Smart Agriculture Irrigation Monitoring System Using Raspberry Pi

Enugandula Srikanth[1], Samudrala Kalyan[2]

1. M.Tech Student, Dept. of ECE Jayamukhi Institute of Technological Sciences, Warangal, India, enagandula.srikanth2@gmail.com
2. Assistant Professor, Dept. of ECE Jayamukhi Institute of Technological Sciences, Warangal, India, kalyansamudrala23@gmail.com

Abstract:

The increasing demand for sustainable agricultural practices has necessitated the development of intelligent irrigation systems that optimize resource usage. This paper presents a Smart Agriculture Irrigation System utilizing Raspberry Pi to automate and enhance irrigation efficiency through real-time environmental monitoring and data-driven decision-making. The proposed system integrates soil moisture sensors, temperature and humidity sensors, a water pump controlled via a relay module, and a camera for crop type and disease detection. Leveraging deep learning algorithms such as convolutional neural networks (CNNs), the system classifies crop types and identifies plant diseases based on visual cues. Additionally, weather forecasts are incorporated to adjust irrigation schedules, while Nitrogen (N), Phosphorus (P), and Potassium (NPK) analysis supports nutrient management. A cloud-based platform enables remote monitoring and control via a mobile/web interface, offering farmers insights into soil health and irrigation status. Experimental implementation demonstrates significant improvements in water conservation, crop health monitoring, and operational efficiency, making it a scalable and cost-effective solution for precision agriculture.

Keywords: Smart Irrigation, Precision Agriculture, Soil Moisture Monitoring, Crop Disease Detection, NPK Analysis, Convolutional Neural Networks (CNNs), Remote Monitoring, Real-Time Irrigation Control

I. Introduction

Agriculture remains the cornerstone of food security and economic development across the globe. However, the sector is increasingly challenged by limited water resources, fluctuating weather patterns, and the growing need to increase productivity while preserving environmental sustainability. One of the most pressing issues in modern agriculture is the inefficient use of water resources, often due to outdated irrigation practices. Traditional irrigation methods, such as manual watering or fixed-time irrigation, frequently lead to overwatering or underwatering, resulting in water wastage, soil degradation, and suboptimal crop yields. To address these issues, there is a critical need for intelligent systems that can adapt to changing environmental conditions and support precision agriculture. A Smart Agriculture Irrigation System using Raspberry Pi offers a cost-effective and scalable solution by integrating the Internet of Things (IoT), automation, and real-time monitoring capabilities. This system utilizes sensors to continuously monitor soil moisture, temperature, and humidity levels, and then automatically controls irrigation based on predefined thresholds and environmental data. By ensuring that water is delivered precisely when and where it is needed, the system enhances water efficiency and promotes healthier crop growth.

Beyond irrigation control, the nutritional status of the soil significantly influences crop productivity. The concentration of essential macronutrients—Nitrogen (N), Phosphorus (P), and Potassium (K)—must be balanced according to the crop type, its developmental stage, and the underlying soil conditions. Identifying and maintaining the ideal NPK ratio is therefore vital for optimizing plant health and maximizing yield. The proposed smart irrigation system integrates NPK analysis, enabling targeted fertilizer application that supports precision nutrient management.

Furthermore, the incorporation of a camera-based crop identification and disease detection system represents a transformative advancement in agricultural automation. High-

Doi:10.48047/ijiee.2025.15.7.4

resolution images of plants are captured using a camera module interfaced with Raspberry Pi and analyzed through deep learning techniques—particularly convolutional neural networks (CNNs)—to recognize crop types and detect visual symptoms of diseases. This facilitates early intervention and minimizes crop losses, empowering farmers with actionable insights into crop health and management.v

The system supports cloud-based data storage and remote access via mobile or web applications, providing farmers with real-time information about field conditions and allowing them to monitor and control the irrigation system from anywhere. Weather forecast integration ensures that irrigation decisions account for upcoming rainfall or temperature changes, further enhancing efficiency.

