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Smart Agriculture Using IoT Sensors and Crop Suggestion System

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Abstract

Smart Agriculture promotes modern technology use to improve efficiency and productivity while decreasing the waste of resources. This research presents an example of the implementation of the Smart Agriculture concept. It features the use of Internet of Things (IoT) Sensors and a Crop Suggestion System, developed using the ESP32/Arduino boards and agricultural sensors. The Smart Agriculture System being developed in this research will be able to continuously monitor key soil and environmental factors; in this case, moisture, pH, temperature and humidity, as well as NPK. The agricultural sensors will collect and send the measurements and the microcontroller will have the capability to assess the condition of the field and aid in making smart agriculture decisions. A crop suggestion system utilizes a set of rules to assess the soil fertility and environmental parameters to provide an appropriate crop suggestion. The crop suggestion, along with the sensor measurements, is displayed on a TFT Module. Performance tests showed excellent measuring, processing, and irrigation functionalities. The system prototype minimizes water waste, industrial effort, and improves the effectiveness of irrigation systems and smart agriculture practices.

Keywords: Smart Agriculture, Internet of Things (IoT), ESP32 Microcontroller, Automated Irrigation System, Soil Monitoring, Crop Recommendation System, Precision Agriculture, Embedded Systems.

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1. Introduction

Agriculture is an essential sector of the economy. It is imperative for the sustenance of the population. Rapid population growth, food demand growth, and changes in the climate are problems for productivity and resource management for the farmer. A lot of farming methods are labor intensive, and in a lot of cases, not only do farmers over irrigate, but they also fail to properly manage soil and ultimately affect their yields negatively. Because of this, the farming sector has to modernize and embrace new methods and ways of thinking to achieve sustained improvement in the productivity of the sector and the sustainability of the practices.

The IoT is one of the technologies that has been adopted in of smart farming and is doing very well. It allows for the use of sensors and other smart technology to collect and monitor environmental and situational data in real time. In farming, parameters such as soil moisture, pH level, temperature, humidity, and nutrients are critical to the growth of crops and the fertility of the soil. Mof farming technology has automated the monitoring of these parameters, which allows farmers to know the conditions of the field and assists them in making better farming decisions.

Automation in agriculture also minimizes manual efforts, reduces human errors, and helps improve water management practices. Smart irrigation can maximize the amount of water that is used by only offering this when required, meaning greater efficiency and less natural resource use, whilst allowing for crops to be healthy. Besides, smart crop recommendation methods help farmers choose appropriate crops according to land and environment conditions.

Traditional agriculture has been revolutionize into smart agriculture due to the amalgamation of IoT, sensor technology and automation. This technology offers rapid, durable, low-cost solutions for making agricultural production more productive and helping farmers to be more sustainable.

2. Literature Review

Due to growing needs of efficiency in agriculture, sustainable resource management and production means optimum agricultural productivity made smart agriculture an important area of research. Wearable technology, for example, allows agriculture to be monitored around the clock with sensor-based systems that continuously detect environmental conditions such as soil moisture content, temperature levels, humidity levels and nutrient content 5. These systems, enabled with IoT devices, assist farmers in making better choices about irrigation, fertilization, and farming tasks while minimizing manual labor and maximizing efficiency. Collecting real-time field data and enabling automated monitoring processes is a prime role of wireless sensor networks [6]. [9].

With the advent of cloud computing capabilities and communication technologies, IoT for agriculture has gained greater extensibility through remotely storaging, processing, and accessing agricultural data [10] [12]. Smart farming systems utilize Internet of Things (IoT) devices and cloud platforms to obtain real-time context-aware information about the field environment, allowing the farmer to monitor their crops/ agronomic resources remotely [8].

These systems increase agricultural productivity, while reducing water consumption, use of energy and cost of operation. Moreover, the data assure supply chain management and traceability of production enhancement using IoT-based agricultural frameworks [8]. The importance of machine learning and artificial intelligence techniques is growing dramatically in agriculture, especially in crop recommendation and predictive analysis. Many researchers have presented automatic crop suggestion systems that consider the soil features, climate and environmental factors to identify crops suitable for cultivation [1] [2] [11].

