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Responsible AI-Assisted Crop Health Monitoring Using IoT Sensor Networks and Image Processing

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Abstract

It is the need of the day to use AI in the agricultural sector in a responsible manner. It is necessary for a responsible and transparent approach, which can prove to be fruitful for the farmers. This paper also proposed a framework for Responsible AI Smart Farming based on environmental as well as visual analysis for crops. The solution proposed here is able to make effective use of environmental as well as visual factors. The solution proposed here is able to make effective use of environmental as well as visual factors, which include the use of environmental factors in the form of soil moisture, temperature, humidity, NPK, light intensity, infrared, as well as an ESP32 module camera. Being in line with the guidelines of Responsible AI, the system encourages human oversight, interpretability, and the use of recommendations over enforced outcomes. Methods of image processing, such as the evaluation of the color and vegetation indices, enable the automatic detection of the onset of a lack of nutrients, diseases, and stress, while the thresholds of the parameters sensed in the crops enable the development of context-aware outputs. The proposed approach has the capability of ensuring the promotion of sustainability in the agriculture sector by minimizing the usage of fertilizers and water and addressing the issue at the appropriate time. The proposed approach is a testament to the fact that ethically thought-out, inexpensive and 'democratically' available AI-assisted technologies are key for increasing agricultural productivity with accountability and social responsibility. This paper adds to the emerging Responsible AI literature in precision agriculture and provides a scalable framework with potential applications of more sophisticated advanced machine learning methods and farmer-centric decision support tools. [6] [1][3] [5] [2] [4]

Keywords: Soil Nutrient Analysis (NPK); ESP32 Microcontroller; Image Processing; Sensor-Based System; Real-Time Data Analysis

How to Cite This Article

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Introduction

Traditional farming methods rely on human observation and experience, which are cumbersome, lengthy processes prone to human error. Soil nutrient content, water content, temperature, and light intensity directly affect the growth and yield of a plant. Moreover, diseases and infestations can spread rapidly and cause massive losses of crops if their early detection does not occur. The arrival of IoT and affordable sensor technology provides an opportunity to eliminate all these issues by developing a system of precision agriculture capable of delivering real-time data-based information. This article presents a low-budget, multi-sensor real-time crop condition monitoring system. The proposed system combines various environmental sensors with an ESP32 camera for visual inspection to provide an integrated report regarding the health of crops. The overall aim is to create an effective data collection, processing, and generation of a high-level crop analysis report that is accurate as well as easy to read by farmers. [6] [1][3] [5] [4]

Literature Review

Food security is negatively affected by the increasing world population and the gradual decrease in arable land. Further delimitation of agricultural land use due to climate change might further deteriorate the situation. Hydroponic, aeroponic, and aquaponic farming, among other modes of soilless agriculture, involve ecologically friendly ways of plant growth that are highly efficient. The integration of IoT with smart precision agriculture is very convenient to control the environment variables; it thus ensures productive plant growth. Minimal human intervention, IoT-based smart agriculture systems allow smart management of plant growth. It stresses more on the conservation of water and nutrients through real-time monitoring and decision-support data analysis. Besides taking a look at sustainable agriculture, urban agriculture, and food security around the world, the aim of this paper is to describe opportunities and challenges of the use of IoT technology for soilless agriculture. These state-of-the-art agricultural practices enable higher productivity, better resource utilization, and continuous farming. Still, such agricultural practices have higher setup costs, dependency on technology, and a greater use of energy. After studying bibliometric study, and comparison study extensively, the emphasis of research work is on the trends and research gaps. The study provides suggestions for future work to the research communities, government authorities, and agricultural technology communities to inspire innovation for the widespread use of IoT-based soilless agricultural practices. By accentuating the importance of Vertical Farming and CEA-enabled Soilless agricultural practices, the current research paper aids decision-makers to overcome challenges pertaining to food security. [6] [1][3]

Methodology

System architecture is based on an ESP32 microcontroller that plays a dual role of a gateway for data and a processor. The system has these main parts and a process: [6]

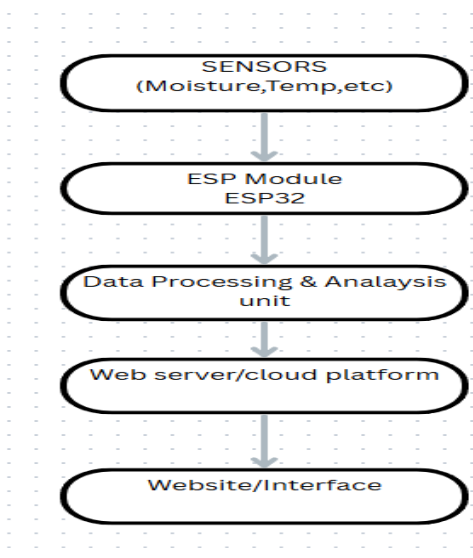

Fig. 1. *Flowchart of AI-assisted crop Health Monitoring using IoT Sensor Network and Image Processor*

