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DEVELOPMENT OF AN AI-BASED SMART GREENHOUSE PROTOTYPE FOR ENHANCED AGRICULTURAL SUSTAINABILITY

GELİŞMİŞ TARIMSAL SÜRDÜRÜLEBİLİRLİK İÇİN YAPAY ZEKA TABANLI AKILLI SERA PROTOTİPİNİN GELİŞTİRİLMESİ

Eray GÜNEY[1] Enes ÖZDEMİR[1] İsmail KAYADİBİ[*2] Nihan KOSKU PERKGÖZ[1] Ümmühan BAŞARAN FİLİK[1]

1 Department of Electrical and Electronics Engineering, Faculty of Engineering, Eskisehir Technical University, Eskisehir, Türkiye

2 Department of Management Information Systems, Faculty of Economics and Administrative Sciences, Afyon Kocatepe University, Afyonkarahisar, Türkiye

ABSTRACT

Addressing the critical global need to combat agricultural scarcity, this research introduces artificial intelligence (AI) based smart greenhouse prototype as a holistic solution for enhanced productivity and sustainable practices. The study presents the design and implementation of an AI-powered intelligent greenhouse that integrates advanced technologies to optimize agricultural processes. Central to this prototype are integrated sensors that continuously capture real-time data on environmental parameters and crop conditions. This data is then used to develop predictive models, mitigating potential issues such as crop diseases. Complementing these capabilities, renewable energy sources, specifically solar power, are harnessed to meet the greenhouse's energy requirements, fostering eco-friendly operations. The research outlines a comprehensive system architecture, encompassing sensor data acquisition, serial communication, Python-based data analysis, and integration with the Thingspeak platform for data visualization and access. This cohesive setup allows stakeholders to gain insights into the greenhouse environment and crop well-being, facilitating informed decision-making. The proposed smart greenhouse prototype presents an innovative approach to precision agriculture, showcasing the potential of AI and renewable energy integration in revolutionizing conventional farming practices. By enhancing productivity, energy efficiency, and adaptability, this prototype offers a promising solution to address the challenges of modern agriculture while promoting sustainability.

Keywords: Artificial Intelligence; Energy Efficiency; Precision Agriculture; Smart Greenhouse

ÖZET

Tarımsal kıtlıkla mücadele için kritik küresel ihtiyacı ele alan bu araştırma, gelişmiş verimlilik ve sürdürülebilir uygulamalar için bütünsel bir çözüm olarak yapay zekâ (AI) tabanlı bir akıllı sera prototipini tanıtmaktadır. Bu çalışma, tarımsal süreçleri optimize etmek için gelişmiş teknolojileri entegre eden yapay zeka destekli akıllı bir seranın tasarımını ve uygulamasını sunmaktadır. Bu prototipin merkezinde, çevresel parametreler ve mahsul koşulları hakkında gerçek zamanlı verileri sürekli olarak yakalayan entegre sensörler bulunmaktadır. Bu veriler daha sonra tahmine dayalı modeller geliştirmek için kullanılıyor ve mahsul hastalıkları gibi potansiyel sorunları hafifletebilmektedir. Bu yetenekleri tamamlayan yenilenebilir enerji kaynakları, özellikle de güneş enerjisi, seranın enerji gereksinimlerini karşılamak için kullanılıyor ve çevre dostu operasyonları teşvik etmektedir. Bu çalışmada sensör veri toplama, seri iletişim, Python tabanlı veri analizi ve veri görselleştirme ve erişim için Thingspeak platformuyla entegrasyonu içeren kapsamlı bir sistem mimarisinin ana hatları sunulmuştur. Bu uyumlu kurulum, paydaşların sera ortamı ve mahsulün refahı hakkında bilgi edinmesini sağlayarak bilinçli karar vermeyi kolaylaştırmaktadır. Önerilen akıllı sera prototipi, geleneksel tarım uygulamalarında devrim yaratmada yapay zekâ ve yenilenebilir enerji entegrasyonunun potansiyelini sergileyerek hassas tarıma yenilikçi bir yaklaşım sunmaktadır. Üretkenliği, enerji verimliliğini ve uyarlanabilirliği artıran bu prototip, sürdürülebilirliği teşvik ederken modern tarımın zorluklarını ele almak için umut verici bir çözüm sunmaktadır.