These are based on machine learning algorithms to analyze vast agricultural datasets and provide precise suggestions for farmers. When IoT sensors are combined with machine learning models, agricultural data can be evaluated continuously in real-time to advance a better crop selection and monitoring [1] [2]. This would help farmers maximize productivity and minimize the exposure to errors from wrong crop decisions. Deep learning and more advanced data analysis approaches have also been explored in agricultural research. Applications of deep learning models in crop classification, disease detection, yield prediction and precision farming applications [4]. These smart methods can work on huge intricate agricultural databases with greater precision.

Moreover, considering the nature of the smart farming systems consisting of a huge data volume generated by IoT devices and sensors [7], big data technologies are also critical in this domain. Big data analytics extracts meaningful insights from real-time agricultural data to support predictive decision-making [7], resource optimization, and efficient farm management. According to survey studies on crop recommendation systems, noted [3, 1], IoT technologies along with machine learning algorithms, wireless sensor networks and cloud computing are the building blocks of modern smart agriculture systems.

Existing systems are primarily targeted at environmental conditions monitoring, automation of the irrigation process, and extraction of crops based on soil + climate parameters [1] [2] [3]. However, cost and scalability limitations associated with deployment, real-time processing of data, or integration of multiple technologies within a single platform complement earlier challenges faced by many agricultural systems. The literature review indicated that adopting smart agriculture systems with real-time monitoring and intelligent decision-making can greatly enhance the efficiency of farming along sustainability. Previous studies have demonstrated the effectiveness of autonomous wireless sensing nodes and IoT-based monitoring systems for precision agriculture applications. Panjagal et al. developed a soil condition management system using autonomous wireless sensing nodes for real-time agricultural monitoring [13]. The integration of IoT sensor networks with predictive analytics has also been demonstrated in sensor-driven monitoring applications [14]. Hence, the suggested technique is to develop a Smart agriculture using IoT Sensors and Crop Suggestion System, which combines sensor monitoring based on IoT technology with machine learning-based crop recommendation techniques to enable suitable agricultural management and boost crop productivity.

3. Methodology

The smart agriculture system presented is developed by integration the Internet of Things (IoT) technology with intelligent crop recommendation techniques to enhance agricultural productivity and efficient resource utilization. Methodology involves monitoring soil and environmental conditions continuously, automating irrigation control while proposing crop based on data analysis provided by sensors. The system consists of a multi-sensing apparatus at the field that collects various agricultural parameters such as soil moisture, pH level, temperature, humidity and nutrient content. These variables are used to analyze soil fertility, the need for irrigation and determine where specific agriculture can be practiced.

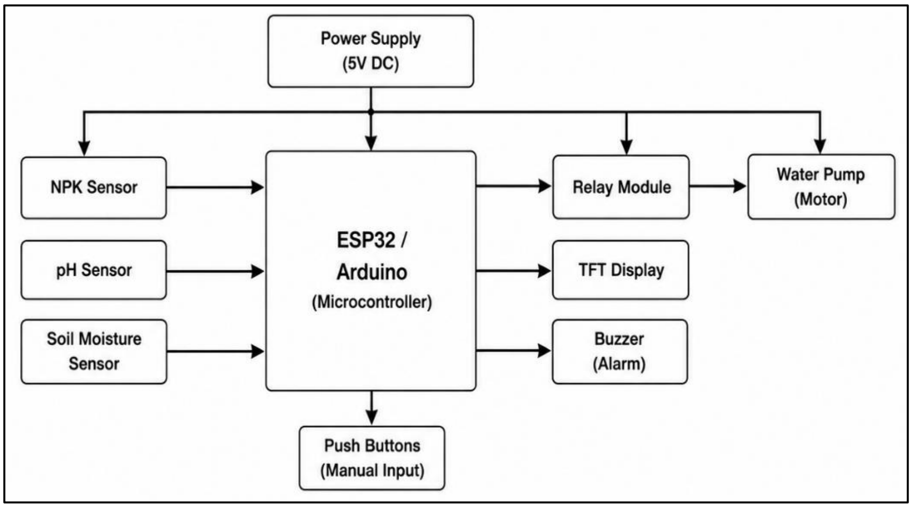

Figure 1. IoT-based Smart Agriculture System

Above Figure 1 demonstrates the physical integration of sensing, processing, and control components of the proposed IoT-based smart agriculture system.

