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SUMMER INTERNSHIP PROJECT REPORT

Smart Hydroponics Vertical Farming using AI and IoT

Supervisor:
Dr. Kamlesh Ahuja
IT and AI & DS Department
Mahakal Institute of Technology

Submitted By:
Jayesh Chak (202111040)
B.Tech CSE
Batch 2021-2025

Smart Hydroponic System – An AI and IoT-Driven Solution for Controlled Environment Vertical Farming

Dr. Kamlesh Ahuja
Dept. (AI & DS and IT)
MIT (RGPV, Bhopal, Vikram University)
Ujjain, IN
ahujakamlesh24@gmail.com

Jayesh Chak
Btech CSE
IIIT Vadodara ICD, 2021-2025
Ujjain, IN
202111040@diu.iiitvadodara.ac.in

***Abstract*—This report details the Smart Hydroponics Vertical Farming project undertaken during my internship at Mahakal Institute of Technology, Ujjain, MP from May 15 to July 15. The internship provided an invaluable opportunity to apply theoretical knowledge to a practical problem. The project's objective is to enhance hydroponics farming practices using AI and IoT technologies, focusing on crop recommendation, fertilizer suggestion, and disease prediction. The report outlines the phases of development, challenges faced, and future directions.**

***Index Terms*—Hydroponics, Artificial Intelligence, Internet of Things, Crop Recommendation, Fertilizer Suggestion, Crop Disease Identification, ResNet45.**

I. Introduction

Hydroponics farming is an innovative method of growing plants without soil, using minerals and nutrient-rich water solutions. This technique allows plants to grow with their roots directly exposed to nutrient-rich water, providing an efficient and sustainable alternative to traditional soil-based agriculture. By precisely controlling the nutrient intake, including essential 16 micro and macro-nutrients, and maintaining optimal pH, electrical conductivity (EC) levels, humidity, and sunlight, hydroponics systems ensure that plants receive the necessary elements for healthy growth.

This method offers numerous advantages, such as faster plant growth, higher yields, and the ability to grow crops in environments with limited or poor-quality resources and space. However, different localities have varying water hardness and quality, which can affect crop yield and require specific adjustments to nutrient solutions and water treatment. Additionally, traditional farming methods have led to significant soil degradation through overuse, erosion, and depletion of nutrients, making hydroponics a viable alternative for sustainable crop production.

The moral motives behind hydroponics farming include promoting sustainability, reducing pesticide use, and enabling urban populations to grow their own food, thus decreasing the carbon footprint associated with long-distance transportation of produce and other irregularities. Despite its benefits, hydroponics faces challenges such as the need for precise nutrient management, constant environmental control, and early disease detection.

These challenges can be effectively addressed using AI and IoT technologies. AI can analyze data and provide precise nutrient recommendations, optimize environmental conditions, and detect early signs of disease through image recognition. IoT sensors offer real-time monitoring of water quality and contents, environmental conditions, and system performance, enabling efficient water and resource management.

The Smart Hydroponics Vertical Farming project aims to leverage AI and IoT to enhance hydroponics farming practices. It follows a structured development roadmap, including requirement analysis, data acquisition and preprocessing, modeling, web user interface development, and IoT integration and deployment. The project provides accurate crop recommendations, fertilizer suggestions, and disease predictions, improving farming efficiency and productivity. Additionally, the project explores the potential of making hydroponics a household activity. Ultimately, this project seeks to create a sustainable and efficient solution for modern agriculture, contributing to food security and environmental conservation.

II. Phase 1: Requirement Analysis

A. Literature Review

To understand the fundamental concepts of hydroponics farming and the integration of AI and IoT in controlled environment agriculture, we reviewed several research papers, including:

1) *IoT-Based Hydroponics System Using Deep Neural Networks* by Manav Mehra, Sameer Saxena, Suresh Sankaranarayanan, Rijo Jackson Tom, and M. Veeramanikandan. This paper presents an intelligent IoT-based hydroponic system using deep neural networks. The system uses sensors to monitor parameters like pH, temperature, humidity, light intensity, and water level in a hydroponic tank for tomato plants. A deep neural network model with two hidden layers is trained on 5000 data points to predict appropriate control actions (labeled 0-7) based on the sensor inputs. The model achieves 88.50% accuracy. The trained model is deployed on a Raspberry Pi 3, which acts as an edge device communicating with an Arduino microcontroller to implement the predicted control actions. The real-time data and

predictions are stored in a cloud database for monitoring. The system aims to automate and optimize hydroponic plant growth.

