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An AIoT-based hydroponic system for crop recommendation and nutrient parameter monitorization

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ABSTRACT

Advancements in technology have revolutionized various sectors, including agriculture, which serves as the backbone of many economies, particularly in Asian countries. The integration of new technologies and research has consistently aimed to enhance cultivation rates and reduce reliance on manual labor. Two key technologies, Artificial Intelligence (AI) and the Internet of Things (IoT), have emerged as pivotal tools in automating processes, providing recommendations, and monitoring agricultural activities to optimize results. While traditional soil cultivation has been the preferred method, the increasing urbanization trend necessitates alternative approaches such as hydroponics, which replaces soil with water as the medium for crop cultivation. Having many significant advantages, hydroponics serves a crucial role in achieving efficient space utilization. To get a higher density of plants in a confined area hydroponic approach provides water, nutrients and other essential elements directly to the plant's root. To utilize the hydroponic system more effectively, our proposed method, integrating AI and IoT helps to provide suitable crop recommendations, monitor the parameters of the plants and also suggest the necessary changes required for gaining optimal parameters. To ensure optimal resource allocation and maximize yields we have used machine learning models and trained them to recommend suitable crops from the given parameters and also refer to the changes in parameters that are needed for better plant growth. We have used the crop recommendation dataset from the Indian Chamber of Food and Agriculture to train our proposed machine-learning model. Our selected machine learning algorithms to predict the best crops are Random forests, Decision trees, SVM, KNN, and XGBoost. Our research combines AI and IoT with hydroponic systems to streamline crop recommendations, automate monitoring processes, and provide real-time guidance for optimized cultivation. Among them, the Random forest algorithm outperformed other algorithms with an accuracy of 97.5%.

1. Introduction

Agriculture being one of the important sectors in Asia region, one important way to enhance this agriculture sector can be combining with computational technology. With the rapid advancements in technology, there is a growing need to explore innovative approaches to enhance cultivation rates, reduce reliance on manual labor, and address the challenges posed by urbanization. Hydroponic systems are a modern method of cultivating crops without the use of soil. Instead, it takes various measures like nutrient-rich water solutions to grow the plants in good condition. When compared to traditional soil-based farming, hydroponic systems offer several advantages. For one, hydroponics can help reduce water usage by up to 70% compared to traditional farming methods, since the nutrient solution is recycled and can be monitored for optimal water usage [19]. However, one of the major things to look over is that, hydroponic system needs careful monitoring and supervision of nutrient and water levels for ensuring positive results from the system. By doing that authors can, understand how different crops respond to various nutrient level parameters [36]. Besides that, to perform automated monitoring, crop recommendation and other actions it needs reliable source of electricity. The world is innovating and enriching itself by combining new technology in every section and agriculture sector is no different. As a result, to revolutionize this sector, hydroponic system serves a promising potential alternative to tradi-

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tional soil-based farming system. New technologies such as, computer science, data visualization tools, and machine learning can be combined with hydroponic farming to optimize plant growth and resource utilization. Authors can use various machine learning algorithms which can be trained to predict optimal conditions for plant growth and adjust hydroponic systems by collecting data of important factors of hydroponic farming such as, nutrient levels, temperature, humidity and other important features if possible. This will help to improve yields, proper management of waste, reduce the need for manual labor, increasing the accuracy and precision of system adjustments which will increase the overall result of hydroponic farming [6].

This system offers numerous benefits over traditional farming methods, including increased productivity and improved water efficiency [17]. Hydroponics also allows for year-round cultivation, regardless of weather conditions, and can be used in urban areas where traditional agriculture may not be feasible. Some main reason for that is urban areas tend to have limited space for farming due to the high demand for land for housing, commercial, and other purposes which leads to poor soil quality and limited access of water [23]. As a result, hydroponic farming has become increasingly popular in recent years due to its numerous benefits, including reduced water usage, faster crop growth, and the ability to cultivate crops in urban or otherwise inaccessible areas. Up till now many kinds or techniques of hydroponic system has been introduced and each technique has its own set of advantages and disadvantages. Among many techniques, some prefer to use deep water culture, where plants are suspended in a nutrient-rich solution [24], while others use the NFT(nutrient film technique), where a thin film of nutrient-rich water continuously flows over the roots of the plants and some use other systems such as ebb and flow, the wick system and so on [18]. Our hydroponic system has been utilized by us focusing on nutrient rich solution for plant growth instead of soil-based farming. The parameters of the nutrient solution, including pH, humidity, temperature, and nutrient concentration levels, are closely monitored to ensure accuracy. Machine learning algorithms are then employed to analyze sensor data from the hydroponic system and make predictions regarding the standard nutrient solution parameters. This predictive model is trained on historical data, encompassing nutrient solution pH, nutrient concentrations, and environmental factors such as temperature and humidity. Whenever any parameters deviate from the desired range, the user is promptly notified, and the model suggests appropriate adjustments tailored to the specific crop. This approach effectively enhances yield quality, increases efficiency, and enables early detection of potential issues.

Cultivating crops and various herbs where traditional farming methods are not feasible can be implemented through hydroponic approach if anyone can monitor and control the nutrient levels and water flow. It is a very popular technique for agriculture in developed countries due to limitations of agricultural area and urbanization. But in our country, it has not been adopted properly yet. Our research team aimed to build a hydroponic system combined with AIoT (Artificial Intelligence of Things) and examine the performance of the system that can be suitable for our climate change. In our work, two techniques (NFT and Tower Garden) are being discussed by our authors that are very popular. Hydroponic system linking with new automation and decision-based technologies has provided the opportunity of growing foods and herbs with more efficiency, precision and sustainability. With more research and development in the near future, the advancement of hydroponic environment will surely take the agriculture sector in a new level. Overall, it can be said that hydroponic farming system has a bright future as the popularity and advertising is growing day by day for sustainable and efficient method of growing plants.

A system is developed by us incorporating both IoT and machine learning to optimize the growth of various crops by continuous monitoring. For suitable crop recommendations a user-friendly web-based framework has been developed. Firstly, IoT sensors collect the data about nutrients from the water and this data is being analyzed by our system and suggests changes in parameters if necessary. Secondly, from our web-based application, users can find the best crop for the suitable parameters.

2. Literature review

Our literature review is divided into three sections, each with a distinct focus on hydroponic systems. This categorization's objective aims to offer a solid comprehension of what hydroponic systems are, their operational patterns, features and application. It has been started by scrutinizing different articles and journals providing wholesome insight into the hydroponics domain including its variety and evolution. Afterwards our team studied researches that creates comparative narratives between traditional farming practices with these innovative hydroponic methods. Finally, our team delved into research papers that explore new technologies, primarily IoT and machine learning, and how they can enhance the hydroponic culture.

