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Smart Soil Health Detection and Automated Irrigation System

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ABSTRACT :

Agriculture plays a vital role in the economy and food security, but improper soil management leads to reduced crop yield and soil degradation. This project is to create a Soil Health Detection Device that continuously keeps an eye on soil parameters and gives real-time advice on better farming practices.The system is constructed using an ESP32 microcontroller, which is placed in the soil to read moisture, temperature, nitrogen (N), phosphorus (P), potassium (K), and other critical soil parameters. The data is then sent to a mobile application, where farmers can see real-time soil health status. According to the soil type, the app recommends appropriate crops, moisture requirements, and proper fertilizers for maximizing soil fertility. Moreover, an automated irrigation system is included in the device. When the water content of the soil declines to below the optimum level, the system initiates irrigation to provide the best environment for the cultivation of crops while ensuring maximum water use efficiency.This project seeks to advance precision agriculture, increase crop yields, cut water loss, and encourage sustainable farm practices. Through the supply of real-time information and actionable recommendations, this system enables farmers to make the best decisions and maximize soil health for sustainable agriculture.

Key words: ESP32 microcontroller, Arduino Nano, sensors, relay, and water motor

Introduction:

Soil health is an essential component of agriculture, influencing directly the growth of crops, yields, and the productivity of a farm. Soil with a good composition of organic matter, nutrients, and beneficial microorganisms helps in plant growth. There are, various factors that can reduce the health of the soil over time. Excessive use of chemical fertilizers, improper irrigation practices, soil erosion, and monocropping can lead to nutrient depletion, reduced soil fertility, and poor water retention capacity. These issues not only affect crop production but also contribute to long-term environmental damage , health issues.

To overcome these issues, we Proposal a "Smart Soil Health Detection Device" that gives real-time feedback of soil status and helps farmers take better decisions. This device assists in the monitoring of key soil parameters like moisture, temperature, and nutrients.

The system also gives advice on appropriate crops depending on soils detected. In case a farmer wishes to plant a particular crop, the system provides advice on ideal levels of moisture and fertilizers to improve yields. This functionality aids precision agriculture, making soil conditions adequately prepared for the desired crops.

Besides, an automated watering system is incorporated to keep the soil in its ideal state of moisture. In case the moisture levels go below the threshold, the system triggers to supply water, thus averting dryness and allowing perfect growing conditions. This conserves water, saves labor, and enhances irrigation efficiency.

By employing this system, farmers are benefited in various ways: • Enhanced Crop Yield: Real-time monitoring and instruction assist in the cultivation of crops effectively. • Effective Resource Management: Water and fertilizers are utilized to the maximum, minimizing wastage. • Sustainable Agriculture: Soil health is maintained, resulting in long-term agricultural sustainability. • Time and Cost Reduction: Automation minimizes the necessity for manual soil testing and irrigation control.

Literature Survey

Ravesa Akhter Shabir Ahmad Sofi discusses the applications of IoT and wireless sensor networks (WSN) in precision agriculture, emphasizing different applications like real-time monitoring of the environment, automated irrigation, and prediction of crop disease. Some studies suggest scalable architectures, edge computing, and machine learning approaches to improve energy efficiency, processing of data, and decision-making. Major technologies such as LoRa, ZigBee, and cloud computing are enumerated as pivotal toward enhancing connectivity and analytics in smart agriculture. Future research challenges include network reliability, cost, and data integration, with advancements in IoT-based agriculture systems as the main focus.[1]

Haroon Ali Khan Musawir Ghani Farooq Shah Sher Shah emphasizes the of soil nutrient analysis in precision agriculture, highlighting the limitations of conventional soil testing approaches, as they consume time and are error-prone. IoT-based solutions such as sensors and microcontrollers such as Arduino and Raspberry Pi allow real-time measurement of soil parameters like pH, moisture, temperature, and NPK. Optical transducers and cloud integration for automated systems improve soil sensor-based fertility assessment and crop management. Also, chemical extraction procedures such as Mehlich-3, Olsen, and Kjeldahl are widely applied for precise nutrient measurement, supporting efficient soil management and enhanced agricultural productivity.[2]

