Smart Agriculture Monitoring and Nutrient Management System with Disease Detection

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Abstract: By utilizing the technology that exists now, the paper focuses on enhancing the efficiency of agriculture and the agriculture system. Keywords: Agricultural resource management, Early disease detection, Crop improvement, Soil nutrient management the research theme tackles pressing agricultural problems like resource management, early disease identification and enhancing crop productivity. This system employs technologies such as IoT, Machine Learning, and image processing to control vital farming parameters. Soil moisture sensor, temperature and humidity sensor, disease detection camera module. These devices gather real-time information, and the data is processed and visualized using a user-friendly mobile application. To save water and keep the crop hydrated properly, automated irrigation is applied according to soil moisture level. The findings demonstrate that the resources tend to be used in a better way, identification of crop diseases occurs faster and the yield of crops has increased markedly. As a commercial product, it allows agronomists and farmers to make data-driven decisions, minimizing human labor, preventing waste of resources. Moving forward, the system will also involve the addition of more sensors to measure other soil characteristics, a wider data set of disease detection capabilities, and predictive analytics to forecast yields. The transformative nature of this work could lead to precision farming and sustainability, creating a much more resilient agricultural ecosystem.

1 INTRODUCTION

As the world's population grows and resources become scarcer, it becomes increasingly difficult to farm in a sustainable manner and to appease the environmentalists. Many complex challenges are not met well with traditional farming techniques, leading to inefficiency in water consumption, soil care, data collection, crop monitoring etc. The adoption of this technology aids in overcoming the limitations of agriculture, enabling farmers to engage in precision agriculture for optimum yield and sustainability. The research generates a new way of helping to increase the efficiency of farming through the real- time monitoring and automated systems. The system uses three main sensors which are soil pH sensor, soil moisture sensor and ultrasonic sensor. The soil pH sensor provides vital data regarding the soil's acid or alkaline nature: Information required when selecting crops in addition to favouring soil health. This is done through a soil moisture sensor which is used to monitor the moisture in the soil and irrigate as needed. Ultrasonic sensor for detecting plant height, giving information about the growth and health of the crop (Evans, R.G. and Sadler, E.J (2008)).

This framework based on IoT technology can execute real-time information collection and remote desk monitoring through a mobile application. Data have been bundled based on plant growth in order to provide farmers easy access to soil pH, moisture levels, etc. to make data-oriented decisions in agriculture using the app (Parimala Devi,et.al., 2022) The automated irrigation feature of this system operates the pump to water only when the soil moisture level is below a specific value, conserving water.(Boopathi Raja,et.al., 2024) Not only does it conserve water, but it also ensures that the crops are adequately hydrated for their healthy growth. This shows that technologies could change the old way of planting crops (Othman, M.F., Shazali, K., 2012). This allows for a streamlined approach to resource management, less wastage, and greater levels of production by targeting key metrics. It also provides a decentralized, scalable, cost-effective system that

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can be adapted to different farming environments. This approach not only addresses current challenges in agriculture but also paves the way for future advancements in smart and sustainable agriculture practices (Gutiérrez, J., et.al., 2023).

2 LITERATURE SURVEY

Sahasrabudhe M et.al (2023) proposed system eliminates the need for traditional monitoring and reduces the possibility of neglect-induced plant deterioration or by offering an automated way to guarantee optimal pH levels and soil moisture of the plants (Sahasrabudhe, M., et.al., 2023). Montazeaud, G et.al (2021) proposed technology saves a tremendous deal of time. While maintaining better accuracy compared to the manual method. Applications, including crop, wild species, and model organisms, its affordable price and small size make it perfect. This encourages such implementations where such resources are free and open access to all (Montazeaud, G., et.al., 2021). Pavel, M et.al (2019) developed a system using fourteen different color, texture, and form features gathered by creating a gray level support vector machine, and the co-occurrence matrix at which is utilized to identify disease; the system has an accuracy of 97.33% in classifying. As a result, environmental parameter analysis and disease classification help farmers efficiently track plant growth for increased output. (Pavel, M.I., et.al., 2019).