2.1. Overview of hydroponic system

In their study on hydroponics, Gaikwad and Maitra (2020) highlight the manifold benefits of this cultivation method, including efficient nutrient and water utilization, space optimization, and precise control over the growing environment. The authors emphasize the superiority of hydroponic systems, particularly the NFT, in terms of producing high-quality and productive vegetables compared to traditional farming methods. They identify six types of hydroponic systems, with the NFT being widely used for growing various vegetables. Various media, such as coco air, perlite, and rice hulls, are utilized to support plant roots in hydroponic systems. Maintaining optimal pH and TDS levels are crucial factors for successful hydroponic cultivation [7].

In a comprehensive overview of hydroponic systems Nisha and colleagues (2014) refer to hydroponic as an alternative to conventional agricultural practices. The authors discuss different hydroponic systems, their functions, and suitability for various plants. Additionally, the article presents a review of research on vegetable cultivation using hydroponic systems and offers insights into water conservation practices and the global market for hydroponic farming [39].

In a comparative analysis by Singh et al., the growth patterns of wheat, spinach, and lily plants were studied over a 2-month period in hydroponic and tap water systems. The experiment revealed that the use of Hoagland solution, a nutrient solution specifically formulated for hydroponic plant cultivation [49], promoted faster growth compared to tap water. The lengthwise growth of plants indicated that the hydroponic system resulted in accelerated plant development compared to tap water [31].

Controlled Environment Agriculture (CEA) systems, which utilize advanced technologies like artificial intelligence and machine learning to optimize plant growth, have been discussed by Srivani and colleagues [42]. The authors evaluated different hydroponic techniques used in CEA systems, including Wick Hydroponic, Ebb and Flow, Drip, DWC (Deepwater Culture), NFT, and Aeroponics. The study also addressed key challenges in CEA with hydroponics, such as power optimization, energy and water conservation and recycling, and pest management. [42].

In another experiment, Wiangsamut et al. (2021) investigated the impact of plant spacing in hydroponic systems on the growth of four vegetable species. Tokyo Bekana cabbage exhibited the highest plant density and fresh yield, while Red Coral had the lowest. The DFT10x12 system resulted in significantly higher yields and the highest gross benefit of vegetable production, except for Red Coral. The study established correlations between fresh yield and plant parameters through statistical analysis. [48].

To address food security challenges, a study focused on hydroponic lettuce cultivation in Uganda explored the physiognomic responses of lettuce to hydroponic techniques. The research aimed to evaluate the growth rate, leaf structure, and nutrient uptake of lettuce in hydroponic

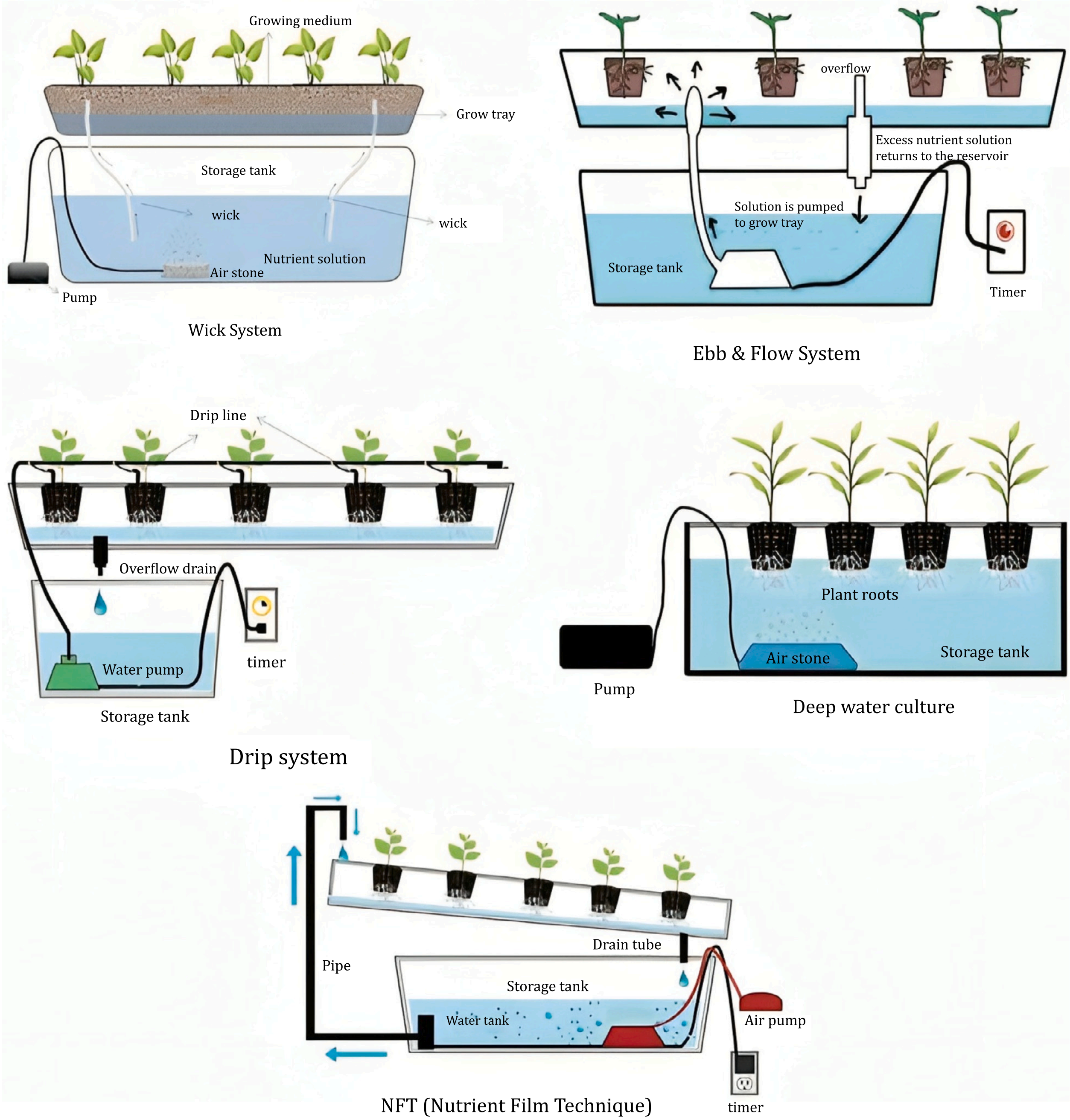


Fig. 1. Various techniques of Hydroponics system [39].

systems, providing insights into the adaptability of lettuce to hydroponics in Uganda. The findings have implications beyond Uganda, offering valuable knowledge for urban areas globally facing similar food security concerns [9].

In Fig. 1 various techniques of hydroponic systems have been shown which were used in various studies. The literature review in this section covers the benefits and challenges of hydroponic systems for crop cultivation, including different techniques and media used for plant growth. Hydroponics offers efficient nutrient and water utilization, space conservation, and environmental control. Various crops such as wheat, spinach, lily water, rice, lettuce, and tomatoes have been studied for their performance in hydroponic systems. Hydroponics is viewed as a potential alternative to conventional farming practices that cause environmental degradation, particularly in urban and industrialized areas. Advanced technologies such as artificial intelligence and machine learning are being integrated into hydroponic farming to optimize plant growth and address challenges such as power optimization, energy saving and recycling, water conservation and recycling, and pest management. Hydroponic systems can provide sustainable and pesticide-free farming while improving the health and quality of crops.