2) *Smart Hydroponics System Integrating with IoT and Machine Learning Algorithm* by Srinidhi H. K., Shreenidhi H. S., and Vishnu G. S. This paper presents a smart hydroponic system integrating IoT and machine learning. The system uses sensors to monitor parameters like temperature, EC, pH and humidity in a hydroponic setup. It employs computer vision with OpenCV to analyze plant growth. The data is processed using KNN and Lasso Regression algorithms to make decisions for optimal plant growth. A mobile app displays sensor data and growth progress to users. The system aims to maximize crop yield and quality while using fewer resources compared to traditional farming. It can be scaled from small personal devices to large farms. The authors developed a prototype and tested it on tomato plants, demonstrating improved growth using this automated, data-driven approach to hydroponics.
3) *Revolutionizing Holy-Basil Cultivation with AI-Enabled Hydroponics System* by G. Lakshmi Priya, Chanthini Baskar, Sanket Sandeep Deshmane, C. Adithya, and Souranil Das. This research presents an AI-enabled hydroponic system for cultivating Holy Basil using IoT and machine learning. The system employs sensors to monitor environmental parameters and uses logistic regression to optimize growth conditions. It features an ESP32-based hardware setup, cloud integration with Azure services for data processing and decision-making, and a React-based monitoring portal. The system achieves 95% validation accuracy and reduces manual monitoring. Key components include temperature, pH, turbidity, and RGB color sensors, along with nutrient dispensing controls. Cloud connectivity enables advanced analytics and remote monitoring. While showing promise for efficient hydroponic agriculture, the system faces challenges in scalability and adaptability. Overall, it demonstrates the potential of IoT and ML in improving hydroponic farming efficiency, particularly for exotic and medicinal plants.
4) *Plant Disease Classification Using Deep Learning* by KP, A., and Anitha, J. (2021). 3rd International Conference on Signal Processing and Communication (ICPSC).This paper discusses using deep learning models for plant disease classification. The authors trained convolutional neural networks (CNNs) and pre-trained models like VGG, ResNet, and DenseNet on a dataset of grape plant leaf images. The models were used to classify leaves as healthy or affected by diseases like black rot, esca, or leaf blight. Data augmentation was used to expand the dataset and prevent overfitting. The DenseNet model achieved the highest accuracy at 98.27%. The authors suggest this approach could help farmers detect plant diseases early using mobile cameras. Future work includes expanding the dataset and deploying the model in a mobile application.

B. Crop Study Summary

We conducted a detailed study on the requirements and suitability of various crops for hydroponics:

1) **Macro and Micro Nutrients**: Essential elements for plant growth are categorized as macronutrients (needed in larger quantities - Nitrogen, Phosphorus, Potassium) and micronutrients (needed in smaller quantities - Sulfur, Copper, Chlorine, Boron, Iron, Zinc, Manganese, Molybdenum, Nickel, Cobalt, Sodium).
2) **Crops Suitable for Hydroponics**: Leafy greens (e.g., Lettuce, Kale), herbs (e.g., Basil, Mint), and some fruiting vegetables (e.g., Cucumber, Tomato) thrive in hydroponic systems due to their shallow root structures and high water requirements.
3) **Atmospheric Conditions**:
    a) **Temperature**: Optimal temperature ranges vary by crop, typically between 65-78°F (18-26°C).
    b) **Humidity**: Maintaining moderate humidity (50-70
    c) **Sunlight**: Depending on the crop, sufficient artificial or natural light is crucial for photosynthesis.

C. Fertilizer Study Summary

Hydroponic nutrient solutions provide a controlled way to deliver essential elements directly to plant roots:

1) **Macro and Micro Nutrients**: Pre-mixed solutions or individual components can be used depending on the chosen crop and its growth stage.
2) **pH and EC**: Maintaining proper solution pH (acidity/alkalinity) and electrical conductivity (EC, nutrient concentration) is vital for nutrient uptake.
3) **Water Hardness**: Hard water can affect hinder crop growth and nutrients in solution. Using a water softener or adjusting the nutrient solution may be necessary.