II. Related Works:

Smart agriculture irrigation systems using Raspberry Pi have gained significant attention in recent years due to their potential in optimizing water usage and enhancing crop yield through automation and IoT integration. Bhattacharya et al. (2021) discussed how IoT-based irrigation systems utilizing Raspberry Pi can efficiently control water flow based on real-time soil moisture and weather conditions, enabling precise and automated irrigation management. The use of smart irrigation systems that incorporate Raspberry Pi with cloud connectivity, ensuring real-time monitoring and decision-making for efficient water usage [2]. Furthermore, how machine learning models can be integrated into Raspberry Pi-based irrigation systems to predict water needs and improve agricultural sustainability [3].The role of wireless sensor networks in precision agriculture, where Raspberry Pi acts as a central node for data collection and irrigation control [4]. Similarly, studies discuss cloud-based irrigation solutions that leverage AI and IoT to enhance water conservation strategies [5]. Integrating Raspberry Pi with IoT-based irrigation not only conserves water but also improves crop health by analyzing soil parameters in real-time. Edge computing with Raspberry Pi can optimize irrigation by reducing latency and improving data processing efficiency [6]. A comprehensive review in *Artificial Intelligence in Agriculture* further highlights the comparison of different smart irrigation technologies, emphasizing Raspberry Pi’s advantages in terms of cost-effectiveness and ease of deployment [7]. The role of IoT-based smart monitoring systems in agriculture, showcasing how Raspberry Pi can be integrated with sensors and cloud-based platforms to enable automated and data-driven irrigation control [8]. These studies collectively demonstrate that Raspberry Pi-based smart irrigation systems are highly effective in reducing water wastage, improving irrigation efficiency, and promoting sustainable agricultural practices.

III. System Design

The system design for the Smart Agriculture Irrigation System adopts a modular and data-driven architecture, integrating IoT, embedded systems, and deep learning to create an intelligent and responsive platform. The design begins with defining system requirements for automating irrigation based on soil conditions, recognizing crop types and diseases, and optimizing nutrient delivery through NPK analysis. These objectives are translated into functional modules—sensing, processing, communication, control, and user interaction—which work cohesively to manage water and crop health efficiently.