Anahtar Kelimeler: Akıllı Sera; Enerji Verimliliği; Hassas Tarım; Yapay Zeka

*Corresponding Author (Sorumlu Yazar), e-mail: ikayadibi@aku.edu.tr

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1. INTRODUCTION

The World Bank's projections indicate that the global population is set to surpass 9.6 billion by 2050 [1]. However, the expansion of urban areas, coupled with land degradation and the diversion of crops for biofuel production, is expected to result in a reduction of suitable agricultural land ranging from 8% to 20% by 2050 [2]. Given these circumstances, there's a pressing need for agricultural production to escalate by approximately 50% by 2050. In terms of energy consumption, insights from greenhouse practices across various nations reveal that cultivating 1 kg of dry lettuce demands 70 kWh of electricity in the Netherlands, 111 kWh in the United Arab Emirates, 195 kWh in Sweden, and 247 kWh in Colombia [3].

Considering the conditions of Turkey and the climate conditions and level of development in the researched countries, it can be argued that this country can provide better greenhouse conditions than the countries involved in the research.

There is a close relationship between global warming and arable land for agriculture. The impact of global warming can result in land degradation, drought, and diminishing water resources, leading to a decrease in agricultural productivity. Excessive heat and climate change can have adverse effects on agricultural production and reduce the amount of land suitable for farming. Additionally, the decline in water resources can restrict the amount of water available for agricultural irrigation. Climate change is also one of the sources threatening food security. It is critical to effectively handle water resources, enhance farming methods, and adopt climate-conscious agricultural approaches to strengthen the resilience and sustainability of agriculture [4].

The main focus of smart greenhouses is to realize more efficient crop production with less energy compared to conventional methods, while also improving the quality of the harvested crops. Among the objectives, renewable energy and energy efficiency are also included in the greenhouse prototype to meet the energy requirements. This is achieved by harnessing solar energy through the use of solar panels within the greenhouse.

The sensors located in the greenhouse, which are connected to a microcontroller, provide data on various parameters such as temperature, humidity, and air quality. Through the microcontroller, the controlled units such as fans and water motors are regulated to maintain optimal conditions for plant growth. This integration of sensors and control units enables the greenhouse to acquire the smart greenhouse feature, ensuring optimal conditions for plant development.

In summary, this paper presents the basic parameters of a greenhouse for a smart greenhouse and the proposed solutions to renewable energy and energy efficiency issues. For this, an example smart greenhouse prototype and microcontroller software have been developed. The primary objectives of this paper and its addition to the literature are as follows:

1) Development of a low-cost smart greenhouse prototype with various electronic hardware to enhance AI applications in agriculture,

2) Demonstration of the use of Industry 4.0 tools such as the Internet of Things in a greenhouse,

3) Transferring the basic parameters such as temperature and humidity that need to be controlled in a greenhouse to remote servers via the Internet of Things, thus enabling the development of data analysis techniques for monitoring plant growth processes in the greenhouse.

In the remainder of the article, Section 2 describes the materials and methods used in the formation of the smart greenhouse. Afterward, Section 3 is the general working diagram of the developed smart greenhouse. Finally, Section 4 describes in detail the results obtained and future work.

2. MATERIALS AND METHODS

In this study, a smart greenhouse prototype has been developed for AI-based precision agriculture applications. The flow diagram of the development stages of this prototype is given in Figure 1.