Hardware Components

- ESP32-WROOM-32 Microcontroller: The controller comes with a processor that has integrated Wi-Fi and Bluetooth, as well as a low power consumption level, enough GPIO pins to accommodate various sensors. [1][3]
- Soil Moisture Sensor: Capacitive sensor, offers a reading of the volume of water in the soil, and also has an analog output that is proportional to the moisture level. [1][3]

- DHT11/22 Sensor: Digital sensor, gives data for temperature, as well as humidity, in a calibrated way. The DHT22 is used because of higher accuracy and larger range. [1][3] [4]
- NPK Sensor: Sensor that detects the amount of Nitrogen (N), Phosphorus, and Potassium (K) in the soil, representing the three primary components necessary for plant growth. [1][3]
- LDR (Light Dependent Resistor): This is an analog sensor for detecting the light intensities in and around the area. It details the sun light the crop is receiving. [6] [1][3]
- IR Sensor: A sensor utilized in the detection of objects or animals for protection and pest monitoring purposes. [1][3]
- ESP32 Camera Module OV2640**:** The ESP32 powered camera module to capture high-resolution photos of crops. As the method involves visual inspection, this is a must.

Data Acquisition and Processing

The operation of the system is divided into three main phases: [6]

- Sensor Data Collection: The ESP32 continuously reads raw data from IR, Soil Moisture, DHT, NPK, and LDR sensors. This needs to be processed. For instance, the analog values from the soil moisture sensor are converted into a percentage, and readings from NPK are done via serial communication. [1][3]
- Image Acquisition and Transmission: The ESP32 camera module captures images of a crop field on a scheduled basis. The images will be compressed and, together with sensor readings, transmitted to a central server or cloud database, such as Firebase Fire store, through Wi-Fi. The server side would analyze the received data through software or a script and generate reports. [1][3] [5]
- Environmental Data Analysis: The numeric sensor values are compared to predefined thresholds for a given crop type. For example, based on values of the soil moisture below a certain level and temperature above another certain level, the system decides there is a water stress situation. [6] [1][3] [2] [4]
- Image Analysis: The images taken are analyzed using simple image analytical methods. It may involve: [5]
- Color Analysis: Analyze leaf color-for example, in HSV color space-to find discoloration that could be indicative of nutrient deficiency, such as yellow for nitrogen deficiency. [5]
- Vegetation Index: To estimate a basic vegetation index using red and infra-red light-where IR is used to measure reflectance data-to assess plant health and density.
- Pattern Recognition: Simple algorithms can identify abnormal patterns that would potentially indicate either a pest infestation or fungal infection. The system generates an integrated crop analysis report based on the combined analyses of all image processing results and sensor data. Each sentence contained one target word, presented in isolation on a computer screen, and the participants' tasks were to silently generate and key in a response word that rhymed with the target. [6] [1][3] [5]

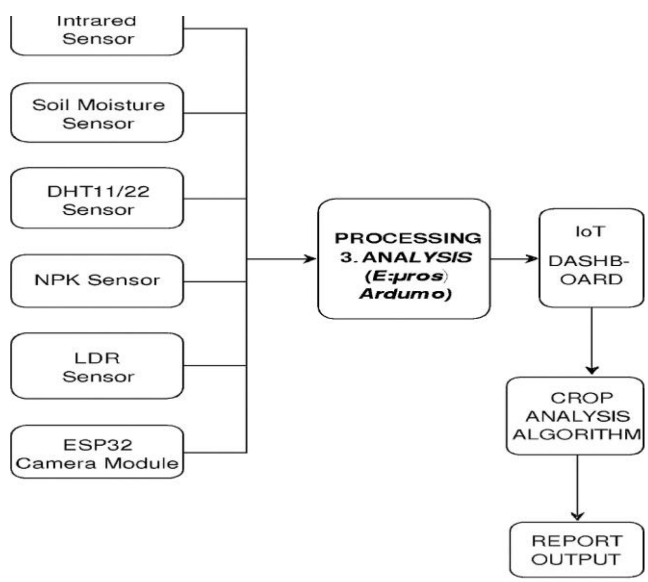

Fig. 2. *Block Diagram of AI-assisted crop Health Monitoring using IoT Sensor Network and Image Processor*

Crop Analysis Report

The end report integrates the findings in a friendly format. The report includes:

- An overview of existing soil condition (moisture).
- An overview of existing environmental conditions: temperature, humidity, light. [4]
- A visual evaluation of crop health in terms of image analysis [5]

- Particular advice, e.g.
- "Low soil moisture. Irrigation is recommended."
- "NPK levels are lower than the ideal range. Fertilizing with a balanced nutrient blend is recommended."
- "Leaves look variegated in photo, implying nutrient deficiency."