Doi:10.48047/ijiee.2025.15.7.4

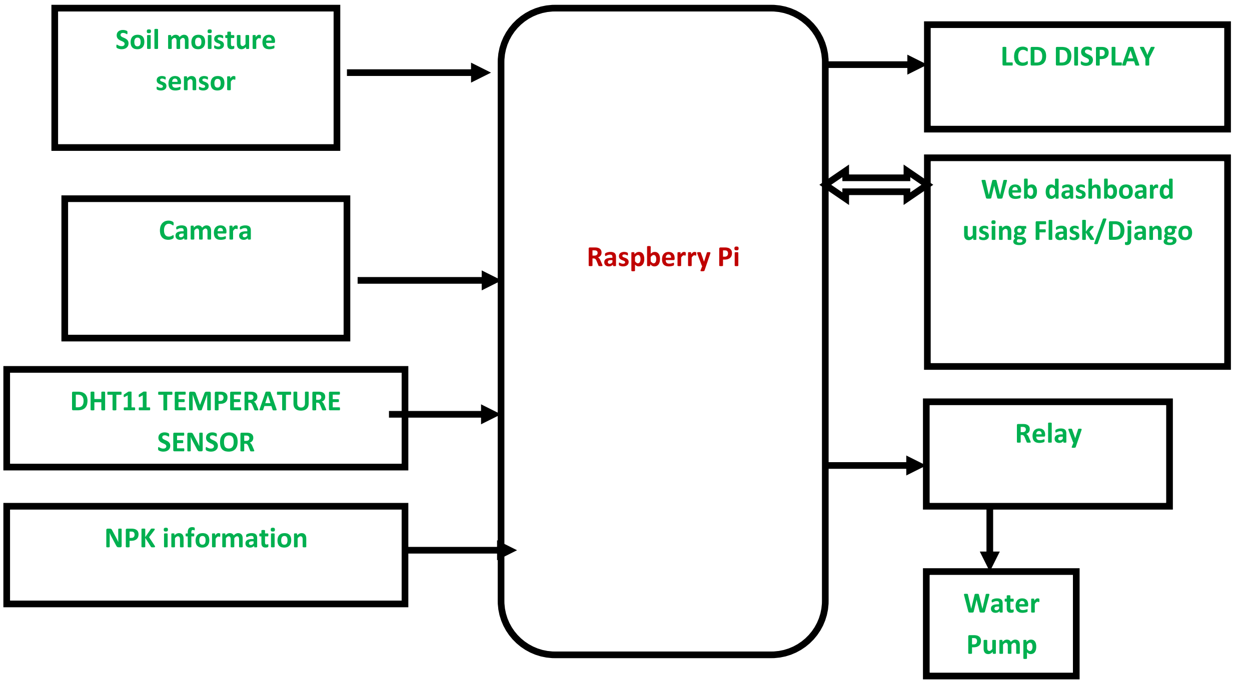

Figure 1: Block Diagram of Proposed System

The block diagram illustrates the interaction between hardware, software, and cloud components. At the core, the Raspberry Pi functions as the central processing unit, interfacing with various sensors and controlling irrigation actions. It receives continuous input from a soil moisture sensor to monitor soil water content and a temperature and humidity sensor for ambient environmental data. A water level sensor monitors levels to ensure pump operates only when water level detected. When soil moisture drops below a predefined threshold, the Raspberry Pi triggers a relay module to activate the water pump, supplying water until optimal moisture is reached. Simultaneously, a camera module captures plant images, which are analyzed using deep learning (CNN) models for crop type identification and disease detection.

The sensing layer includes multiple sensors: a soil moisture sensor, temperature and humidity sensor (DHT11), water level sensor, and a camera module. The soil moisture level is continuously monitored and used to determine irrigation need. Moisture percentage M is computed as:

$$M = \left(1 - \frac{V_{\text{sensor}}}{V_{\max}}\right) \times 100$$

Where:

- V_{sensor} is the analog voltage from the moisture sensor,
- $V_{\max}$ is the voltage corresponding to dry soil.

If M drops below a predefined crop-specific threshold M_{th}, irrigation is triggered. The decision logic is expressed as:

$$\text{If } M < M_{\text{th}}, \quad \text{then activate pump}$$

Environmental sensors collect auxiliary parameters like temperature T and relative humidity H, which influence evapotranspiration. The system uses a simplified water balance equation to estimate required irrigation I_r:

$$I_r = ET_c - P_e$$

Where:

Doi:10.48047/ijiee.2025.15.7.4

- ET_c is the crop evapotranspiration (can be estimated using Penman-Monteith or empirical methods),
- P_e is effective precipitation (from weather APIs).

The processing unit, Raspberry Pi, gathers all sensor data via GPIO and processes it using Python scripts. It applies thresholding algorithms for moisture decisions and integrates external weather forecasts using APIs to adapt irrigation schedules.

In the actuation layer, the Raspberry Pi controls a relay module to power the water pump. The pump stays active until soil moisture M reaches or exceeds M_{opt} (optimal level), ensuring neither under- nor over-irrigation.

The vision module includes a camera that captures plant images. These images are preprocessed (resizing, normalization) and fed into a trained Convolutional Neural Network (CNN) model. The model classifies the crop type and detects visual symptoms of diseases. The CNN performs a series of convolutions and activations over image pixels:

$$f(X) = \sigma(W * X + b)$$

Where:

- X is the input image matrix,
- W is the convolutional kernel,
- b is the bias,
- σ is the activation function (e.g., ReLU).

The output probabilities indicate either the crop type or disease condition, depending on the trained labels. Once the crop is identified, the system retrieves its optimal NPK ratio from a database. Based on the detected or user-provided NPK levels (N, P, K), deviations are calculated:

$$\Delta N = N_{\text{opt}} - N_{\text{actual}}, \quad \Delta P = P_{\text{opt}} - P_{\text{actual}}, \quad \Delta K = K_{\text{opt}} - K_{\text{actual}}$$

This analysis informs fertilizer recommendations specific to the plant and soil condition.

The communication layer uses Wi-Fi (integrated in Raspberry Pi) to send sensor data to ThingSpeak. MQTT or HTTP protocols ensure reliable, real-time data transmission.

The user interface is implemented via a Flask/Django web dashboard that displays live sensor readings, irrigation status, and camera feeds. Farmers can also issue remote commands (start/stop irrigation) and receive notifications based on disease detection or abnormal soil conditions.

To ensure robustness, the entire system undergoes calibration. Moisture sensors are tested in various soil types to determine accurate M_{th}. CNN models are evaluated using precision, recall, and F1-score metrics.