Marcus Johansson compares Raspberry Pi Pico and ESP32-DEVKITM-1 for low-power applications on the basis of performance, availability, and power consumption. Though the Pico is more suitable to project requirements with regard to price and availability, the ESP32-DEVKITM-1 is typically superior in terms of specifications. The Pico's dormant and sleep modes use 0.8mA and 1.3mA, respectively, and would provide an estimated battery life of 2.1 months and 1.3 months, short of the five-year project requirement. More assessment, such as MicroPython deep sleep capabilities compared to C implementations, needs to be made prior to the selection of a new MCU.[3]

Shravan P. Wargantiwar, Aryan K. Gaddewar points out the combination of soil monitoring and testing systems with drones to transform precision agriculture, particularly in remote locations.Soil NPK, moisture, and temperature sensors in drones offer real-time soil analysis for enhanced decision-making efficiency. The system, with an Arduino UNO, Modbus module, ESP32 board, and NR24L01 module, provides smooth data communication and remote monitoring. The autonomous drone-based solution increases accessibility to soil diagnostics, maximizing resource management and increasing agricultural productivity. The method is a significant improvement in precision agriculture, making soil testing quicker, more efficient, and responsive to contemporary farming requirements.[4]

Ritika Srivastava, Vandana Sharma, Vishal Jaiswal, Sumit Raj discusses the role of IoT-based smart sensors in transforming agriculture by enabling real-time environmental monitoring.

The paper by Anand Nayyar and Er. Vikram Puri (2016) highlights how IoT enhances agricultural productivity through cost-effective and intelligent solutions, reducing wastage and improving efficiency. The proposed smart agriculture framework provides live data on temperature and soil moisture, allowing farmers to optimize farming practices. The research focuses on the importance of IoT research in agriculture to overcome challenges such as farm size constraints, climate volatility, and policy limitations to make farming sustainable and technology-based. [5]

Gilroy P. Pereira, Mohamed Z. Chaari and Fawwad Daroge agriculture cites improvements in IoT, sensor networks, and data analytics as the foundation for intelligent farming systems. Research indicates the use of wireless sensors, remote sensing technologies, and communication protocols for efficient monitoring of environmental parameters. Data-based methodologies such as machine learning improve decision support systems with optimized irrigation and nutrient application. Additionally, real-time data acquisition through IoT platforms has facilitated automated interventions with enhanced efficiency and crop health.[6]

Vijendra Kumar a, Kul Vaibhav Sharma a, Naresh Kedam b, Anant Patel, Tanmay Ram Kate a,Upaka Rathnayake d , revolutionizing agriculture through increased efficiency and productivity.

Wireless sensor networks (WSNs) and ZigBee protocols are utilized for real-time soil conditions, humidity, and temperature monitoring. Automated farming solutions, including polyhouse tracking systems and crop-tracking technologies, maximize growing conditions and yields. Additionally, GSM-based irrigation tracking and Bluetooth-enabled weather stations help farmers make data-driven decisions. IoT applications in animal health monitoring further demonstrate the technology's impact, enabling early disease detection and improved livestock management. [7]

Jayakumar R ,Karthikeyan S N,Naveen Perumal M,Methini M demonstrate that IoT-based smart agriculture, integrating Arduino technology with various sensors, significantly enhances real-time monitoring of soil moisture, humidity, and water levels.

Research indicates that such systems enable timely and precise irrigation, thus optimizing resource usage and boosting crop yields. Literature further emphasizes that remote monitoring via mobile applications empowers farmers to make informed decisions and improve overall productivity. Additionally, advancements in sensor technology and data analytics pave the way for more sustainable and profitable agricultural practices.[8]

Kaouthar Chetiouia, Ghizlane Orhanoub,Hicham Bensaidc, Ilias Cherkaouib, Youness Chibib focuses on the adoption of IoT technology in agriculture to enhance resource utilization and productivity by monitoring soil moisture, humidity, and water levels in real-time.