D. Disease Study Summary

Common hydroponic diseases and their impact on crop health were studied:

1) **Common Hydroponic Diseases**: Fungal diseases like Pythium rot and bacterial diseases like Soft rot can be problematic in stagnant water environments.
2) **Damage**: Diseases can cause stunted growth, wilting, and even crop loss. Early detection and preventative measures like maintaining good sanitation and proper nutrient levels are crucial.
3) **Resolution**: Management strategies include regular sanitation to prevent pathogen buildup by cleaning and sterilizing equipment, tools, and hydroponic systems. Water quality management ensures proper aeration and circulation, preventing stagnant water conditions while monitoring and adjusting pH and nutrient levels to support plant health. Biological controls involve using beneficial microbes or biofungicides to suppress pathogenic organisms. Chemical controls, such as fungicides or

bactericides, are applied as a last resort following integrated pest management (IPM) principles to minimize resistance development. Additionally, selecting crop varieties that are resistant or tolerant to common diseases in hydroponic systems is essential.

III. Phase 2: Data Preparation and Preprocessing

In this phase, we focused on preparing and preprocessing our datasets that we have gathered from Phase 1 Analysis: `crop.csv`, `fertilizer.csv`, and `Disease (Images Dataset from Kaggel)`. Data preparation and preprocessing are critical steps in any data-driven project. They ensure that the data is clean, reliable, and suitable for analysis and modeling. Below are the steps we followed:

A. Data Cleaning

We began by inspecting the datasets for missing values, outliers, and inconsistencies. This involved checking for any missing values, duplicates, and anomalies in the data. We used various techniques to address these issues, such as:

1) **Handling Missing Values**: We filled in missing values using appropriate imputation methods, such as mean, median, or mode imputation, or by using more advanced techniques like regression imputation.
2) **Removing Duplicates**: We identified and removed duplicate entries from the datasets to ensure data integrity.
3) **Outlier Detection and Treatment**: We used statistical methods to identify and handle outliers that could the results.

B. Data Transformation

To make the data suitable for analysis, we performed various transformation steps:

1) **Normalization and Scaling**: We normalized and scaled the data to ensure that all features are on a similar scale. This step is essential for machine learning algorithms that rely on distance measures.
2) **Encoding Categorical Variables**: We converted categorical variables into numerical representations using techniques like one-hot encoding or label encoding.
3) **Feature Engineering**: We created new features or transformed existing ones to enhance the predictive power of the data. This involved deriving new attributes from the existing data based on domain knowledge.

IV. Phase 3: Model Development and Training

In this phase, we focused on developing and training machine learning models for crop recommendation, fertilizer suggestion, and disease prediction using the preprocessed data that we have obtained. Below are the steps we followed:

A. Crop Recommendation Model

To recommend suitable crops based on water quality and atmospheric factors, we developed a machine learning model using various algorithms. The steps involved were:

1) **Feature Selection**: We selected relevant features from the dataset that are indicative of crop suitability. These features included water quality parameters, atmospheric conditions, and nutrient requirements.
2) **Model Training**: We trained the model using supervised learning algorithms like Decision trees, Gaussian Naive Bayes, Random forests, Linear Regression, XGBoost and Support Vector Machines (SVM). We also employed Hyper parameter tuning to improve the accuracy of the predictions.
3) **Model Evaluation**: We evaluated the each model's performance using metrics such as accuracy, precision, recall, and F1-score. We also performed cross-validation to ensure the model's robustness and generalization and chose the model with highest accuracy i.e., (Gaussian Naive Bayes 97.3%).