Kashyap, B et.al (2021) suggested the studies on different approaches, there is a trend in development of inexpensive, user-friendly, portable sensing systems. This will tend to effective crop and soil management, which will advance agricultural sustainability (Kashyap, B., et.al., 2021). Singh, G et.al (2022) recommended process for producing weekly WDI maps using easily accessible measurements is presented in this study. By selecting certain areas with greater water demand for the best water distribution to support health of crop and, eventually, maximum water-use productivity, these demand helps in water resource management (Singh, V., et.al., 2021). Sarkar, C et.al (2023) intended performance of the algorithms is frequently assessed using measures such as clarity, and F1 scores. Researchers searching for efficient ML and DL-based classifiers for leaf disease identification will find this review helpful (Sarkar, C.,et.al., 2023).

3 AGRICULTURAL MONITORING TECHNIQUES & ACCURACY

IoT, sensors, and machine learning have all contributed to advancements in agricultural monitoring. Ultrasonic measurement had the highest accuracy (97.33%), while leaf disease detection was between 84% and 87%. Future improvements will prioritize IoT and AI integration for precision farming. Table 1 shows the Smart Agriculture Methods and Accuracy Overview (2017–2023).

Table 1: Smart agriculture methods and accuracy overview (2017–2023).

Authors	Methodology	Year	Data Type	Accuracy
V Singh,et.al	Image Processing/Machine Learning (Image segmentation and soft computing for leaf diseases).	2017	Leaf images	84%
MI Pavel, et.al	IoT (Plant health monitoring with image processing).	2019	Plant images	85%
B Kashyap, et.al	Sensing (Soil moisture and nutrient monitoring in agriculture).	021	Soil samples	88%
G Montazeaud, et.al	Embedded Systems (Low-cost ultrasonic device for plant height measurements).	2021	26 sorghum genotypes	97.33%
S Raina, et.al	Image Processing (Techniques for detecting plant leaf diseases).	2021	Leaf images	86%
G Singh, et.al	Remote Sensing (Using soil moisture data to identify water demand).	2022	Satellite images	89%

M Sahasrabudhe, et.al	Embedded Systems (Arduino Uno for plant soil moisture and pH sensing).	2023	Soil samples	90%
C Sarkar, et.al	Machine Learning (Leaf disease detection using machine learning and deep learning).	2023	Various leaf images	87%

4 METHODOLOGY

The proposed system uses a structured methodology to optimize farming practices by leveraging IoT and sensor technology. The system is based on three major sensors: soil pH, soil moisture, and ultrasonic. The soil pH sensor measures the soil's acidity or alkalinity. The information needed for crop growth. Soil moisture sensor acts as a measure for the moisture level present in the soil so that when the moisture content is low enough, the irrigation is triggered accordingly. The ultrasonic sensor measures the height of the plant and serves a critical measure of crop development and health. The system heavily relies on the data collecting process. Each sensor regularly gathers data and sends it to a microcontrollerfor processing (Lee, W.-S., et.al.,2010).

The soil pH sensor shows a numerical value for either acidity or alkalinity, the soil moisture sensor measures whether the soil is wet or dry, and the distance between the plant and ultrasonic sensor is used to estimate plant height (Mowla, M.N.,et.al., 2023). The processed data is then wirelessly transferred to a mobile application through an IoT module, enabling the real-time remote monitoring of these conditions (Kirianaki, N.V.,et.al., 2002).

It also features an automatic irrigation system. A simple, tiny water pump is operated by the microcontroller when the microcontroller detects that the soil moisture level falls below the pre-defined threshold (Yin, H.,et.al., 2021).The pump automatically shuts off when moisture levels are optimal, saving water and surprising crops. The app also offers real- time data, which helps farmers easily monitor soil pH, moisture levels and plant height. Notifications are also sent out when soil conditions or irrigation triggers are not aligned, enabling fast-action responses.