Research finds that smart sensor networks and mobile apps enable farmers with timely information, supporting better irrigation and nutrient decision-making. Researchers also note that such technologies contribute to sustainable farming practices, reducing water waste and promoting environmental conservation. Furthermore, the adoption of IoT-driven smart farming has been linked to improved food security and economic growth in rural regions .[9]

Varnit Goswami developed soil health monitoring systems that utilize optical transducers based on LEDs and LDRs to measure critical soil nutrients (N, P, K) in real time.

These systems integrate NodeMCU microcontrollers and IoT technologies to convert sensor data into digital readings, which are then displayed on local web platforms for easy analysis. Experimental results indicate that such devices can effectively quantify nutrient levels, enabling more precise fertilizer application and better crop planning. Overall, this innovative approach promises enhanced soil fertility management and more sustainable agricultural practices.[10]

Kapalik Khanal, Sandeep Chataut, Grishma Ojha, Umesh Kanta Ghimire.highlights the transformative potential of IoT-based systems for real-time soil health monitoring in precision agriculture.

Such systems combine several sensors—measuring moisture, pH, electrical conductivity, and levels of nutrients (N, P, K)—with sophisticated microcontrollers like the ESP32S3. These systems use different communication protocols such as Wi-Fi, GSM, and LoRaWAN for secure data communication from the field to central servers. The harvested data is graphically represented in easy-to-understand web interfaces, enabling farmers to make optimal, timely decisions to maximize yields and efficiency in the use of resources.[11]

Sujan Adak, Partha Pratim Maity, Nandita Mandal, Arkadeb Mukhopadhyay discusses the application of digital technology in soil health monitoring. It addresses the diverse components and methods applied in digital soil health monitoring, such as soil sensors, Internet of Things (IoT) devices, remote sensing, imaging methods, data analytics, and modeling. The paper also identifies the advantages and disadvantages of digital soil health monitoring.[12]

Proposed Methodology:

The proposal methodology adopts a systematic method for soil health tracking and automated watering, incorporating a combination of sensors, microcontrollers, and cloud storage. The system is set to operate autonomously while presenting precise and timely data to farmers, enabling them to make intelligent decisions to maximize agricultural output. The methodology has a number of major phases that include system design, sensor placement, data capture, processing, decision-making, and remote tracking.

The first phase involves establishing a reliable power supply to ensure uninterrupted operation of all system components. Like ESP32 microcontroller, Arduino Nano ,sensors, relay, and water motor. The ESP32 microcontroller acts as the central processing unit, handling data acquisition, analysis, and communication. The Arduino Nano assists in sensor-related tasks, ensuring accurate and efficient real-time data collection.

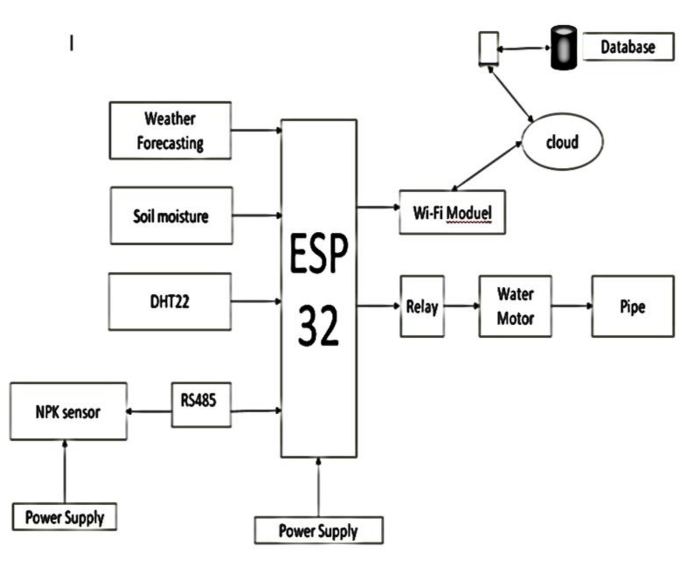
During the deployment of sensors ESP32 microcontroller, Arduino Nano ,sensors, relay, and water motor are placed in the soil to record important environmental factors.