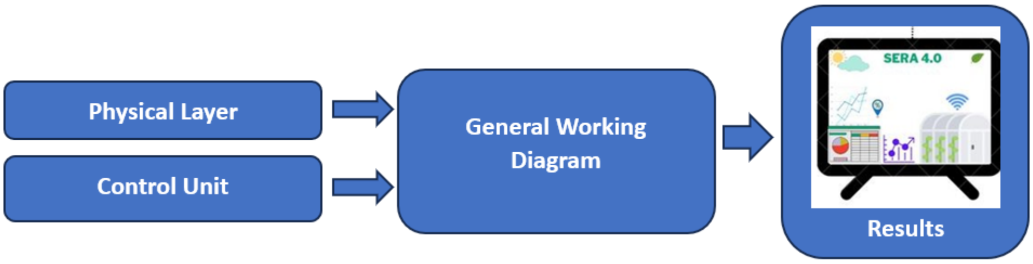

Figure 1. Flow Diagram

As shown in Figure 1, firstly, the greenhouse prototype is prepared with the physical layer and control unit stage. Then, the software to control the greenhouse is developed in the general working diagram section and finally, the results obtained from the smart greenhouse are exhibited in the conclusion section. For this developed greenhouse, all the main process steps are explained in detail below.

2.1. Physical Layer

The physical layer of the greenhouse consists of three parts. These parts are explained in detail in the sub-headings

2.1.1. Flower Pot and Plexiglass

While constructing the prototype greenhouse, plexiglass was used. The reason for using Plexiglass is that it is lighter and more durable than glass. In addition, the light transmittance of plexi is better than other materials. Likewise, plastic pots were used to make the greenhouse lighter and more portable. The use of plexiglass and plastic containers for the greenhouse is shown in Figure 2.

Figure 2. Flower Pot and Plexiglass

2.1.2. Solar Panel and Batteries

A 24V solar panel was used to meet the energy needs of the prototype greenhouse. The solar panels used are shown in Figure 3. The electrical energy obtained with this panel was transferred to 2 parallel connected 12V 9Ah batteries via a solar charge controller. When the energy consumption of the greenhouse is examined, two different situations are observed.

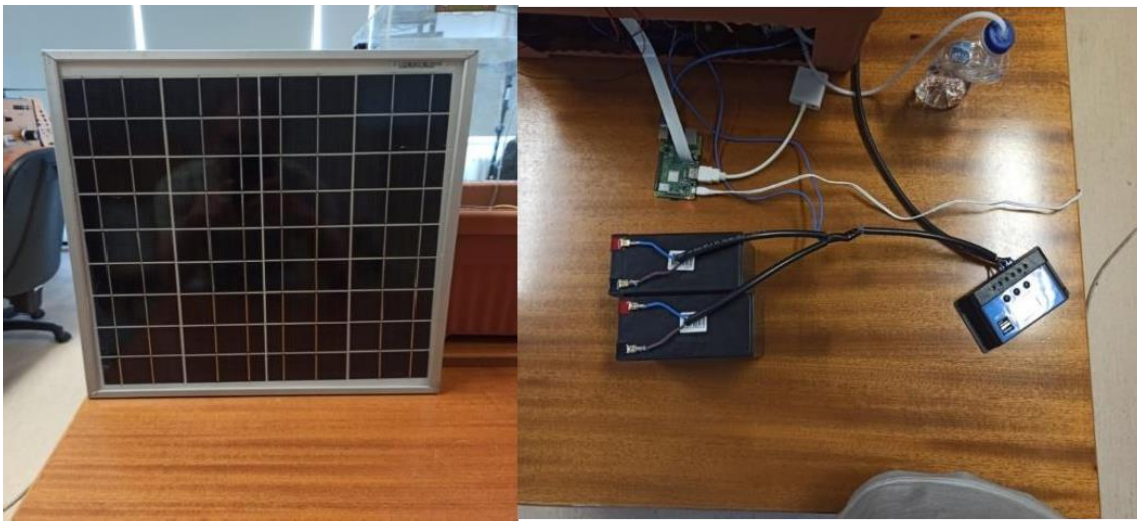

Figure 3. Solar Panel, Batteries, and Charge Controller

When the indoor environment needs to be heated in cold weather conditions, the energy consumed increases and the energy need of the system is met by the solar panel at a rate of 25 percent. This is because the heater draws a large amount of current. However, in hot weather, 80 percent of the system's energy needs are met by the solar panel.