2.2. *Comparison between traditional soil system and hydroponic cultivation system*

In a comparative experiment conducted by Gashgari and his fellow researchers (2018), the growth of cucumber and Armenian cucumber plants was analyzed in both hydroponic and traditional soil systems. Here, Cucumber and Armenian cucumber seeds are categorized by type and numbered sequentially [H(1,1) for cucumber seeds in hydroponic condition, H(2,1) is for American cucumber seeds, S represents the soil based system]. The research targeted the identification of how varying seed types and planting systems influenced plant height and leaf span. After carrying out ANOVA (Analysis of Variance), it was estab-

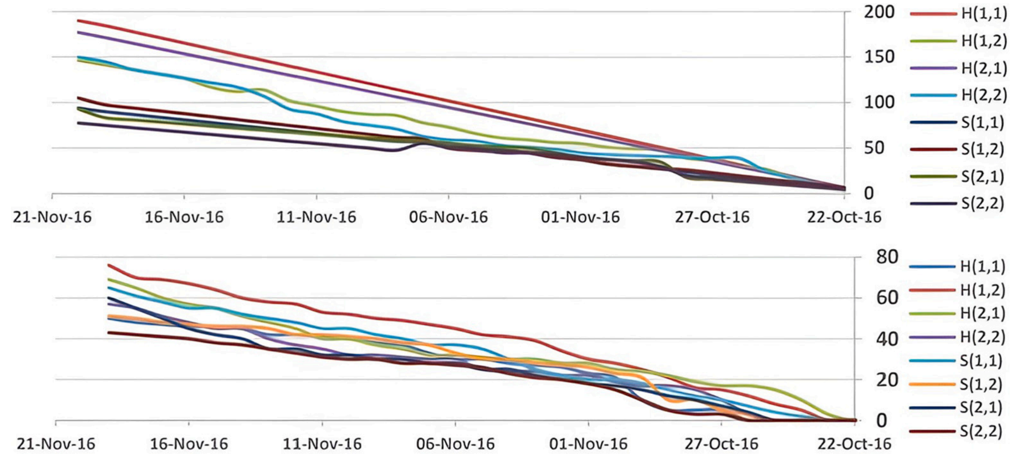


Fig. 2. Growth of plants and plant's leaves – 30 days observation (H- Hydroponic, S – Traditional Soil [8]).

lished that plants using hydroponic methods showed a significantly noticeable increase in height, when compared to their soil-based counterparts as illustrated by Fig. 2. However, interestingly enough there wasn't any meaningful variation discovered pertaining to the length of leaves among both these systems. These findings support the hypothesis that hydroponic systems outperform traditional soil systems in terms of plant growth [8]

In a study conducted in 2015 comparing lettuce production in a hydroponic system to conventional farming methods in southwestern Arizona, researchers found that the hydroponic system yielded 11 times more lettuce while using less water. While it's true that hydroponic farming demanded a bit more energy, the outcomes point that hydroponic system has the potential to deliver superior crop yields and excellent water-use efficiency when contrasted with traditional agriculture. Focusing efforts on diminishing energy use through enhanced effectiveness and combining renewable power sources would pave the way for sustainable practice [4].

AlShrouf (2017) underscores the significance of streamlined food production techniques to cater to an expanding populace. The writer accentuates the advantages of contemporary farming methods like hydroponics, aeroponics, and aquaponics which bring greater crop volumes, less water usage, and incessant cultivation by capitalizing on a resourceful rich-nutrient water solution instead of soil. The utilization of precision agriculture technologies, including sensors, automation, and mobile apps, further enhances farmers' control and promotes sustainability. Hydroponic cultivation, due to its lower usage of water and land in contrast with ordinary farming methods, has showcased the effectiveness of using 10-25 kg/m3 water. Not only does it use substantially less amount of water than soil-based agriculture processes but also succeeds in increasing overall productivity [3].

Research conducted in Kashmir, India assessed the impact of deep-water culture, nutrient film technique and traditional soil cultivation on lettuce growth as well as financial implications with respect to solar radiation. Deep-water culture displayed quick crop maturity and abundant yields; however, regular soil-based growing presented increased plant dispersal and leaf surface area. The nutrient film method exhibited the least productive outcomes. The study indicated that hydroponic systems, particularly deep-water culture, are a sustainable alternative to conventional lettuce cultivation, offering multiple crops per year and water savings which was shown in Fig. 3. The adoption of hydroponic systems in temperate regions could be accelerated by their commercial viability, and future research could explore vertical hydroponic cultivation and automation [20].

Gurung et al. (2019) discovered that hydroponic plants grow faster and produce greater yields than soil-grown plants, with the Hoagland solution being the most effective nutrient solution. The pH of the medium largely controls nutrient absorption, and liquid media are suitable for seedlings, but solid media are necessary for full maturity. Hydroponic systems were found to be more productive than conventional soil culture, and hydroponic lettuce had the same quality as organic and field lettuces. Hydroponics allows for high plant control with low maintenance and crop pollution, making it important for global food safety and security [11].

Based on the reviewed papers, it is evident that hydroponic farming has numerous advantages over traditional farming. Hydroponics provides higher yields, water efficiency, and continuous production, utilizing less water and land. Hydroponic tomato production has a water use efficiency of 10-25 kg/m3, with closed systems having higher efficiency than open systems. The studies suggest that hydroponic lettuce has similar quality, texture, odor, and taste as organic and field-grown lettuces. However, the feasibility of hydroponic farming depends on factors such as water and land availability, government and community support, and the cost-effectiveness of new technologies. If energy consumption can be reduced through improved efficiency and renewable energy sources, hydroponics can offer a sustainable solution to feed the growing world population [2].

2.3. Hydroponic system combined with IoT and machine learning

In 2018 Mehra and fellow researchers developed a hydroponic system that utilizes IoT and Deep Neural Networks to control plant growth. The system showed an accuracy rate of 88% in controlling tomato plant growth using data collected by sensors on pH, temperature, humidity, level, and lighting. The system design in Fig. 4 includes sensors connected to an Edge device (Arduino and Raspberry Pi3), a Deep Neural Network model for real-time control, and a cloud-based classification system. The study demonstrates the effectiveness of the proposed intelligent IoT hydroponic system, with enhanced performance and efficiency compared to other machine learning algorithms such as Bayesian networks [22].

In a similar vein, S.V.S. Ramakrishnam Raju and colleagues in 2022, introduced AI-SHES, a smart farming solution for hydroponic operations that integrates Raspberry Pi, IoT, and a mobile app. The system utilizes sensors and deep convolutional neural networks to monitor and control plant statistics in real-time. The system includes Prediction-DLCNN and Classification-DLCNN models that predict nutrient levels and identify plant diseases, respectively. The AI-based IoT cloud server accurately classified various plant diseases and predicted appropriate nutrients using the NUOnet and Plant Village datasets, outperforming traditional methods. The proposed solution aims to address the challenges faced by farmers and improve the performance of hydroponic farming operations [32] (see Fig. 5).