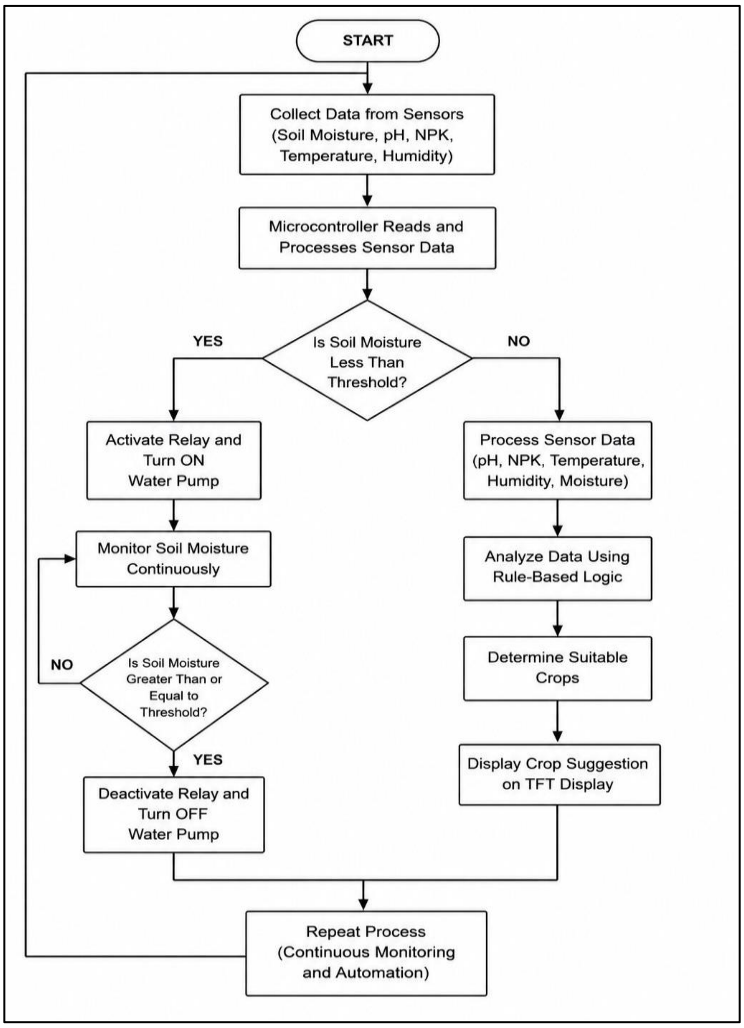

Figure 2. Overall Workflow of the Proposed Smart Agriculture System

The operational flow of the proposed system involving sensor data acquisition, embedded processing, irrigation control and crop recommendation is represented in Figure 2. It denotes the chain of sensor-decide-act workflow implemented in the system.

The sensing unit is made up of moisture, pH and NPK sensors which are connected to the ESP32/Arduino microcontroller that acts as a central processing unit. The sensors constantly read environmental and soil parameters and send all the information that is collected to the microcontroller, thus processing the data. Microcontroller reads the sensor values periodically, followed by analysis based on some predefined threshold conditions and rule-based logic.

The soil moisture percentage is calculated from the sensor readings using:

$$\text{Soil Moisture } (\%) = \frac{\text{Sensor Value}}{\text{Maximum Sensor Value}} \times 100 \tag{1}$$

Similarly, the temperature values obtained from the sensor are processed using:

$$T(\,^{\circ}\mathrm{C}) = \frac{V_{\text{out}} \times 100}{V_{\text{ref}}} \tag{2}$$

Rule-Based AutomationIn this system, automated decision making is implemented using rule-based logic This method employs conditional statements to decide on irrigation and crop suggestions from environmental sensor values. A microcontroller reads the sensed parameters, compares them to predefined threshold values, and automatically performs an action. They are easy to configure, trustworthy and somehow computationally cheap approaches that do not require fancy model training nor high processing power for embedded agricultural applications.