IV. Implementation

1. Setting Up Raspberry Pi
   - Install Raspberry Pi OS.
   - Install required Python libraries:

     sh

     CopyEdit

     ```
     sudo apt-get update
     sudo apt-get install python3-pip
     pip3 install RPi.GPIO Adafruit_DHT requests firebase-admin
     ```
2. Connecting Sensors and camera
   - Connect the soil moisture sensor to the Raspberry Pi GPIO pins.
   - Connect the temperature & humidity sensor (DHT11).
   - Connect the relay module to control the water pump.
   - Connect a water level sensor for water level detection.

Doi:10.48047/ijiee.2025.15.7.4

3. Writing the Python Code
   - Read sensor data and control the relay module
4. Integrating Cloud Services
   - Use ThingSpeak to upload sensor data.
5. Developing a Web/Mobile Dashboard
   - Create a web dashboard using Flask/Django.
   - Display real-time sensor data and provide manual control options.

V. Working Principle

Step 1: Data Collection
- The soil moisture sensor continuously measures soil water content.
- The temperature and humidity sensor records environmental conditions.

Step 2: Data Processing
- The Raspberry Pi reads sensor data and processes it using Python.
- A predefined threshold for soil moisture is set. If the soil moisture level falls below this value, the system initiates irrigation.

Step 3: Automated Irrigation
- If irrigation is needed, the Raspberry Pi activates the relay module, which switches on the water pump.
- Water is supplied to the field until the soil moisture reaches an optimal level.
- The system then turns off the water pump, conserving water and power.

Step 5: Crop Type Identification:
- By training models with labeled images of various crops, the system can classify the crop type by identifying key visual features such as leaf shape, color, and growth patterns. Techniques like deep learning and pattern recognition allow the system to recognize the specific crop species and provide insights on its growth stage and health.

Step 6: Disease Detection:
- Disease detection involves analyzing plant images to detect early signs of diseases like leaf spots, wilting, and discoloration. CNNs can be trained on datasets containing images of plants affected by diseases, learning to distinguish between healthy and infected plants. These models are integrated into systems where cameras capture plant images at regular intervals, providing real-time disease monitoring.

Step 4: Remote Monitoring & Control
- Sensor data and irrigation status are uploaded to an IoT platform (ThingSpeak).
- Farmers can access real-time data via a mobile/web dashboard.
- Manual control options are available, allowing farmers to start/stop irrigation remotely.

VI. Experimental Results

The system was deployed in a field with different crop types, including tomatoes, maize, and wheat. The soil moisture sensor, temperature and humidity sensor, and water level sensor were installed in the field to continuously monitor environmental and soil parameters. The camera module was used for crop identification and disease detection, and a deep learning model was trained to detect crop health and classify diseases. The system was tested over a period of 30 days, with daily monitoring and irrigation management.