In another study, a new tool for plant growth has been developed using hydroponics and machine learning. Sensors like pH sensor, DHT

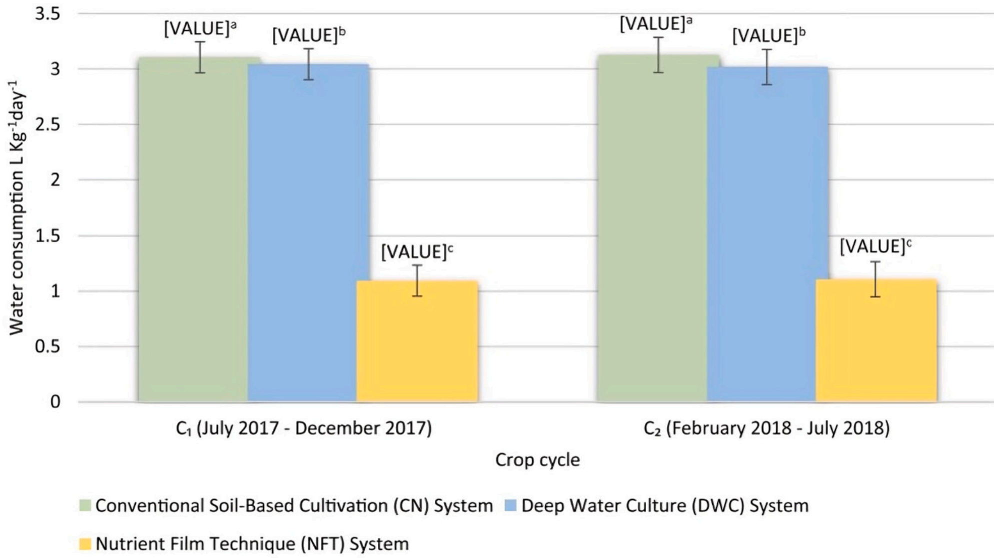


Fig. 3. Comparison of traditional soil system and hydroponic techniques in terms of water consumption [20].

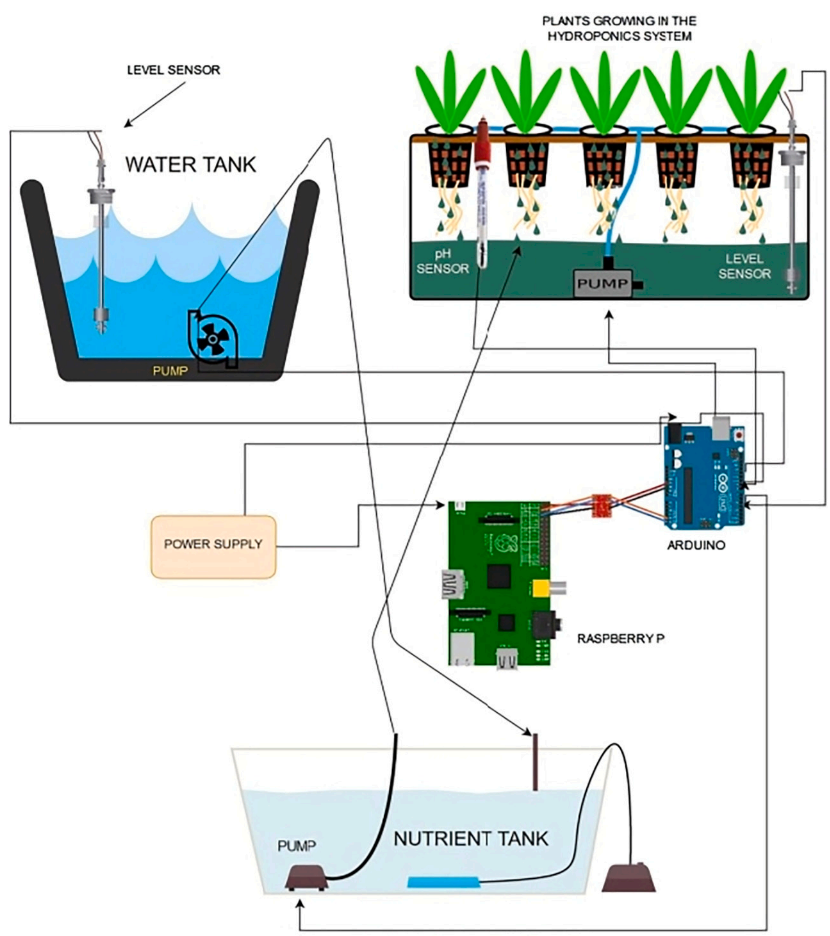


Fig. 4. System design of the hydroponic system using IoT and Deep neural network [22].

11 sensor, and DS18B20 sensor are used to measure different parameters like temperature, humidity, and soil moisture. A hydroponic and machine learning system has been developed to monitor plant growth using those sensors for pH, temperature, humidity, and soil moisture. Real-time data is collected and analyzed using IoT and machine learning algorithms. A linear regression model is trained to predict plant growth based on the sensor data. The system maintains optimal pH and temperature for plant growth and can be remotely monitored through a server. The system minimizes human intervention and helps farmers save time and money while increasing profits [37].

A machine learning framework for predicting the crop growth rate (CGR) of tomato crops in hydroponics was proposed by Verma et al. (2021). The framework in Fig. 6 uses parameters such as dry weight matter, nutrient solution, ion uptake, EC limit, and nitrogen content to

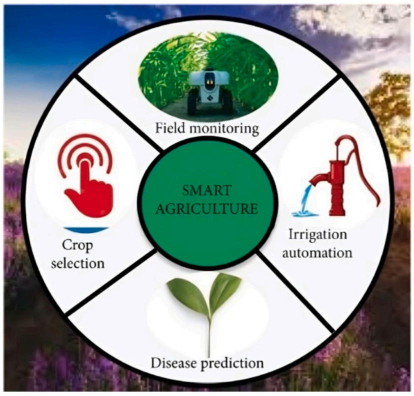


Fig. 5. Features of AI-SHES- a smart farming system for hydroponic condition [32].