2.2. Control Unit

The control unit of the smart greenhouse to be developed consists of three parts. These are the microcontroller, sensors, and components controlled by the microcontroller.

2.2.1. Microcontroller

The microcontroller to be used in this research is Arduino. Arduino has a relatively simple programming process compared to other microcontrollers with its simple software language, which is open to development thanks to its open-source codes. It is a kind of small computer that can read inputs from sensors, control actuators, and communicate with other devices through various communication protocols. Arduino development environment is software that allows one to write code for the microcontroller and upload the code to the board. It is also generally used in education and research to teach programming and electronics. In this system, an Arduino "MEGA" microcontroller will be used because there are many analog inputs [5]. The Arduino Mega used in this study is shown in Figure 4.

Figure 4. Arduino “MEGA” Microcontroller [6]

2.2.2. Sensors

In this study, in determining the sensors to be used in smart the greenhouse, the parameters to be followed in a greenhouse were examined and the parameters that could be important for the plants were determined. These are the preferred air temperature and humidity, soil moisture, light measurement, air quality, and CO_2 parameters for plant status indicators. In this case, suitable sensors that will enable the microcontroller preferred in this study to measure these parameters are explained in detail below.

In the smart greenhouse, it was first preferred to use DHT22 to measure air temperature and humidity. DHT22 is an air temperature and humidity sensor that works with Arduino. This sensor uses a capacitive humidity sensor and a thermistor to measure the surrounding air and sends digital data over a single wire interface [7]. Another used sensor is the soil moisture sensor. This sensor is used in this system to measure the moisture ratio in the soil. It includes a sensor that can be installed into the soil and an analog interface, connected to the sensor to an Arduino board. When it is connected, the Arduino can be programmed to read the sensor's output and convert it into a moisture level reading [8]. For light measurement in the smart greenhouse, Light Dependent Resistor (LDR) is preferred for the measurement of the light state. This sensor has the feature of changing the resistance of the sensor depending on the intensity of light coming into the sensor. In this way, it sends data to Arduino depending on the light intensity coming into the greenhouse and undertakes the task of providing data in the operation of the plant growth light [9]. For air quality measurement, MQ-135 is a sensor that detects harmful gases (alcohol and smoke) in the air and gives a value of "ppm" according to the particle ratios of these gases in the air. It is connected to the Arduino via an analog pin [10]. For the CO2 measurement of a smart greenhouse, an MH-Z14 sensor is preferred. The MH-Z14 is an Arduino-compatible sensor that measures the CO2 composition in the air. It works by measuring the absorption of infrared light at a specific wavelength by CO2 molecules. The sensor has an infrared emitter and a detector, and it uses a microcontroller to analyze the signal and calculate the CO2 concentration [11]. In summary, in total, five sensors were used to monitor the basic parameters in the smart greenhouse in this study.

2.2.3. Controlled Components

Optimum conditions for plant growth are provided by these components, these components are controlled by the microcontroller with relays. These are ventilation fans, heater fans, plant grow lights, and peristaltic liquid pumps. Its use is detailed below.

As ventilation fans, two fans will be used. The first is for fresh air to enter the greenhouse. Our aim here is to provide the most suitable conditions for the plant to perform photosynthesis. For this purpose, it will be ensured that fresh air from the outside is taken into the greenhouse. The second fan will be used to remove the harmful gases accumulated in the greenhouse from the greenhouse. The Arduino will control the fans. Thanks to the data it receives from the Arduino sensors, it will monitor the air in the greenhouse and run the fans when necessary. On another issue, temperature is an important factor for plant growth. The appropriate temperature for each plant may vary. The Arduino will monitor the temperature in the greenhouse with sensors and perform the necessary actions. The heater fan will be used to heat the greenhouse interior and will be controlled by the Arduino. Plant growth light is used for plant growth.

The purpose of using plant growth light is to achieve plant growth as soon as possible. Plants develop in a light environment. For this reason, in this study, we will use these special lights so that the plant can develop overnight. Finally, the peristaltic liquid pump provides the facility's water needs by drawing water from the water tank with a water pump.