B. Fertilizer Suggestion Model

To suggest the appropriate fertilizer based on crop name, growth stage, and current water quality, we developed a machine learning model using the following steps:

Input:

1) Dataset: `crop.csv`, `fertilizer.csv`
2) Input Parameters: Crop name, Crop growth rate, Current water nutrition content (Nitrogen, Phosphorus, Potassium, Sulfur, Copper, Chlorine, Boron, Iron, Zinc, Manganese, Molybdenum, Nickel, Cobalt, Sodium, pH, EC)

Steps:

1) **Load Data:** Load the datasets `crop.csv` and `fertilizer.csv`.
2) **Extract Crop Requirements:**
   a) Find the tuple in `crop.csv` matching the crop name and growth stage.
   b) Extract crop nutrient requirements, pH, and EC from this tuple.
3) **Compute Nutrient Differences:**
   a) Create a difference array where each element is calculated as:
   `Difference = Crop Requirement - Current Water Content`.
   b) Compute the net difference quantity by summing up the positive values in the difference array.
4) **Find Suitable Fertilizers:**
   a) Initialize an empty list for recommended fertilizers.
   b) For each positive difference value:
      i) Use `fertilizer.csv` and the difference values to find fertilizers that satisfy the nutrient requirements.
      ii) Append the fertilizer name to the list and update the remaining nutrient needs.
      iii) Repeat until the difference values are minimized.
5) **Categorise Fertilizers:**

a) Create four variables to store fertilizers for:
   i) Base Fertilizer List
   ii) Fertilizer for pH balancing
   iii) Fertilizer for EC balancing
   iv) Fertilizer for Growth promotion

6) **Output:**
   a) Return the list of recommended fertilizers and the net difference quantity.

C. Plant Disease Identification and Treatment Tips

The project *Plant Disease Classification Using ResNet-45* aims to leverage deep learning techniques to accurately identify and classify diseases in plant leaves from images. This notebook provides a comprehensive guide, covering everything from basic terminologies to advanced implementation, making it an excellent resource for learners at all levels.

1) Introduction to Basic Concepts:

a) Convolutional Neural Networks (CNNs)::

- **Convolution Layer:** Extracts features from the input image by applying filters (kernels).
- **Pooling Layer:** Reduces the spatial dimensions of the feature maps, preserving essential information while reducing computation.
- **Fully Connected Layer:** Connects every neuron in one layer to every neuron in the next layer, used for making predictions.

b) ResNet Architecture::

- **Residual Blocks:** Helps in training deeper networks by allowing gradients to flow through the network directly. It addresses the vanishing gradient problem.
- **ResNet-45:** A simplified version of ResNet with 45 layers, providing a good balance between performance and computational efficiency.

2) Dataset Description: The dataset used in this project is an augmented version of the original PlantVillage Dataset, consisting of about 87,000 RGB images of both healthy and diseased crop leaves categorized into 38 different classes. The data is split into an 80/20 ratio for training and validation sets, maintaining the directory structure. A separate directory with 33 test images is created for prediction purposes. The dataset includes images from 14 plant species, with 26 types of diseases excluding healthy leaves.

3) Tools and Technologies:

- **PyTorch:** A deep learning library used for implementing and training neural networks.
- **Torchvision:** Provides easy-to-use datasets and transformations for computer vision tasks.
- **Torchsummary:** Used for generating a well-formatted summary of the model.
- **Matplotlib and Seaborn:** Libraries for data visualization to understand the distribution and characteristics of the dataset.

4) Data Exploration and Preprocessing:

a) Loading Data:: Import necessary libraries and load the dataset.

b) Data Augmentation:: Apply transformations such as random rotations, flips, and crops to increase the diversity of the training data.

c) Normalization:: Scale the pixel values to a range suitable for training neural networks, typically [0, 1] or [-1, 1].

5) Model Implementation:

a) Defining the ResNet-45 Model::

- Implement the ResNet-45 architecture using PyTorch.
- Use residual blocks to improve training efficiency and performance.

b) Training the Model::

- Define loss function (Cross-Entropy Loss) and optimizer (Adam).
- Train the model over multiple epochs, adjusting weights to minimize the loss function.

c) Evaluating the Model::

- Use metrics such as accuracy, precision, recall, and F1-score to evaluate the model's performance.
- Plot training and validation loss/accuracy to visualize the training process and detect overfitting.