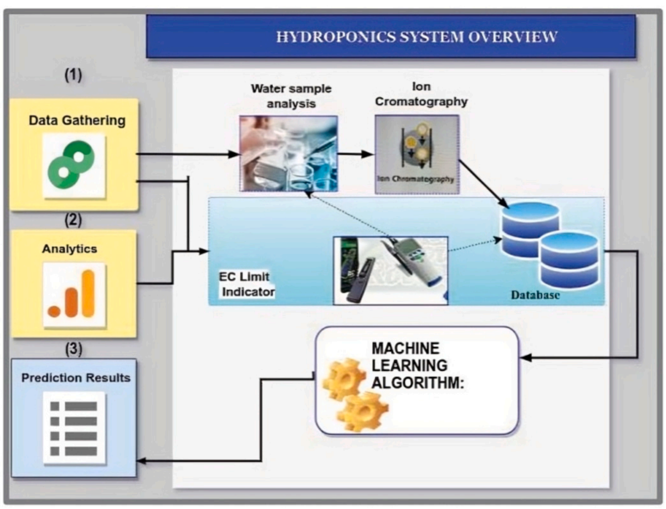


Fig. 6. Hydroponic system for predicting the growth rate of tomato plant [47].

predict the CGR. The study found positive and negative correlations between the growth parameters and CGR, with Na ions having the highest correlation and Ca ions having the lowest correlation with dry weight matter. The proposed framework considers the dynamics of ion uptake and EC limit during the different stages of tomato growth, suggesting specific ion monitoring and adjustments are necessary for optimal growth in hydroponics [47].

Another research explores machine learning algorithms' effectiveness in analyzing hydroponic system data. Real-time data from sensors measuring temperature, humidity, pH levels, and nutrient concentrations is collected. Algorithms such as decision trees, random forests, support vector machines, and artificial neural networks are compared. The evaluation provides insights into their strengths and limitations in predicting plant growth outcomes. The findings contribute to developing intelligent hydroponic systems for optimized resource utilization and increased productivity. It advances the understanding of machine learning's potential in revolutionizing plant cultivation and offers practical implications for hydroponic system improvement [17].

From the reviewed research articles, it can be understood that the integration of IoT, machine learning, and deep neural networks can improve plant growth and disease detection in hydroponic systems. Real-time control and monitoring of hydroponic parameters can be achieved using sensors, edge devices, cloud-based classification systems, and deep neural network models. The effectiveness of using machine learning models is demonstrated for improved accuracy and performance. Specific parameter monitoring and adjustments are crucial for optimal growth and development in hydroponics. The proposed solutions aim

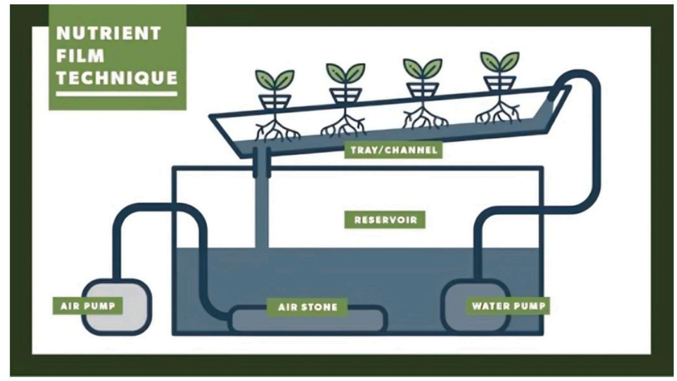


Fig. 7. Nutrient Film Technique process [29].

to improve the performance of hydroponic farming operations, leading to increased profits and reduced losses due to natural disasters. Overall, IoT, AI and machine learning have potential to optimize hydroponic farming practices.

3. Methodology

After the completion of the literature reviews, it can be concluded that combining new technology with soilless agriculture which is referred as hydroponic system, it gives us a chance for innovation in the agricultural sector. It may also be the solution for our future depending on the rise of population, mostly in Asia. Keeping that in our mind, our methodology will explore the use of hydroponic systems for crop cultivation, specifically focusing on NFT(Nutrient Film Technique) and Tower Garden which basically falls into aeroponic cultivation culture. Both NFT and Tower Garden are good hydroponic systems that can be used to grow plants without soil. Here both IoT and machine learning techniques are incorporated to optimize the growth of various crops by monitoring the parameters of nutrient solutions. In hydroponic systems, the nutrient solution is a mixture of water and essential plant nutrients that is used to grow plants without soil. The nutrient solution provides all the necessary elements for the plant's growth, including nitrogen, phosphorus, potassium, calcium, magnesium, and other micro nutrients [40]. The process of creating a balanced nutrient solution can be done by incorporating fertilizers into water. But it is crucial to guarantee that the plants intake adequate nutrients. Varying plant species require diverse nourishments; henceforth, the proportion of elements in each nutrient solution can differ based on what type of plant it's intended for.

Prior to explaining into the details of our recommended procedure, it's crucial you understand about two specific hydroponic setups we've selected - NFT(Nutrient Film Technique) and Tower Garden. Both operate under hydroponics but their functioning mechanisms are distinctly varied.

NFT: NFT, short for Nutrient Film Technique, is a variant of hydroponic system. This technique operates by propelling nutrient rich water in a thin layer over the roots of plants. Designed to grow within distinct channels or gutters set at slight inclinations which assist in continual recirculation back into its reservoir [46], these NFT-grown crops are typically nestled inside net cups or pots placed strategically within said channels. Granting direct access to crucial nutrients via constant stream supplied through re-circulating rather than repeated refilling; it's not only resource-efficient both on nutritive values and our valuable water but also cultivates an oxygen-rich environment around roots promoting their rapid yet healthy growth. The main components of a Nutrient Film Technique (NFT) Fig. 7 hydroponic system is as follows:

1. Channels: Generally crafted from plastic, these act as the primary framework for an NFT system. They're purposefully designed with a slight tilt to facilitate the downward flow of nutrients back into their source reservoir.

2. Nutrient Solution Reservoir: It is kind of a container holding the nutrient-rich water solution for feeding the plants.

3. Pump: The pumping device takes the role of moving this nutrient mix from its container through various ducts or trenches encompassing plant roots. Integrated into the system are air stones designed not only to oxygenate our nutrient blend but also facilitate root airing. By creating little bubbles within this mixture, these air stones contribute significantly towards enhancing dissolved-oxygen levels in that liquid.

4. Net Cups or Pots: These containers are utilized to secure the plants in place and allow their roots to have contact, with the solution. Typically the net cups or pots are suspended within the channels or gutters.

6. Timer: The timer is employed to regulate the pump ensuring that the nutrient solution flows over the plant roots at intervals.

7. pH and EC (Electrical Conductivity) meters: These devices are utilized to monitor and maintain a pH level and nutrient concentration in the solution, which is crucial for optimal plant growth. In this case sensors are being used to gather data from factors including pH and EC for continuous monitoring.

8. Lighting: Although not essential supplementary lighting can be added to the NFT system to ensure that plants receive light for photosynthesis particularly in indoor environments or areas, with limited natural light.

These different parts collaborate harmoniously to construct a hydroponic system that's both uncomplicated and effective. It is particularly suitable, for cultivating a range of plants those, with roots that don't go very deep.