2.3. Communication and Data Tracking Unit

In this subsection, Raspberry Pi is used for data collection and the Thingspeak interface is used for data monitoring. Details of these uses are given below.

2.3.1. Raspberry Pi 3B+

Raspberry Pi 3B+ is a small and affordable single-board computer with a 1.4 GHz quad-core processor, 1GB RAM, built-in Wi-Fi and Bluetooth, multiple ports for connectivity, and support for various operating systems. It is widely used for educational, DIY, and IoT projects [12]. Arduino sends the data it receives from the sensors to the Raspberry via serial communication (USB). These data are recorded as strings with the developed Python software and then these data are sent to the Thingspeak interface created for the smart greenhouse. The Python code developed for the data read via Arduino and sent to the Thingspeak interface is given in Figure 5.

```python
import serial
import time
import schedule
arduino = serial.Serial('/dev/ttyUSB0', 9600)
import urllib.request
import requests
import threading

list_values = []
def main_func():
    print('Established serial connection to Arduino')
    arduino_data = arduino.readline()
    decoded_values = str(arduino_data[0:len(arduino_data)].decode("utf-8"))
    print(decoded_values)
    list_values = decoded_values.split('x')
    print(list_values[0])
    sensor_readings={'api_key':'K0796GCPZEE94FFS','field1':list_values[0],'field2':list_values[1],'field3':list_values[2],'field4':list_values[3],'field5':list_values[4],'field6':list_values[5],'field7':list_values[6]}
    url='https://api.thingspeak.com/update.json'
    requests_headers={'Content-Type':'application/json'}
    print("Sending data to thingspeak.com")
    response=requests.post(url,sensor_readings,requests_headers)
    print("Response code:",response.status_code)
    print("Response code:",response.text)

schedule.every(15).seconds.do(main_func)
while True:
    schedule.run_pending()
    time.sleep(1)
```

Figure 5. Python Code for ThingSpeak

2.3.2. ThingSpeak

An Internet of Things (IoT) platform called ThingSpeak.com allows users to gather, examine, and visualize data from connected devices. In addition to providing tools for data processing, analysis, and visualization, it offers cloud-based storage for sensor data. ThingSpeak enables customers to effortlessly monitor and control their IoT applications by supporting a variety of IoT devices and integrating with well-known platforms. For advanced data analysis and machine learning capabilities, it also provides MATLAB Analytics integration. ThingSpeak offers a flexible and user-friendly solution for IoT data administration and application development thanks to its open-source status and vibrant community. The data of the smart greenhouse was sent to ThingSpeak via Raspberry Pi with Python Code and the graphic examples obtained are given in Figure 6.

Figure 6. Illustration of smart greenhouse data posted to Thingspeak

3. GENERAL WORKING DIAGRAM

The general operation diagram is detailed in two parts the control unit and communication subsections.

3.1. Controller Unit

All steps performed in the controller unit of the general flow diagram are explained below.

1) Data Acquisition from Sensors: The system acquires data from sensors, which detect various physical or environmental variables. These variables are converted into electrical signals and transmitted to the Arduino microcontroller.
2) Data processing: The signals that are received are processed by the Arduino microcontroller. The data from the sensors are analyzed as part of this processing, and they are then mapped to particular value ranges. The Arduino code makes decisions in accordance with this data processing and analysis.
3) Relay Control: The Arduino code utilizes relays to control the operation of the monitored components.
4) Signal Transmission: Based on the specified value ranges in the Arduino code, the relays of the monitored components receive "HIGH" or "LOW" signals. The "HIGH" signal shows that a component should be activated and operated, while the "LOW" signal shows that a component should be deactivated and not operate.
5) Operation of Components: The "HIGH" or "LOW" signals sent to the relays affect their switching. This enables the operation of the monitored components.

Therefore, by transmitting data from the sensors to the Arduino microcontroller, decisions are made based on this data, and appropriate signals are sent through the relays of the monitored components to enable their operation. An example of the general operation diagram of the smart greenhouse is given in Figure 7.