This guide walks through the extensive testing and validation processes to ensure the system remained accurate and reliable. To ensure that sensors are functioning properly, sensor data are compared against manual measurements, while the automatic irrigation feature is tested for responsiveness and efficiency. The system will be expanded in the future with additional sensors for temperature, humidity or nutrient levels that will be integrated and predictive analytics that will estimate crop yields.

Thus, it allows the system to be capable of solving contemporary agriculture problems and contributing to sustainable agriculture (Yin, H.,et.al., 2021).

The Soil Moisture Index (SMI) is calculated to determine the soil's water content and guide irrigation decisions. The equation used is: (Poyen, F.B.,et.al., 2020)

$$\mathrm{SMI} = \frac{V_{moist} - V_{dry}}{V_{wet} - V_{dry}} \times 100 \tag{1}$$

Where V_{moist} is the current moisture reading, $V_{dry}$is the voltage for dry soil, and V_{wet} is the voltage for wet soil. When the SMI falls below a certain threshold, the irrigation system is activated. The condition for triggering irrigation is given by:

$$I_{on} = \begin{cases} 1, \text{if SMI} < \text{SMIthreshold} \\ 0, \text{if SMI} \geq \text{SMIthreshold} \end{cases} \tag{2}$$

In addition, the plant height is measured using an ultrasonic sensor. The height of the plant is determined by the formula:

$$H_{plant} = H_{sensor} - D_{measured} \tag{3}$$

Where H_{sensor} is the fixed height of the sensor from the ground, and $D_{measured}$ is the distance between the sensor and the plant. The soil pH is also an important parameter to assess the soil's suitability for crop growth. The pH status is categorized as acidic, neutral, or alkaline based on the following:

$$pH_{status} = \begin{cases} \text{Acidic, if pH} < 6.5 \\ \text{Neutral, if } 6.5 \leq \text{pH} \leq 7.5 \\ \text{Alkaline, if pH} > 7.5 \end{cases} \tag{4}$$

Finally, the Water Consumption Efficiency (WCE) is calculated to evaluate how effectively water is being used in irrigation:

$$\mathrm{WCE} = \frac{w_{used}}{w_{available}} \times 100 \tag{5}$$

Where W_{used} is the amount of water used for irrigation, and $W_{available}$ is the total available water. These equations form the foundation for automating the monitoring and management of key agricultural parameters, ensuring efficient use of resources and improving crop health.

4.1 Implementation

The Figure 1 displays a smart agriculture system built on Arduino Uno that includes moisture, pH, and ultrasonic sensors for monitoring. A tiny water pump, UV light, and LCD monitor automate irrigation and data visualization, while NodeMCU provides wireless control with software support for precision farming.

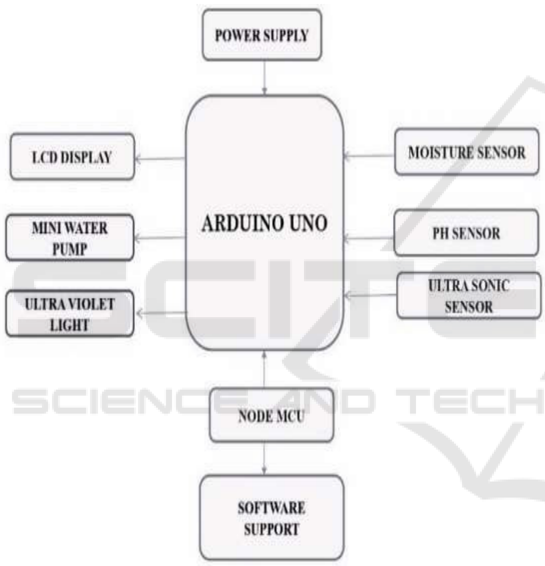

Figure 1: Block diagram of smart agriculture system.