The general rule-based operation can be represented as:

IF <Condition> THEN <Action>

For example:

- If soil moisture $< 40\%$, then switch ON the water pump.
- If soil moisture $\geq 75\%$, then switch OFF the water pump.

The irrigation control process receives information from soil sensors and is automated through a relay module driving a water pump. The microcontroller turns ON the relay module to turn ON the water pump when soil moisture level goes below predefined value. The process continues until the soil reaches the necessary amount of moisture. When the required amount of moisture is achieved, the microcontroller automatically deactivates the relay module. This not only reduces water wastage but also enhances irrigation efficiency.

The irrigation control mechanism is mathematically represented as:

$$\text{Pump} = \begin{cases} ON, & M < M_{\text{threshold}} \\ OFF, & M \geq M_{\text{threshold}} \end{cases} \tag{3}$$

where M represents the current soil moisture value and $M_{\text{threshold}}$ represents the predefined threshold moisture level.

The methodology also comprises a recommender system which predicts crops using the analysis of environment parameters followed by rule-based approaches. The readings from the sensor are compared with crop condition datasets to determine which crops can be identified and grown under specific soil conditions. Crop recommendation is a description of the ideal parameters for a crop, and soil moisture, pH value, nutrient concentration, temperature and humidity together are considered in such descriptions.

The crop recommendation score is represented using:

$$CRS = w_1 S_m + w_2 pH + w_3 NPK + w_4 T + w_5 H \tag{4}$$

where:

- CRS = Crop Recommendation Score
- S_m = Soil moisture value
- pH = Soil pH value
- NPK = Nutrient content
- T = Temperature
- H = Humidity

- w_1, w_2, w_3, w_4, w_5 are weighting coefficients assigned to each parameter

The suggested crop information and sensor readings are presented directly on the TFT display module attaching to the microcontroller. The implementation of the complete system is by using Embedded programming in Arduino IDE. The ESP32 microcontroller maintains sensor interfacing, data acquisition, processing and irrigation control and display operations in a continuous loop. Table 1 includes a summary of the major hardware and software modules involved in the deployment of the proposed system. It consists of sensors, microcontrollers for embedded processing water control elements and the necessary tools for development in order to run a system.

Table 1. Hardware and Software Components Used in the Proposed System

Component	Purpose
ESP32 / Arduino Microcontroller	Central processing and control unit
Soil Moisture Sensor	Measures soil water content
pH Sensor	Measures soil pH level
NPK Sensor	Measures nitrogen, phosphorus, and potassium levels
Relay Module	Controls switching operation of water pump
Water Pump / Motor	Performs automatic irrigation
TFT Display	Displays sensor values and crop suggestions
Power Supply (5V DC)	Provides power to the system
Breadboard and Jumper Wires	Circuit connections and prototyping
Push Buttons	Manual control and input operations
Arduino IDE	Embedded system programming platform
Embedded C / C++	Programming language for system implementation

The overall implementation is a compact and an independent smart agriculture system which provides real time monitoring, automatic irrigation as well as intelligent crop recommendation for sustainable farming applications.

4. Results and Discussion

The proposed system successfully implemented and tested a Smart Agriculture system with IoT sensors and crop suggestion technologies, using an ESP32/Arduino board. The project setup included sensors for soil moisture, pH, temperature, humidity, and NPK levels. The prototype worked great, monitoring conditions and carrying out agriculture functions. Figure 3 shows the experimental validation setup of the developed smart agriculture system during real-time operation.