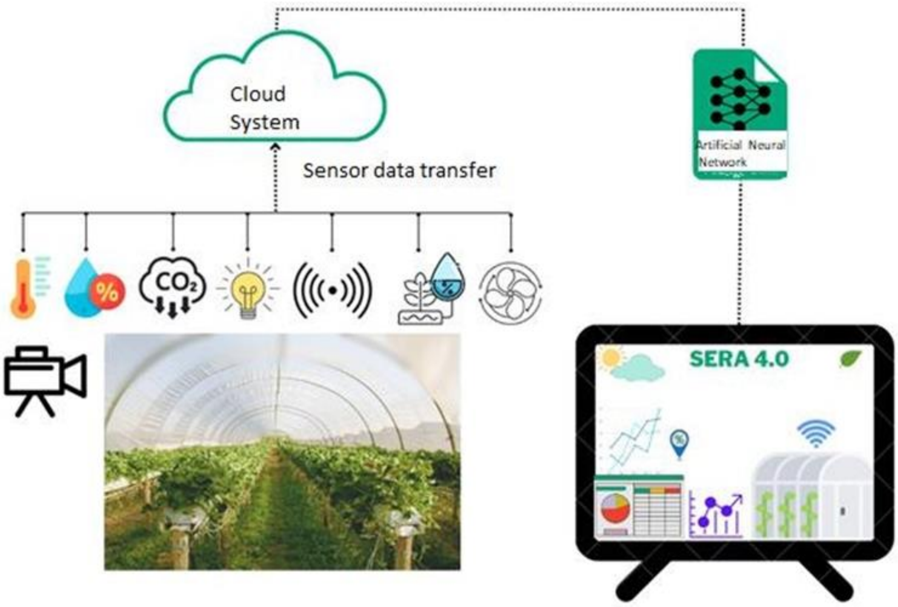

Figure 7. General working diagram of smart greenhouse

As seen in Figure 7, basic parameters such as temperature and humidity obtained from a greenhouse can be given as input to an artificial neural network (ANN). In this direction, a sample ANN model can be developed for the estimation of parameters such as energy, heat, etc., or the determination of normal/abnormal conditions in the greenhouse (14). ANN, one of the AI methods, is a method used in many different fields for processing and modeling numerical values. For this purpose, this study aims to show that the sensor information obtained can be processed with an ANN model and feedback can be provided on a smart greenhouse using digital twin technology. Accordingly, in this study, the development of a smart greenhouse example modeling that can provide mutual feedback between the digital twin and the greenhouse and take actions according to the situation is shown.

3.2. Communication

All steps performed in the communication section of the general flow diagram are explained below.

1. Data Acquisition from Sensors: The system collects data from sensors that detect various physical or environmental variables. This sensor data is transmitted to the Arduino microcontroller.
2. Serial Communication: The Arduino microcontroller uses serial communication to transmit the sensor data to Raspberry Pi. Serial communication allows data transfer between Arduino and Raspberry Pi.
3. Data Analysis with Python: Raspberry Pi receives sensor data and uses Python code to analyze the data. The Python code processes and interprets the received data according to the desired analysis algorithms or logic.
4. Sending Data to Thingspeak: After data analysis, Raspberry Pi sends the processed data to the Thingspeak platform. Thingspeak is an IoT analytics platform that allows users to store, analyze, and visualize their sensor data.
5. Accessing Data: By sending the data to Thingspeak, the user gains access to the latest sensor data. Users can access this data through the Thingspeak platform's user interface or retrieve it programmatically through APIs provided by Thingspeak.

By employing this setup, the sensor data is transmitted from the sensors to the Arduino via serial communication. The Arduino forwards the data to the Raspberry Pi, where it is analyzed using Python code. Finally, the processed data is sent to Thingspeak, enabling users to access and interact with the data for various purposes. The developed smart greenhouse prototype is shown in Figure 8.