Microcontrollers: The Arduino Uno is a microcontroller board built upon the ATmega328P that is commonly used for electronics programs, automation, and IoT applications. It runs at 5V and has 14 digital I/O pins (6 PWM), 6 analog inputs, and UART, SPI, and I2C connectivity. It features 32 KB Flash memory, 2 KB SRAM, and 1 KB EEPROM, and operates at 16 MHz. The board is programmed with the Arduino IDE using (Kondaveeti, H.K., et.al., 2021) USB Type-B connector and can be driven by USB, an adapter (7- 12V), or a battery. Its open-source nature and compatibility with numerous sensors make it suitable for both novice and advanced users of embedded systems, robotics, and smart agriculture. One open-source, inexpensive IoT platform is the NodeMCU ESP8266. It was first created by the Chinese business Espress if Systems and is now widely used by developers and enthusiasts working on IoT applications (Kondaveeti, H.K.,et.al., 2021). The ESP8266 Wi-Fi microchip, a potent, standalone SoC (System on Chip) that can manage networking features and run user-defined programs in a variety of programming languages, is the foundation of the platform (Xia, W.,et.al., 2014).

Sensors: Soil moisture sensors detect water content in soil, an important statistic for agriculture and the environment (Parimala Devi, M.,et.al., 2020). These sensors aid in optimizing irrigation, conserving water, increasing plant development, and monitoring environmental conditions. Soil moisture sensors are of three types: capacitive, resistive, and tensiometric, each with its own set of characteristics and specifications (Leib, B.G.,et.al., 2003). A pH meter sensor consists of two electrodes: a sensitive electrode made of special glass and a reference electrode. The electrode detects hydrogen ion activity in a solution, which is then used to calculate pH based on the voltage difference between the pH electrode and the reference electrode (Vonau, W., et.al.,2006).

Ultrasonic sensors are extensively employed in many different fields, including agriculture, where they perform a number of tasks such object detection, level monitoring, and distance measurement (Boopathi Raja, et.al., 2022). The basic idea behind these sensors is to send out ultrasonic waves and time how it extended takes for an echo to return from an object. (Abbasi, A.Z.,et.al., 2014)The speed of sound in the atmosphere and the time delay are then used to determine the object's distance(Colaço, A.F.,et.al., 2018).

Mini Water Pump: The system uses brushless mini DC water pump that uses DC 4.5V to 24V to power a brushless motor. The impeller rotates as a result of the brushless motor's spin, raising the liquid's pressure and creating the illusion of liquid transfer. For small-scale water movement applications, a micro water pump is a lightweight, portable pump. Due to their versatility, these pumps are used in a variety of settings, such as homes, farms, and factories. They are perfect for applications with limited space and no need for large flow rates because of their compact size. A miniature submersible water pump uses both an impeller and a motor to pump water. The impeller pumps water at high speeds (Zheng, X.,et.al., 2014). Water travels through the eye, the impeller's center, along the outside portion of the blades (Takacs, G., 2017).

Ultraviolet Light: UV light, particularly UV-A (315-400 nm) and low levels of UV-B (280-315 nm), can enhance plant growth and photosynthesis. It promotes chlorophyll production, improves nutrient absorption, and stimulates the development of flavonoids and antioxidants, all of which help plants withstand environmental stress. Controlled UV light exposure can also help to strengthen stems, improve leaf health, and increase crop output (Nawkar, G.M., et.al.,2013). Furthermore, UV radiation promotes disease resistance by activating protective responses in plants, making them more resistant to pests and diseases (Paradiso, R.,et.al., 2022).

4.2 Software Support

The purpose of this webpage is to use crop leaves to identify illnesses. HTML and CSS were used in the development of this webpage, which shows the extent of disease propagation and integrates a trained AI model to detect the disease. The type of illness in that crop is displayed if a farmer uses any camera linked to this webpage to scan the leaf of the damaged crop. Farmers can use their web browsers to access the Sprout website. Farmers are able to scan the crop's afflicted leaf (van Bruggen, A.H.,et.al., 2016). This website provides information about the disease so that farmers can take preventative actions including applying fertilizer and other materials in advance of the disease's occurrence.