6) Mathematical Foundations:

a) Convolution Operation::

$$(I * K)(x, y) = \sum_m \sum_n I(x - m, y - n) \cdot K(m, n) \tag{1}$$

Here, I is the input image, K is the kernel, and (x, y) represents the coordinates of the output feature map.

b) Activation Functions::

- **ReLU (Rectified Linear Unit):** $f(x) = \max(0, x)$
- **Softmax:** Used in the final layer for multi-class classification,

$$\sigma(z_i) = \frac{e^{z_i}}{\sum_j e^{z_j}} \tag{2}$$

c) Loss Function::

- **Cross-Entropy Loss:**

$$L = -\sum_i y_i \log(p_i) \tag{3}$$

Here, y_i is the true label, and p_i is the predicted probability.

V. PHASE 4.1: WEB USER INTERFACE DEVELOPMENT

In this phase, we developed a user-friendly web interface using Flask, React, JavaScript, HTML, CSS, Bootstrap, Python, and Postman.

A. User Interface Design

We designed the interface to provide a seamless experience, including a Home Page with an overview of the project and its objectives, a Services Page showcasing services like crop recommendation, fertilizer suggestion, and disease prediction, and interactive forms for user inputs such as water quality parameters, crop type, and images of diseased crops.

B. Development

We created the backend to handle user requests and interact with the models by developing RESTful APIs for input processing and model predictions, and integrating a database to store user data and model results.
We focused on displaying model predictions and enhancing user experience through visualization with card, ensuring responsive design for various devices, and incorporating user feedback channel to improve usability.
This phase ensured an accessible and efficient interface for user interaction with the models.

VI. Phase 4.2: IoT Integration (Future Work) and Deployment

In this phase, we focused on integrating IoT sensors into the hydroponics system and deploying the solution. The steps involved were:

A. IoT Sensor Integration

We integrated IoT sensors to monitor and control various aspects of the hydroponics system. This included:

1) **Water Quality Sensors**: Sensors to measure parameters like pH, EC, and nutrient levels.
2) **Environmental Sensors**: Sensors to monitor temperature, humidity, and light levels.
3) **Actuators**: Devices to control water pumps, lights, and nutrient delivery systems.

B. Data Collection and Analysis

We collected and analyzed data from the IoT sensors to provide real-time insights into the hydroponics system. This included:

1) **Data Logging**: Storing sensor data in a database for historical analysis and trend detection.
2) **Real-Time Monitoring**: Displaying real-time sensor data on the web interface to allow users to monitor the system's performance.
3) **Automated Alerts**: Implementing automated alerts to notify users of any anomalies or issues detected by the sensors.

C. System Deployment

We deployed the complete solution, including the web interface and IoT sensors, to a cloud platform. Here's the blueprint to follow : IoT enabled Hydroponics for Smart Farm Nuwan Wijewardane
This also included:

1) **Cloud Hosting**: Hosting the web application on a cloud platform to ensure scalability and reliability.
2) **Continuous Integration and Deployment (CI/CD)**: Implementing CI/CD pipelines to automate the deployment process and ensure that updates are seamlessly integrated into the system.
3) **Performance Optimization**: Optimizing the system's performance to handle large volumes of data and user requests efficiently.

VII. Challenges and Solutions

During the project, we encountered several challenges and implemented solutions to address them. Some of the key challenges and solutions are outlined below:

A. Data Quality and Availability

1) **Challenge**: Ensuring the availability of high-quality data for training the machine learning models was a significant challenge.
2) **Solution**: We addressed this challenge by sourcing data from reliable sources, performing rigorous data cleaning and preprocessing, and augmenting the data using techniques like data synthesis and transfer learning.

B. Model Performance

1) **Challenge**: Achieving high accuracy and generalizability, we studied and implemented different models, was challenging.
2) **Solution**: We used appropiate to dataset machine learning techniques, ensemble methods, and hyperparameter tuning to improve model performance. We also employed cross-validation and rigorous testing to ensure the models' robustness.

C. IoT Integration (Possible)

1) **Challenge**: Integrating IoT sensors into the hydroponics system and ensuring seamless communication between the sensors and the web application was challenging.
2) **Solution**: We used standardized protocols and frameworks for IoT integration and implemented robust data collection and communication mechanisms. We also performed extensive testing to ensure the reliability and accuracy of the sensor data.