Tower Garden: The Tower Garden is a creative implementation of hydroponics, allowing for vertical plant growth in multiple layers or towers constructed from plastic. Esteemed for its versatility and popularity, this system facilitates the cultivation of vegetables, herbs, and other varieties on small platforms such as balconies or interior spaces. It performs by circulating nutrient-fortified water across plants with a pump that releases it at the tower's apex. This nutrient solution further cascades downward through each level eventually dripping onto roots delivering essential elements required to prosper [30]. The adaptability extends to different growing media compatibility which includes soil, rockwool or coconut coir options within its repertoire. An immense advantage associated with the application arises due to impressive conservation rates upon usage since up-to 90% less hydration requirements than comparable soil-based farming methods can be expected.

In Fig. 8 the components utilized in a Tower Garden can differ based on the design and setup of the system. However here are some used components:

1. Tower structure: Typically made of plastic the tower structure consists of stacked trays or containers where plants and growing media are placed.

2. Pump: A submersible water pump is employed to circulate a water solution, from the reservoir to the top of the tower. Controlling the pump with a timer helps regulate water flow to the plants.

3. Reservoir: Positioned at the base of the tower a large container holds the solution that circulates throughout the system. The reservoirs size may vary depending on how many towers and plants are being cultivated.

4. Growing media: To support plant growth and provide an environment for roots to thrive in various growing media options is utilized in Tower Gardens such, as rockwool, coconut coir and perlite.

5. Nutrient solution: This formulated mixture contains minerals and nutrients that furnish plants with what they need for healthy growth. The solution is mixed with water and added to the reservoir.

6. pH testing kit: Because the pH of the nutrient solution can affect the plants' ability to absorb nutrients, a pH testing kit is used to monitor and adjust the pH levels as needed.

7. Trellis: A trellis is often used to support vining plants, such as tomatoes or cucumbers, as they grow upward in the tower.

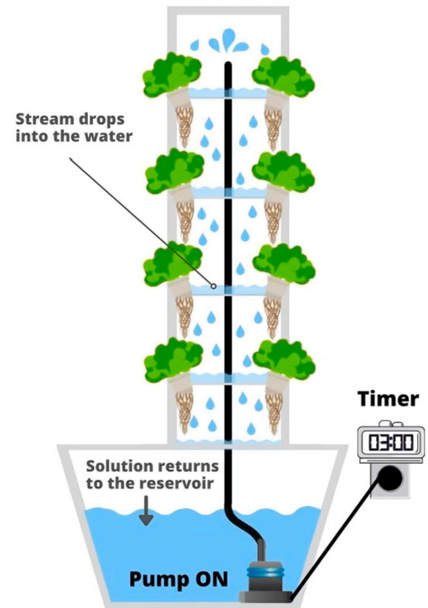


Fig. 8. Tower Garden process [27].

Overall, the components of a Tower Garden work together to create an efficient and productive hydroponic system that allows for vertical growing of a variety of plants.

As discussed before both the techniques (NFT and Tower Garden), now it needs to combine them with IoT and machine learning to achieve our goal, which is crop recommendation and monitoring. Our proposed method actually can be divided into two main parts. Firstly, the sensor is implemented to get the required data and secondly, after getting the desired data, concentrated on the nutrient solution and other prime factors to recommend and monitor the plants in the hydroponic system. More details are given below,

3.1. Role of IoT (identifying the sensors for different types of parameter):

IoT stands for "Internet of Things," and it refers to the network of physical objects (such as sensors, devices, and appliances) that are connected to the internet, enabling them to collect and exchange data. Using IoT, hydroponic systems can be monitored and controlled in aspects such as temperature, humidity, pH levels, and nutrient levels. This is done through sensors that are connected to a central computer or mobile device. When all this data is collected it's easy to make adjustments that benefit the system. Another great use of IoT in hydroponics is automation. It can automate tasks like watering, nutrient dosing, and lighting [25]. Hydroponic systems using IoT have been able to grow plants better by having complete control over what conditions the plants grow in. This has led to an increase in yields, improved quality, and efficient use of resources (see Table 1).

These are the main sensors to cover up our data collection part from the nutrient solution and also to measure the perfect humidity. Besides these sensors, there are other sensors that can be used to enhance more monitoring power in a hydroponic system. Such as, light sensor which is used to measure the intensity of the light that the plants are receiving. This data can be used to adjust the lighting system and ensure that the plants are receiving the optimal amount of light for their growth stage. Temperature sensors allow growers to monitor and control the temperature of the growing environment. Temperature sensors are an important tool for maintaining optimal growing conditions in hydroponic systems, leading to improved plant growth, reduced risk of plant stress or failure, and more efficient use of resources.

Table 1
Different types of sensors to collect data from the hydroponic system.

Sensor	Description	Sensor Types
pH Sensor	A pH sensor is used to measure the acidity or alkalinity of the nutrient solution. Maintaining a proper pH level is critical for plant growth [26].	Glass electrode pH sensor (a thin glass membrane to measure the pH of a solution) Solid-state pH sensor (a solid-state electrode made from materials such as silicon or diamond to measure the pH of a solution)
Electrical Conductivity (EC) Sensor	An EC sensor measures the level of dissolved salts in the nutrient solution. This is an important measure of the nutrient concentration in the solution.	TDS (Total Dissolved Solids) sensors (An electrical current is passed between the electrodes, and the resistance of the solution is measured. The resistance is inversely proportional to the electrical conductivity of the solution, which is a measure of the concentration of dissolved salts (including nutrients) in the solution) [15].
Humidity Sensor	A humidity sensor measures the amount of moisture in the air. This can help growers maintain proper humidity levels for optimal plant growth.	DHT11/DHT22 (detects changes in capacitance caused by changes in the moisture content of the air)
Detecting Nitrogen, Potassium, and Phosphorus	Nitrogen, potassium, and phosphorus are all essential nutrients for plant growth and development. Monitoring their levels in the nutrient solution ensures that plants have access to the nutrients they need to grow and produce high-quality crops.	Ion-Selective Electrodes (detect specific ions, including nitrogen, potassium, and phosphorus. These sensors work by measuring the electrical potential difference between an electrode and a reference electrode, which is proportional to the concentration of the ion being measured.) [12]

3.2. Role of machine learning (processing different types of parameters):

Machine learning enables computers to learn from data and make predictions or decisions without being explicitly programmed to do so. It involves building models that can learn and make decisions based on patterns and relationships within the data. In hydroponic systems, machine learning can be used to improve the efficiency and productivity of the system, by analyzing data collected from various sensors and making decisions or adjustments based on that data. By considering various factors like plant growth stage, environmental conditions, and nutrient requirements, machine learning models can recommend adjustments to optimize resource utilization and minimize waste. By promptly identifying anomalies, the system can take corrective actions or notify operators to prevent any adverse effects on plant health. As a result, machine learning plays a vital role in processing different types of parameters in hydroponic systems.

To train our machine learning model authors used the crop recommendation dataset from the Indian Chamber of Food and Agriculture. The dataset consists of many combinations of parameters for various crops. The parameters are Nitrogen, Phosphorus, Potassium, temperature, pH, Humidity, and rainfall. By focusing on those parameters, this study has trained machine-learning model for predicting the right crops for the right conditions. This dataset has more than 2000 inputs of data for various crops. Such as bananas, rice, jute, apples, etc. Authors can also further analyze the dataset to get standard parameters of a selective crop for parameter recommendation.