5 WORKING OF AGRICULTURE MONITORING SYSTEM

The pH sensor in the soil ascertains the in order to safely reduce the voltage from a higher source level (230V/240V) to a lower level (12V) appropriate for powering the Arduino Uno and other low-voltage devices, a step-down transformer is utilized in this work. Since every component in this system operates on a DC supply, an AC voltage transformer is converted to a DC voltage using a rectifier. The Arduino Uno board is the circuit's brain. Soil's acidity or alkalinity, according to the ATmega328P microcontroller, the Arduino Uno is a well-known open-source microcontroller board. It has 32 KB of flash memory, 2 KB of SRAM, and 1 KB of EEPROM and runs at a clock speed of 16 MHz. The board has fourteen digitals. Six analog input pins (A0 to A5) and I/O pins (0 to 13) enable flexible interface with sensors and actuators. PWM output is supported by six of the digital pins for controlling devices, such as LEDs and motors. The Arduino Uno has internal 5V voltage regulator, an external power source (7–12V), or USB. The Arduino IDE, which supports a C/C++-based language and provides a wealth of libraries and examples, is used for programming. It is perfect for educational and recreational works because of its open-source nature, which promotes customization and community involvement (Nvs, B.,et.al., 2020).

A Node MCU ESP8266 12E was used to give microcontroller-based plan Wi-Fi connectivity. Its foundation is the ESP8266 microcontroller, a highly integrated Wi-Fi chip capable of offering a comprehensive Wi-Fi solution. In addition to controlling the water pumps and RED light, it can show the PH level, soil moisture content, and plant height. An ultrasonic sensor expels a 40 kHz pulse that travels through the atmosphere and returns to the sensor if a plant is present. It is possible to determine the height by computing the travel time and the speed of sound. Since they provide real-time information on the soil's water content, soil moisture sensors are essential to smart agriculture. By monitoring and controlling irrigation more effectively, these sensors assist formers in providing the best possible growing environment for crops.

6 RESULTS

The board's electrical circuit includes a power supply unit, Arduino UNO board, Node MCU board, soil moisture sensor (figure 2), pH meter sensor (figure 4), ultrasonic sensor (figure 3), tiny water pump, and LCD display. The soil moisture sensor monitors soil moisture content, whether wet or dry. If the soil is dry, the LCD display alerts the user to activate the tiny water pump until the moisture level increases. The soil pH meter analyzes the acidity and alkalinity of the soil. The device uses an LCD monitor to show soil pH levels. Farmers can boost soil pH if it is below "7" by adding calcium and/or magnesium- containing components, such as Examples include limestone, baking soda, eggshells, and wood ashes.

Figure 2: Soil moisture sensor.

Figure 3: Ultrasonic sensor.

Figure 4: pH meter sensor.

Farmers can use elemental sulfur, aluminum sulfate, or sulfuric acid to raise pH levels above "7". The ultrasonic sensor is used in agriculture to measure crop height. Crop height should be checked often to monitor growth and defend against weeds, resulting in increased yield. It is a website for detecting agricultural diseases using the leaves. This webpage uses HTML and CSS to depict illness spread levels and integrates a trained AI model for disease identification. Scanning infected crop leaves with a camera attached to this webpage identifies the disease type. Farmers can utilize the software support on their internet browser. Farmers can scan the afflicted leaves of specific crops. This website provides disease information, allowing farmers to take proactive steps such as fertilizer use and other preventative materials. Software support is shown in figure 5.

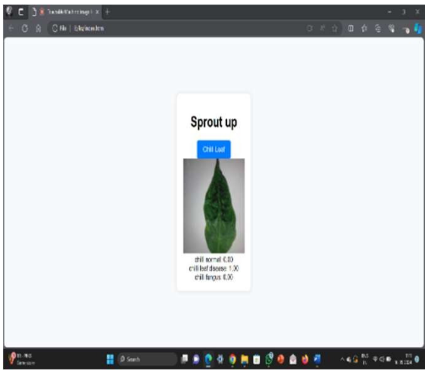

Figure 5: Software support.