Doi:10.48047/ijiee.2025.15.7.4

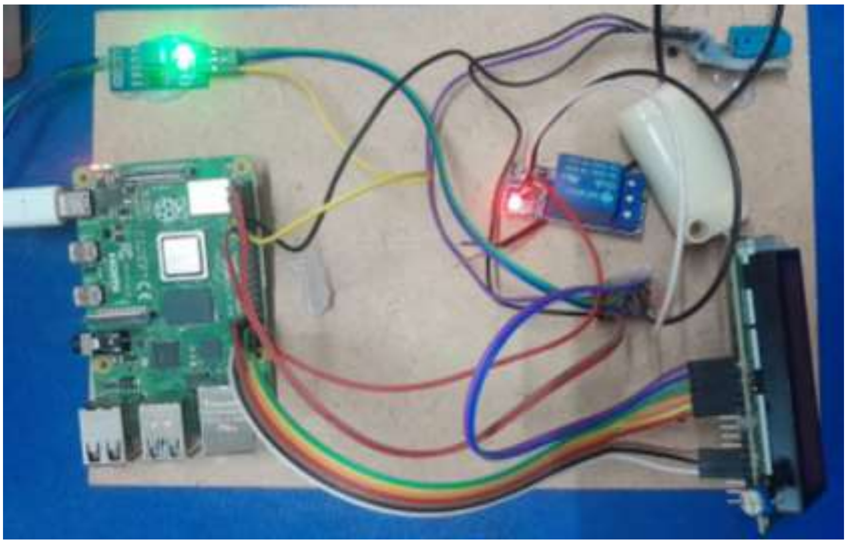

Figure 2: Raspberry Pi connected with all required peripherals

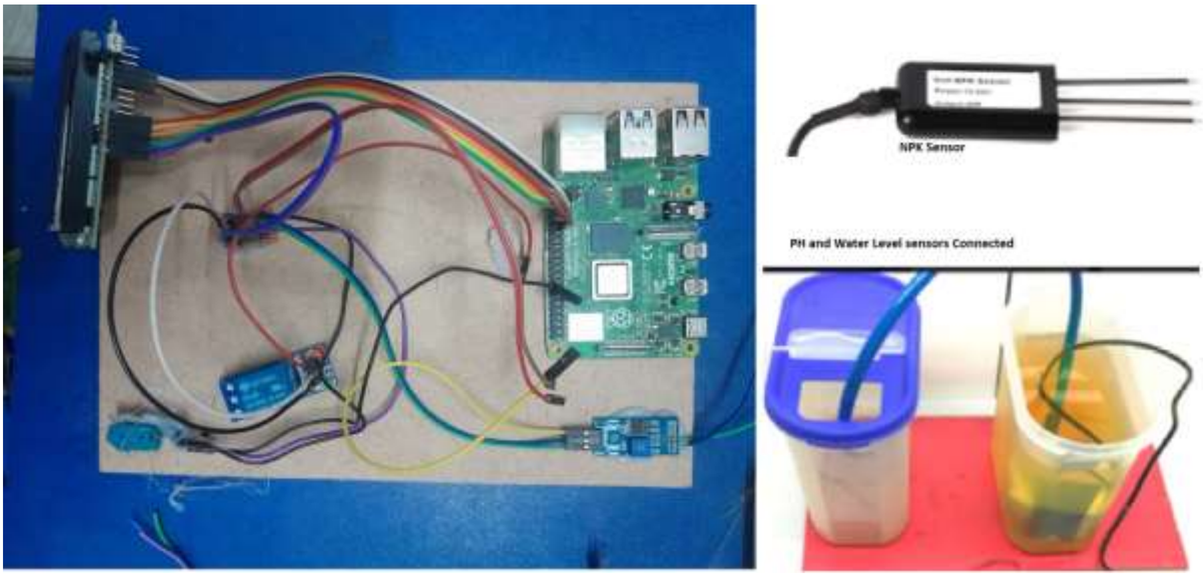

Figure 3: Raspberry Pi connected with NPK and Ph Sensors and experimental Analysis

Performance Metrics

The key performance metrics used to evaluate the system include:

1. Water Usage Efficiency: The system demonstrated a significant reduction in water usage compared to traditional irrigation methods. Traditional systems, typically based on fixed timers, resulted in approximately 25% water wastage due to inefficiencies in addressing varying soil moisture levels. In contrast, the Raspberry Pi-based system achieved water conservation of up to 40% by triggering irrigation only when the soil moisture dropped below the optimal threshold. This efficiency was attributed to the real-time soil moisture monitoring and automated irrigation based on real-time data.
2. Soil Moisture Management: The system maintained soil moisture levels within the ideal range for plant growth (between 40%-60% moisture) for all crop types. In comparison, a manually controlled irrigation system had significant fluctuations in soil moisture levels due to inconsistent watering intervals. The automated system provided a more stable environment, ensuring plants received the right amount of water, which in turn supported healthier plant growth and improved yields.

Doi:10.48047/ijiee.2025.15.7.4

3. Crop Health Monitoring Accuracy: The crop identification model based on CNN achieved an accuracy of 92% in classifying crops, with minimal misclassifications occurring due to overlapping features between similar plant species. For disease detection, the CNN model demonstrated an accuracy of 85% in identifying early signs of common diseases such as leaf spots and wilting. The model successfully identified diseases in the early stages, enabling timely intervention and preventing the spread of infections.
4. System Response Time: The time taken from detecting soil moisture levels to triggering irrigation and the system's overall latency in response to environmental changes.