Then preprocess the dataset to ensure that the data is in a format that can be used effectively by machine learning algorithms and that the model is trained on clean, reliable, and relevant data, which can improve the accuracy, efficiency, and generalizability of the model. Handling missing values in features such as pH, N, P, and temperature. Also handled inconsistent data, such as variations in the format of the data. Then transformed the data, which is also referred as normalization so that it has a mean of zero and a standard deviation of one. This process scales the data to a similar range and helps in better convergence and faster training of the machine learning model. The correlation matrix in Fig. 9 shows the relationships between different variables in the dataset. Nitrogen (N) and Phosphorus (P) have a negative correlation, meaning higher levels of one tends to be associated with lower levels of the other. Nitrogen (N) and Potassium (K) also have a negative correlation, while Phosphorus (P) and Potassium (K) have a positive correlation. There are generally weak correlations between temperature, humidity, pH, rainfall, and other variables. The specific correlations vary, with some positive and negative associations observed. Removed the rainfall feature from the dataset as in hydroponic conditions the value of rainfall is negligible. Another important preprocessing technique is data splitting which will be discussed in the following part.

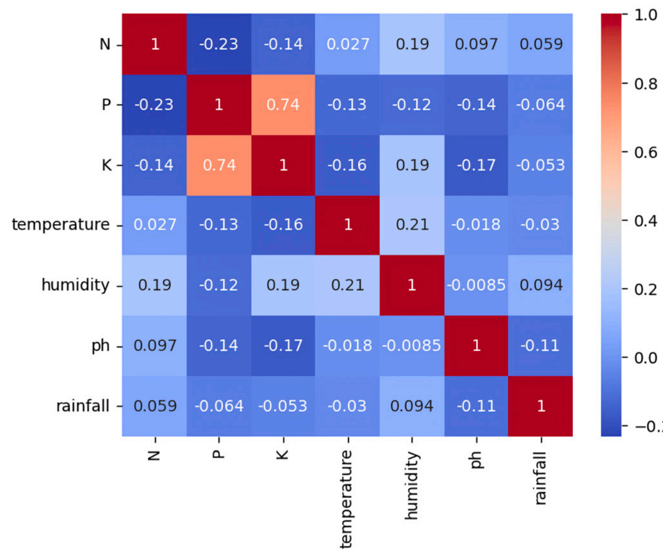


Fig. 9. Correlation between the parameters of the dataset.

Then divided the dataset into training and testing sets which is also referred as data splitting. The training set is used to train the model, and the testing set is used to evaluate the performance of the model. For building our machine learning model we will split 80 percent of the data as training data and the remaining 20 percent as testing data.

Five machine learning algorithms have been selected to predict the best crops from the given parameters. They are, random forest, decision trees, svm, knn, and xgboost. Based on the other similar studies it can be concluded that these five algorithms work well on the given dataset with proper tuning [45] [5] [33] [44]. As the dataset consists of only few parameters or features, that authors have used hyper parameter tuning carefully to improve our model's accuracy. The selected algorithms are explained in the following,

Random Forest: Random Forest is an ensemble learning method that combines the predictions of multiple decision trees to improve accuracy. It randomly selects subsets of features for each tree, and the final prediction is determined by majority voting [16].

Decision Tree: Decision trees recursively partition the data based on features to create a tree-like model. Predictions are made by traversing the tree based on the values of features, following decision rules at each node [14].

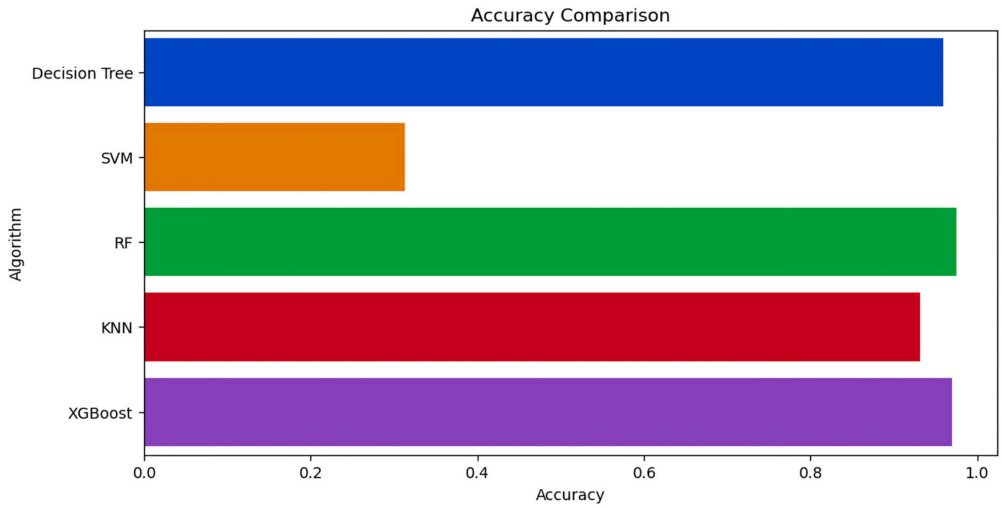


Fig. 10. Accuracy of the ML Algorithms.

Table 2
Performance Comparison of Machine Learning Algorithms.

Algorithm	Accuracy	F1 Score	Precision	Recall
Decision Tree	0.96	0.96	0.96	0.96
SVM (Support Vector Machine)	0.31	0.41	0.89	0.31
Random Forest	0.975	0.98	0.98	0.97
KNN	0.93	0.93	0.95	0.93
XGBoost	0.97	0.97	0.97	0.97

Support Vector Machine (SVM): SVM finds a hyperplane that maximizes the margin between classes, classifying new data based on its position relative to the hyperplane. It can handle linear and non-linear separable data using kernel functions [28].

K-Nearest Neighbors (KNN): KNN predicts the class of a new data point by considering the classes of its nearest neighbors. The majority class among the k nearest neighbors determines the final prediction [10].

XGBoost (Extreme Gradient Boosting): XGBoost uses a sequence of decision trees to make predictions. Each subsequent tree corrects the errors of the previous trees, resulting in improved predictions [38].

To evaluate the performance of the algorithms, multiple evaluation metrics have been used which includes accuracy, F1 score, precision, and recall. As we split the dataset into training and testing sets using a 80:20 ratio. This process is being repeated five times and computed the mean and standard deviation of the evaluation metrics for each algorithm. This means that, a new random split was performed between the training and testing data. This is done to ensure that the evaluation is not biased towards a particular split of the data. The mean provides an estimate of the average performance of the algorithm, while the standard deviation provides a measure of the variability or uncertainty in the performance estimate. Cross validation is also used to evaluate model performance by splitting the data into 5 subsets, training the model on 4 subsets, and evaluating it on the remaining subset iteratively, providing a robust estimation of the model's generalization ability. By computing the mean and standard deviation across multiple evaluations, authors got a more reliable estimate of the algorithm's performance.