6.1 Sensor Output (Soil Moisture, pH, and Plant Height)

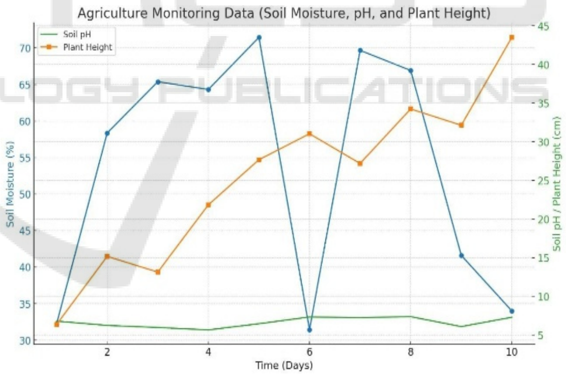

Figure 6: Trends in Soil Moisture, Ph, and Plant Growth: a 10-Day Agricultural Monitoring Study.

The graph in figure 6 tracks three key factors that impact soil health and plant growth over the course of a 10- day agricultural monitoring study: soil pH, plant height, and soil moisture. With plant height increasing slowly, soil pH being relatively constant during the observation period, and soil moisture varying considerably, the results show dynamic tendencies. Over the course of the 10-day period, the blue line, which represents soil moisture (%), varies greatly, exhibiting abrupt declines and strong increases that reflect changes in water availability.

- **Dynamics of soil moisture:** On day one, the soil moisture percentage is around 30%, but by day two, it has sharply increased to about 60%, indicating the start of irrigation or rainfall. This rising tendency persists, peaking at over 70% on day six, followed by a sharp decline to around 0%. After this dip, soil moisture rapidly recovers and varies further, declining noticeably after day 8. These discrepancies point to the necessity of better irrigation techniques to sustain steady soil moisture levels.
- **Growth in the plant height:** In contrast to soil moisture, plant height increases steadily over the course of ten days. It grows steadily, with only little variations, from about 30 cm on day 1 to a height of about 45 cm on day 10. This suggests that the plant is thriving in spite of changes in soil moisture, which could be the result of an adaptable root system or lingering soil moisture.
- **pH stability of soil:** Soil pH varies only slightly and remains fairly stable. It starts at about 6.5 and fluctuates a bit through the course of the 10-day period. Soil pH does not change with the change of soil moisture or plant growth as the soil pH measured in the observed conditions showed a steady state. This would indicate that the soil is buffered well or that there were no external inputs such as fertilizers and soil amendments throughout the course of the study.

7 CONCLUSIONS

The Smart Agriculture Monitoring and Disease Detection System is a significant breakthrough in modern agriculture that helps address several critical aspects, including the management of resources and maintenance of plant health, as well as environmental sustainability. Combined with IoT sensors for monitoring soil moisture, pH levels, and plant development, this technology offers farmers a complete automated solution. With the real-time monitoring and control system of Blynk app, Farmers can take data-driven decisions and improve the efficiency and productivity of their Farming techniques. This technique, in addition to minimizing the use of dangerous pesticides, inspires better crops and improves the farming ecology; by allowing for early disease detection, it creates an efficient use of resources especially the water needed for irrigation. Its scalability and versatility make it appropriate for a variety of farming contexts, from small-scale agriculture to major farming enterprises, making it a new versatile instrument for the future of agriculture. Innovations such as this provide a pathway to efficient and sustainable farming practices as the world seeks to feed a larger population without harming the environment. A Smart Agriculture Monitoring and Disease Detection System, which represents a move toward a future in which nature and technology can coexist harmoniously to promote food security and safeguard the planet's resources for future generations. Its strength can be enhanced by impending technologies which can use complex sensors, ML models among other tech components. This will also advance the precision and efficiency of farming methods, creating more opportunities for environmental conservation, crop production improvement, and sustainability

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