VIII. Conclusion

In conclusion, the Smart Hydroponics Vertical Farming system successfully integrates AI and IoT technologies to enhance crop management and yield. The system provides valuable insights and recommendations for crop selection, fertilizer application, and disease prevention, contributing to sustainable and efficient farming practices.

A. Future Work

The project has significant potential for further development and enhancement. Some areas for future work include:

1) **Expanding Crop Database**: Increasing the diversity of crops supported by the system by sourcing and integrating additional data.
2) **Advanced Disease Detection**: Enhancing the disease prediction model by incorporating more sophisticated image recognition techniques and expanding the dataset of diseased crop images.
3) **IoT Automation**: Implementing IoT features, such as predictive maintenance and automated nutrient delivery systems.

4) **User Feedback Integration**: Continuously improving the system based on user feedback and real-world performance data.

IX. Acknowledgments

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Dictionary of Terms

Term	Definition
AI (Artificial Intelligence)	The simulation of human intelligence by machines.
Algorithm	A step-by-step procedure for solving a problem or performing a task.
Arduino	An open-source electronics platform for building digital devices.
Cloud Database	A database that is hosted and managed on a cloud computing platform.
Computer Vision	A field of AI that enables computers to understand visual data.
Convolutional Neural Network (CNN)	A type of deep neural network used for processing visual data.
Crop Recommendation	Suggesting suitable crops based on environmental factors.
Data Augmentation	Techniques to expand the dataset by modifying existing data.
Data Cleaning	The process of correcting or removing inaccurate data.
Data Preprocessing	Techniques to prepare raw data for analysis.
Deep Learning	A subset of machine learning with neural networks that have multiple layers.
Electrical Conductivity (EC)	A measure of a material's ability to conduct electricity.
Feature Engineering	Creating new features from raw data using domain knowledge.
Fertilizer Suggestion	Recommending fertilizers based on crop needs and nutrient levels.
Hydroponics	Growing plants without soil, using nutrient-rich water.
Image Recognition	Identifying objects or patterns in images using software.
Internet of Things (IoT)	Connecting devices through the internet to exchange data.
Logistic Regression	A statistical method for binary classification problems.
Machine Learning	Algorithms that allow computers to learn from data without explicit programming.
Macronutrients	Nutrients needed in large amounts for plant growth, like Nitrogen, Phosphorus, and Potassium etc.
Micronutrients	Nutrients needed in small amounts for plant growth, like Iron, Zinc, and Copper etc.
Neural Networks	Computing systems modeled after biological neural networks.
Normalization	Adjusting values to a common scale for comparison.
Nutrient Solutions	Water mixed with essential minerals used in hydroponics.
Outlier Detection	Identifying data points that significantly differ from the rest.
pH	A measure of the acidity or alkalinity of a solution.
Preprocessing	Techniques applied to data to make it suitable for analysis.
Random Forest	An ensemble method for classification and regression using multiple decision trees.
Regression Imputation	Estimating missing data using a regression model.
Raspberry Pi	A small, affordable computer for learning programming and building projects.
ResNet45	A deep neural network architecture designed for image recognition.
Scaling	Adjusting the range of data values.
SVM (Support Vector Machine)	A model used for classification and regression tasks.
TensorFlow	An open-source library for machine learning and dataflow programming.
Water Hardness	The concentration of calcium and magnesium ions in water.
Data Mining	The process of discovering patterns and knowledge from large amounts of data.
Dimensionality Reduction	Techniques for reducing the number of features in a dataset.
Ensemble Learning	Combining multiple models to improve performance.

Hyperparameter Tuning	The process of optimizing model parameters to improve performance.
K-Nearest Neighbors (KNN)	A simple algorithm that classifies data points based on their closest neighbors.
Principal Component Analysis (PCA)	A technique for reducing the dimensionality of data while retaining most of its variance.
Support Vector Regression (SVR)	A type of support vector machine used for regression tasks.
Recurrent Neural Network (RNN)	A class of neural networks designed for sequential data.
Gradient Descent	An optimization algorithm used to minimize the cost function in machine learning models.
Cross-Validation	A technique for evaluating the performance of a model by partitioning data into training and test sets.