energy Integration:

The technology uses solar energy to improve sustainability. The sensors, Arduino, ESP, and other parts are powered by electricity produced by solar panels. In order to sustain operations during periods of low solar power, excess energy is stored in lithium-ion batteries, which have a 3.3 kWh capacity.

Efficient energy distribution is guaranteed by an Energy Control Unit (ECU). When battery reserves are low, the ECU smoothly transitions to grid electricity while giving irrigation pumps priority over stored energy.

Data Flow and Visualization:

Sensor data travels smoothly to user interfaces and the cloud:

1. Data Collection: The Arduino processes the data that sensors continuously collect.
2. Wireless Transmission: Data is sent to the Thing Speak cloud via the ESP module.
3. Data Processing and Visualization: Thing Speak uses MATLAB to visualize patterns, allowing farmers to monitor temperature, rainfall probability, and soil moisture.

Scalability and Adaptability:

Farms of various sizes can use the system because it is scalable. Additional sensors or connections to several farms are made possible by its support for modular expansion. Options for customization allow the system to be tailored to certain soil types, crops, and layouts.

While ZigBee efficiently serves smaller regions, GPRS guarantees long-distance connectivity for big expanses. Power management, sensor location, and communication protocols may all be changed thanks to the system's flexible design, which guarantees that it works in a variety of farming environments.

IV. RESULT

According to the sources, the results of putting smart agriculture systems into place a strong emphasis on resource optimization via IoT-enabled technology, data-driven decision-making, and real-time monitoring.

1. Temperature and Humidity Patterns:

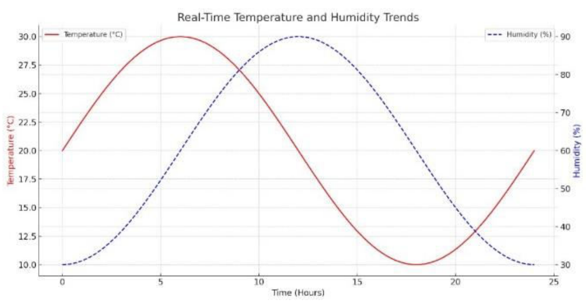

Figure 9: Temperature and humidity graph in real time

Daily changes typical of intelligent agricultural settings are depicted in a graph that shows temperature and humidity patterns over a 24-hour period. The TMP36 sensor records temperature variations, with a sinusoidal curve that peaks at 30°C during the day and falls to 20°C at night. The humidity shows a negative trend, peaking at 60% at night and falling to 30% during the day. Since plants need less water in cooler, more humid weather, these findings are essential for modifying irrigation schedules. This kind of data integration guarantees effective use of resources, promoting plant

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development without wasting any. Precision agriculture relies on real-time environmental tracking to maintain ideal crop growth conditions and respond to changing conditions.

2. Soil Moisture and Rain Predictions

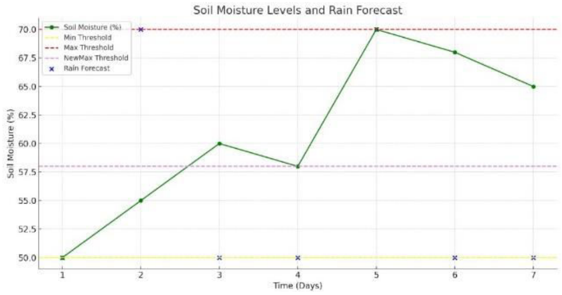

Figure 10: Rain forecast and soil moisture level graph

Weekly variations in soil moisture and the impact of rain projections are depicted in a graph. The minimum threshold (50%) and maximum threshold (70%) for soil moisture levels are different. The technology reduces the threshold range to 50%–58% when rain is expected (shown in blue), saving water by stopping irrigation. Rainfall, for example, naturally increased moisture levels on the third day. This dynamic irrigation system exemplifies how soil sensors and weather forecasts work together to meet plant hydration requirements while conserving water. It demonstrates the system's capacity to react sensibly to environmental factors, fostering sustainability by reducing water waste and maintaining crop health.