Figure 8. Prototype smart greenhouse

4. RESULTS AND FUTURE WORKS

The system has been carefully designed to be self-sustaining in terms of energy consumption and user-friendly for easy control. The prototype greenhouse serves as a confirmation of these qualities. However, the system has further development potential and there are future studies that could expand its capabilities. One of the areas of development is digital twin technology. Thanks to the real-time information and insights provided, digital twin technology offers various advantages such as improved performance, predictive capabilities, and remote monitoring. In this context, this technology involves creating a virtual copy of a physical system in a computer environment. Accordingly, sensors data from a greenhouse can be used for remote monitoring and predictive features to improve performance.

Digital twin technology involves creating a virtual replica of a physical system in a computer environment. In the case of the prototype greenhouse, the most significant resource for creating a digital twin would be the sensor data. Once this data is stored, it can be used to generate various scenarios. Risk analysis can be performed based on these scenarios, and necessary warnings or alerts can be provided to the user. Ultimately, by automating the control of the components within the system, the goal is to achieve a fully automated system.

Future developments in the system's evolution encompass the integration of digital twin technologies and its transition toward a fully automated state. These advancements are poised to augment the system's capabilities, efficiency, and dependability, thereby paving the way for a more sophisticated and intelligent control of the greenhouse environment. The incorporation of a soil mineral level sensor represents a noteworthy contribution to the research endeavor. This sensor enables us to monitor the essential minerals required for plant growth. Consequently, it allows us to supply the requisite minerals to the soil via the irrigation system. The irrigation system, equipped with sensor data, is poised to deliver the essential minerals to the plants automatically. For instance, in the event of a sensor detecting a low nitrogen level, it can administer a nitrogen-rich fertilizer or nutrient solution to the soil autonomously. This proactive approach promotes the healthy growth and development of the plants. The soil mineral level sensor plays a pivotal role in furnishing minerals necessary for plant growth promptly and accurately. This not only enhances plant development and productivity but also facilitates the judicious utilization of fertilizers and water, thereby contributing to the optimization of resource management.

This new development will improve the ability to provide the essential mineral nutrients for optimal plant growth, transforming it into a more sophisticated plant cultivation and management system. Plant growth optimization will boost production and improve resource management. Image processing is widely used for plant disease detection. Plant diseases are symptoms produced by pathogenic organisms or infections that degrade plant health and reduce production. Image processing tools let us detect plant illness by analyzing photos of plant leaves or other plant elements [13].

The following steps are commonly included in the identification of plant diseases using image processing:

1. Image Acquisition: First, high-resolution photographs of plant leaves or plant components are obtained. These photos will be obtained with the help of a Raspberry Pi camera.
2. Preprocessing: The resulting images go through preprocessing steps. These steps are contrast enhancement, color conversion, noise reduction, and image corrections. Their purpose is to improve image quality to get better analysis.
3. Feature Extraction: To identify disease signs, features are retrieved from photos. The color, shape, texture, and morphological properties of leaves are examples of these qualities. Feature extraction allows for picture analysis utilizing statistical or artificial intelligence-based techniques.
4. Classification: The collected characteristics are added to the classification models utilizing machine learning or artificial intelligence approaches. These models are used to tell the difference between healthy and diseased plants. Diseases are detected using categorization findings.
5. Disease Detection and Analysis: Plant diseases are detected and evaluated based on classification results. The purpose of this analysis is to ascertain the type, severity, or scope of the disease. Based on this knowledge, relevant actions or interventions can be implemented to lessen the disease's impacts.

Image processing represents a rapid, efficient, and automated approach to the detection of plant diseases. This technology has evolved into a pivotal tool for both monitoring plant health and facilitating the early diagnosis of diseases within the agricultural sector.

In summary, in this study, a smart greenhouse prototype was developed and an exemplary digital twin technology infrastructure was prepared. In future research, a completely automated greenhouse system could be realized through the analysis of collected data using AI techniques. Sophisticated greenhouse management systems can be created by capturing parameter values from sensors at specific intervals. This process can facilitate the generation of recommendations for optimal climatic conditions conducive to plant growth.

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