The soil moisture sensor monitors moisture levels on a continuous basis, and update database on condition basis which is important for managing irrigation.

The DHT22 sensor records temperature and humidity values, which determine soil moisture storage and plant growth. The NPK sensor measures soil fertility based on the amount of nitrogen (N), phosphorus (P), and potassium (K) present, which are vital for plant nutrition. The weather forecasting module is incorporated to fetch real-time climatic information using an online API, which aids in optimizing irrigation scheduling according to forecasted rainfall and weather. After the sensors have recorded data, the data is sent to the ESP32 microcontroller for processing. The microcontroller analysis the data and checks it with pre-defined threshold values to analyze the soil's present status.

When the moisture level of the soil goes below the specified level, the ESP32 prompts a relay module to switch on the water motor and sprinkler system. The relay acts as an electronic switch to operate the motor, supplying water efficiently. As the water is absorbed by the soil, the moisture sensor continues monitoring the levels, and once the soil reaches the desired level of moisture, the relay turns off the motor to avoid overwatering. This is a cycle that maximizes irrigation management while conserving water resources while ensuring appropriate conditions for plant growth. An important feature of the system is the implementation of cloud-based storage and remote monitoring. The ESP32 comes with an onboard Wi-Fi module that allows wireless communication and enables real-time data transfer to a cloud database.

The cloud storage system keeps past records of soil health, which allows farmers to monitor long-term trends and make informed decisions. Farmers are able to access real-time reports of soil conditions using a specialized mobile or web app, where they are given advice on the choice of crop and application of fertilizers depending on the levels of soil nutrients. This aspect equips farmers with accurate cues to improve productivity and sustainability. The system also uses weather forecasting for optimized irrigation efficiency. When the weather module predicts a rain event in the near future, the ESP32 postpones irrigation to prevent overwatering, which leads to waterlogging and erosion of the soil. Through weather-based decision-making integration, the system guarantees that water is utilized efficiently without unnecessary irrigation, and environmental sustainability is enhanced. The system operates a coordinated workflow comprising sensor data acquisition, microcontroller-based processing, irrigation decision-making, cloud-based data logging, and remote access for the farmers. The process is automated, and the need for manual intervention is eliminated, and the farmers can attend to other agricultural responsibilities while their crops are watered and supplied with necessary nutrients.



By adopting this smart soil health detection and automated irrigation system, farmers benefit from improved crop yields, reduced water wastage, and optimized fertilizer application this (TES) productivity. The automation reduces manual labor while promoting sustainable agricultural practices. The combination of real-time monitoring, cloud-based data analysis, and weather-based irrigation control makes this system an advanced solution for modern precision farming. The convergence of these technologies guarantees effective soil health maintenance, leading to long-term agricultural sustainability and enhanced farm efficiency.

Results:

Sample Of Sandy Soil :

Parameter	**Values**
Soil Moisture	**9%(Soil is Dry)**
Nitrogen	**25 mg**
Phosphorous	**12 mg**

Potassium	**22mg**
Temperature	**30°C**

Soil is dry
Irrigation turn ON
Suggestion: This soil is able to grow crops like carrots, potatoes.

Sample Of Loamy Soil:

Parameter	**Values**
Soil Moisture	**31%(Soil is Moist)**
Nitrogen	**57 mg**
Phosphorous	**23 mg**
Potassium	**47mg**
Temperature	**22°C**

Soil is moist
Irrigation is OFF
Suggestion: This soil is able to grow crops like sugarcane, cotton,wheat.

Sample Of Clay Soil:

Parameter	**Values**
Soil Moisture	**74% (Soil is Wet)**
Nitrogen	**66 mg**
Phosphorous	**76 mg**
Potassium	**100mg**
Temperature	**15°C**

Soil is Wet
Irrigation is OFF
Suggestion: This soil is able to grow crops like cabbage sprouts, spinach.

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