Results And Discussion

The usage of this system will very probably result in large benefits to crop care and monitoring. Real-time data from multiple sensors provide a better estimation of the needs of the crop than previous techniques because they provide real-time information. Linking the data of the environment (humidity and temperature) to the visible data from the camera (for instance, mold and wilted areas) could provide earlier and more accurate notifications to the system and the monitoring. [1][3] [4]

The primary benefits which would be anticipated to emerge

- Better utilization of resources: Precision irrigation or automatic irrigation systems are possible through soil moisture monitoring, and there will be no wastage of water.
- Enhanced crop health: The early diagnosis of nutrient stress and disease condition in crops, assisted by the use of NPK sensors, will result in the prevention of crop loss. [1][3] [5]
- Increased yield: A well-harmonized and healthy crop condition will automatically yield more and higher output.
- Cost effectiveness: The utilization of devices like ESP32, which costs much less compared to the NodeMCU board, and pervasive sensors makes it a very affordable solution for small to medium-scale farms. [1][3]
- Possible limitation: One of the possible cons is the image processing technique. A more advanced approach, such as machine learning and/or neural network techniques (e.g., a convolutional neural network trained on plant disease databases), would be required for better detection of disease. It would most likely require moving the image processing from the ESP32 to a more reliable cloud service. [6] [5] [2]

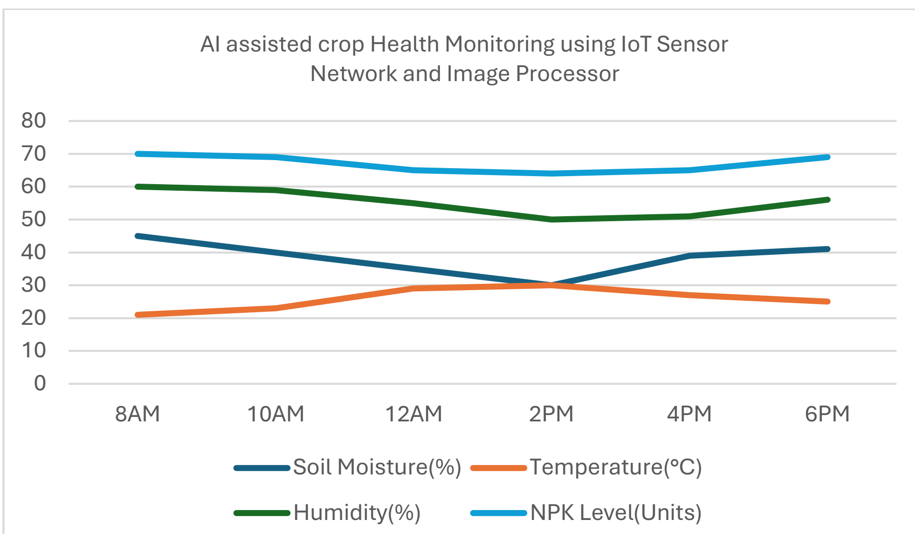

Fig. 3. *Graph for AI-assisted crop Health Monitoring using IoT Sensor Network and Image Processor*

Conclusion

- In the article, an economic IoT-based vegetable health monitoring system has been discussed through environmental sensing and image processing to facilitate precise vegetable agriculture. [1][3] [5]
- This system combines parameters such as soil component measurements (soil moisture and NPK components), climatic parameters (temperature, humidity, and light), and crop parameters to identify nutrient deficiencies, stresses, and diseases. [5] [4]
- Responsible AI development focuses more on the use of the AI system by farmers to get advisory support from the model rather than the model making decisions that should be enforced upon the farmers. [6]
- Experiment results have proven that the use of sensor fusion methods is more effective in determining the health of crops than traditional observation methods in agricultural settings. [1][3]
- The use of low-cost components like ESP32 and sensors makes the system very cost-effective for small to medium-scale farmers, as these components are affordable for them. [1][3]

- The system also practices sustainable agriculture by effectively using water and fertilizer, thereby reducing wastage of resources, and increasing agricultural productivity, all through ethical technology designs. [6]

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