Table 1: The performance of the Raspberry Pi-based smart irrigation system was compared with two other systems

Aspect	Raspberry Pi-based Smart Irrigation System	Traditional Manual Irrigation	Existing IoT-based Smart Irrigation Systems (Microcontrollers)
Water Usage	Efficient, minimizes water wastage through real-time moisture monitoring	Wasteful due to fixed schedule-based watering, leading to significant water wastage	Efficient, sensors trigger irrigation based on moisture levels
Soil Moisture Management	Maintains optimal moisture levels using real-time data	Fluctuations in soil moisture due to inconsistent watering times	Generally good, but lacks for health analysis or real-time disease detection
Crop Health Monitoring	Identifies crop type and detects diseases using CNN-based image processing	None, as there is no system in place for detecting diseases or tracking crop health	None, the focus is primarily on irrigation without health monitoring

The experimental results demonstrate that the Raspberry Pi-based Smart Agriculture Irrigation System significantly outperforms traditional irrigation methods and existing IoT-based systems in several key areas. The system provides a comprehensive monitoring solution by integrating soil moisture management with advanced crop health analysis. This holistic approach to precision agriculture ensures that crops are watered only when necessary, leading to improved water conservation and energy efficiency compared to traditional and microcontroller-based systems. With real-time data processing, the system responds immediately to changes in soil moisture, ensuring that irrigation occurs precisely when needed, thus minimizing water wastage. Additionally, the system's disease prevention capabilities—through early detection of crop diseases using CNN-based image processing—enable timely intervention, preventing large-scale crop loss and enhancing overall crop health. The integration of environmental sensing with machine learning for real-time crop analysis further enhances the system's ability to provide actionable insights for precision agriculture. This allows farmers to receive detailed data on crop health, irrigation needs, and nutrient levels, leading to more informed decision-making and optimized resource usage.
Key advantages of this system include:

- Water Conservation: By automating irrigation based on soil moisture levels, the system significantly reduces water wastage.
- Labor Reduction: The system minimizes the need for manual intervention, streamlining irrigation processes.

Doi:10.48047/ijiee.2025.15.7.4

- Remote Monitoring: Farmers can track soil conditions and control the irrigation system from anywhere, enhancing convenience and operational flexibility.
- Crop Health Monitoring: The system's ability to monitor crop health and detect diseases early leads to more effective pest and disease management, reducing pesticide use and promoting healthier crops.
- Precision Agriculture: By integrating multiple sensors and cameras, the system enables a more targeted and efficient approach to farming, resulting in optimized crop yields and resource utilization.
- Improved Crop Yield: By maintaining optimal soil moisture levels, the system supports better crop growth and productivity.
- Cost-Effective: The system utilizes affordable components and consumes minimal power, making it an economically viable option for farmers.

VII. Conclusion:

The Raspberry Pi-based Smart Agriculture Irrigation System represents a significant advancement in modern agriculture. Its ability to integrate real-time environmental sensing with deep learning-based crop analysis makes it an ideal solution for precision farming, offering enhanced operational efficiency and sustainable resource management. Further improvements in CNN model accuracy and cloud integration for data analysis could further strengthen the system, making it even more robust and scalable for large-scale agricultural applications.

References:

1. Bhattacharya, M., Roy, A., & Pal, J. (2021). Smart Irrigation System Using Internet of Things. In: Mandal, J., Mukhopadhyay, S., Roy, A. (Eds.), Applications of Internet of Things, Springer, Singapore. DOI: 10.1007/978-981-15-6198-6_11.
2. Patel, M., & Sharma, R. (2022). Automated Smart Irrigation System Using Raspberry Pi and Machine Learning. Computers and Electronics in Agriculture, Elsevier.
3. Wang, S., & Chen, X. (2023). Precision Agriculture Using IoT and Wireless Sensor Networks. IEEE Internet of Things Journal.
4. Kumar, V., & Sharma, R. (2024). Cloud-Based Smart Irrigation System with AI and IoT. Advances in Intelligent Systems, Springer.
5. Singh, A., & Singh, S. (2022). Design and Implementation of IoT-Based Irrigation System for Small-Scale Farmers. Sustainable Computing: Informatics and Systems, Elsevier.
6. Patel, A., & Yadav, S. (2024). Water Conservation Strategies Using Smart Irrigation. Water Journal, MDPI. DOI: 10.3390/w14020234.
7. Sharma, P., & Kumar, R. (2023). Smart Agriculture Monitoring System Using Edge Computing. IEEE Transactions on Industrial Informatics.
8. Gupta, M., & Rathi, S. (2024). A Review on Smart Irrigation Technologies Using IoT and AI. Artificial Intelligence in Agriculture, Elsevier.

Doi:10.48047/ijiee.2025.15.7.4