3. Reservoir Water Levels:

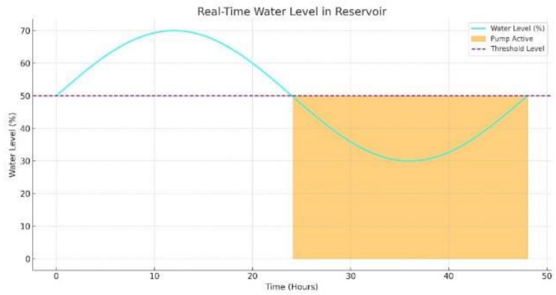

Figure 11: Reservoir water level graph in real time

This graph shows two days' worth of reservoir water level monitoring. As water is used and refilled by irrigation pumps, levels change. Pumps are activated by the system when levels fall below 50%, as indicated by orange highlights that represent pump functioning. For example, steady water levels at night save energy by lowering demand and requiring fewer pumps. By guaranteeing steady water availability, this automated system avoids overflow and underwatering. Threshold-based monitoring simplifies water management and protects crops. The system's ability to adjust reservoir levels improves sustainability and operating efficiency, assisting with resource management and agricultural productivity.

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4. IoT Data Visualization Platforms:

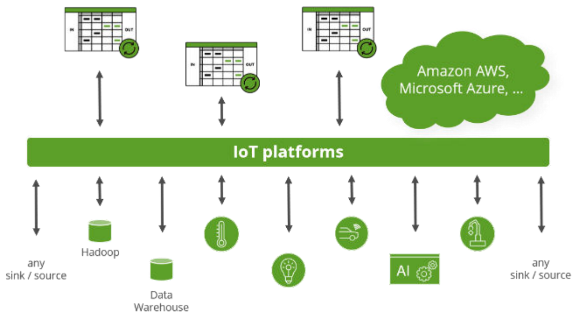

Figure 12: Visualization of IOT data

To show gathered data, the systems make use of IoT platforms like Thing Speak and Node-RED. These technologies let users keep an eye on things like water levels, soil moisture, temperature, and humidity in real time. Thing Speak helps with irrigation planning by producing line graphs that show temperature variations over time. Node-RED facilitates data-driven decision-making by providing rain forecasts and soil moisture thresholds. Regardless of technical expertise, farmers can readily understand complex data thanks to these user-friendly interfaces, which increases the systems' usefulness and uptake.

V. CONCLUSION

An important step toward more effective and sustainable farming methods is the incorporation of IoT and smart technology in agriculture. These technologies improve water and energy use while increasing productivity through the use of automated systems, real-time data collecting, and predictive analytics. Research shows how adaptable they are for a range of agricultural uses, including as monitoring temperature and humidity, controlling soil moisture, and managing reservoir water. By modifying irrigation schedules in response to rain projections or preserving soil moisture levels within optimal thresholds, these systems dynamically adjust to changes in the environment. Due to the low cost of IoT devices like wireless sensors and Arduino microcontrollers, small and medium-sized farms can now use these systems. Additionally, using renewable energy sources like solar panels reduces their negative effects on the environment and promotes international sustainability efforts. These technologies' relevance in contemporary farming is shown by their demonstrated capacity to improve resource management and increase agricultural outputs. But putting these systems into practice also highlights the necessity of constant innovation to get over obstacles such limited scalability, adaptation to different crop varieties, and interaction with sophisticated prediction frameworks.

VI. FUTURE PROSPECTS

Future advancements in smart agriculture ought to focus on increasing the IoT-driven systems' scalability and capabilities. Incorporating artificial intelligence (AI) and machine learning (ML) could lead to predictive models that forecast weather patterns, pest infestations, and crop yields. Better resource optimization and proactive decision-making would be made possible by such models, which are based on historical and current data.

Furthermore, expanding sensor networks to incorporate variables like pest activity and soil nutrient levels would offer a more thorough comprehension of agricultural ecosystems. Adoption of cutting-edge communication technologies, such as 5G networks and LoRa WAN, could greatly improve data transmission reliability, particularly in rural agricultural areas.

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