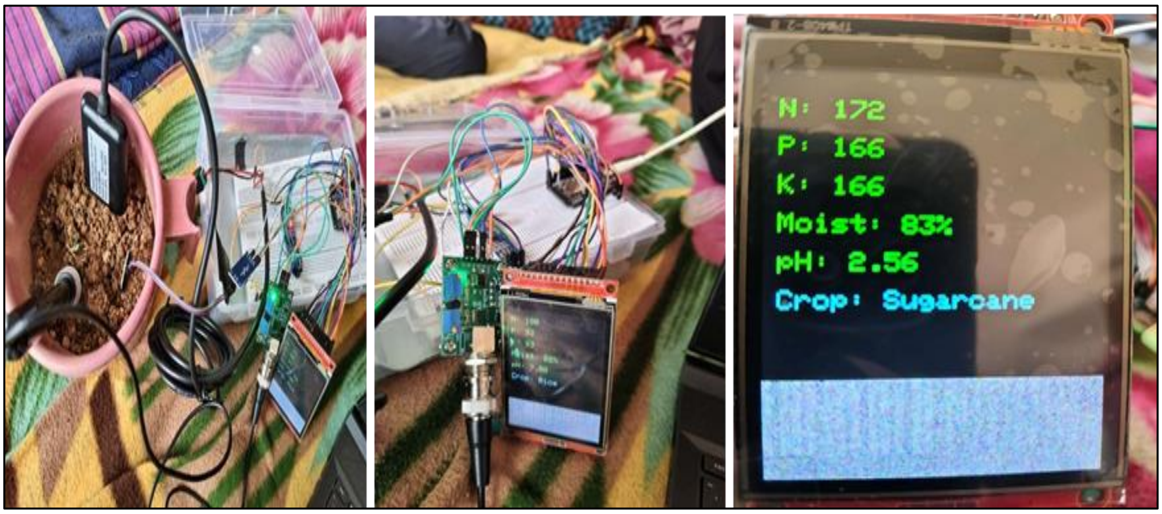

Figure 3. Experimental Setup and Real-Time Implementation Results

The sensor modules were read continuously during experimentation, and acquired environmental data was sent to a microcontroller for processing. The parameters sensed are displayed on the TFT display in real-time, so Soil and climatic conditions can be monitored continuously. During uninterrupted monitoring of the system, there was no measurable disruption in operation on either sensing or display functionality.

The automated irrigation mechanism performed well according to the specified soil moisture conditions. As soon as the soil moisture level fell below the threshold condition, the relay module automatically turned on its water pump for watering of soil. Once it hit the required moisture condition then microcontroller turned the relay over and finally Diode was turned OFF. This operation is completely automatic and greatly helped in irrigation management without requiring any manual work for unnecessary tasks. The experiment shows that at field scale automatic irrigation supports efficient water use and soil moisture control in agricultural systems.

The pH and NPK sensors were used to test the soil fertility parameters that are mandatory for an analysis and recommendation of crops. The data gathered from the sensors was processed through rule-based logic that was hardcoded in the embedded controller. As per environmental and soil information, the cropped recommendation system recommended crop production as well as showed all optimum crop information through TFT display module. The rule-based crop recommendation mechanism is capable in providing the crops based on different soil and nutrient conditions.

Embedded rule-based analysis is used for irrigation control and crop suggestion process which reduced computational complexity and helped to make real time decisions on microcontroller. The presented standalone implementation removed the requirement for external processing systems and resulted in a compact low-cost solution-a cost-effective sensing and analytic node that can be deployable in smart farming solutions.

After that, experimental results confirm how application of IoT sensors, embedded processing and automation can address the demands for precision agriculture. The proposed system had the potential to increase monitoring capability, automate irrigation operation, select crops intelligently and minimise manual work in agricultural management. In conclusion, the feasibility of the suggested prototype for smart agriculture applications realistically has been explored.

5. Conclusion

Smart Agriculture using IoT sensors and crop suggestion system in thought process the smart agricultural strategy proposed has been established and implemented for the efficient and intelligent farming process. The system also uses a wide range of agricultural sensors along with the ESP32/Arduino microcontroller for real-time monitoring of key parameters that include soil moisture, pH value, temperature, humidity and NPK nutrient levels. With this sensor data, automatic control of irrigation and crop recommendations are happened based on the soil and environmental conditions through relay-controlled water pump. Experimental results confirmed the validity of the developed system capable to carry out real-time monitoring and automation processes. This helped in increasing the effectiveness of minimising wastage of water and limiting manual intervention by providing water only when needed. The crop recommendation mechanism helps farmers identify the best crops according to soil fertility and environmental conditions in order to make informed agricultural decisions. Overall, the IoT sensors, embedded processing and automation encouraged irrigation efficiencies and sustainable farming practices while increasing agricultural productivity.

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