Table 2 and Fig. 10 summarize the accuracy, F1 score, precision, and recall for each of the five algorithms.

Based on these results, it can be concluded that Decision Tree, Random Forest, and XGBoost achieved high accuracy and balanced performance across the evaluated metrics, while SVM had lower accuracy but higher precision. KNN performed well in accuracy and F1 score but had slightly lower precision and recall compared to the top-performing algorithms.

3.3. Role of AIOT (IoT and machine learning)

AIoT can be defined as the integration of machine learning and deep learning, with IoT devices. In AIoT, machine learning algorithms are used to analyze data collected by IoT devices, such as sensors, cameras, and other connected devices [50]. This analysis can be used to identify patterns, predict outcomes, and make decisions based on the data. In our proposed method, AIoT has been used for continuously monitoring the nutrient solution of the water for better crop growth. Machine learning algorithms have been used to analyze the data of humidity, pH, and nutrient levels collected from hydroponic systems to identify patterns and correlations that can be used to monitor and identify the optimal conditions for plant growth [43]. This information and metrics are used to refer the hydroponic system's settings to create the ideal growing conditions for the plants.

3.4. Flowchart and process

To commence hydroponic cultivation according to our flowchart in Fig. 11, there are two alternatives. Firstly, anyone can opt for a specific crop and subsequently identify and supervise its growth. Alternatively, it may utilize crop recommendations to suggest a specific crop suitable for hydroponic cultivation, as determined by the machine. Subsequently, regardless of our choice in the initial stage, the subsequent step involves analyzing nutrient solution parameters, pH levels, and humidity. Our goal is being reached by using three detectors to collect information about levels of nitrogen, phosphorus, and potassium in the nutrient mix, as well as pH balance and moisture surroundings within the hydroponic farming system. The sensors are listed in Table 3.

Our research employs a highly specialized machine-learning model to process the sensor data collected from our hydroponic system. Seamless and efficient wireless communication is achieved through the utilization of cloud computing. The sensors are connected to an ESP32 microcontroller, chosen for its exceptional reliability and low failure probability in transmitting data to the cloud via Bluetooth [41]. The ESP32 is renowned for its robust Bluetooth capabilities and built-in Wi-Fi connectivity, making it ideal for transmitting data to the cloud with flexibility in communication options [21]. By integrating with sensors that monitor parameters such as pH, temperature, humidity, and nutrient levels, the ESP32 wirelessly transmits this data to the cloud [13], where it is stored, analyzed, and encoded in XML format for efficient transmission. Cloud-based services receive the transmitted data, enabling real-time monitoring, anomaly detection, and crop recommendations. Furthermore, the ESP32 facilitates automation of hydroponic

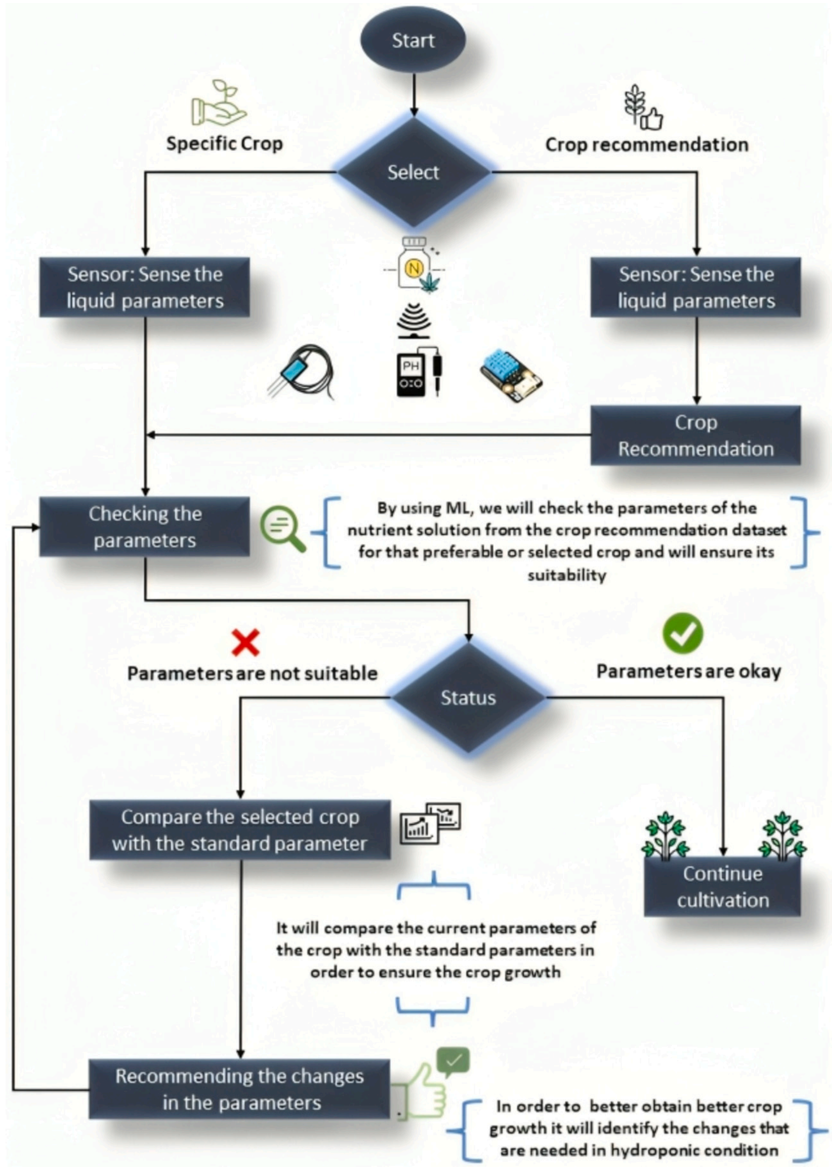


Fig. 11. Overall process of our proposed approach combining IoT and machine learning.

Table 3
Sensors and Descriptions.

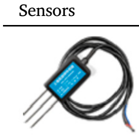
Sensors	Description
 NPK Sensor	An NPK sensor is a device that measures the levels of three key nutrients: nitrogen (N), phosphorus (P), and potassium (K). The NPK sensor provides real-time measurements to farmers so they can make adjustments accordingly. This is important because it ensures that crops get the amount of nutrients they need at the perfect time. [1].
 pH Sensor	The pH sensor is a device that measures how much acid or base there is in a liquid. It usually does this by using a glass electrode. The scale it uses goes from 0 to 14. With 7 being the sweet spot for neutral, anything below that is acidic, and from there on up to 14 it's alkaline or basic. This helps farmers figure out the levels of nutrient solution and adjust the pH condition using water to make sure they grow healthy and strong. [34].
 Humidity Sensor	A humidity sensor is a tool used to measure the moisture or water vapor in the hydroponic environment. The level of humidity plays a role, in hydroponic farming as it impacts the speed at which plants release moisture and absorb nutrients. By employing a humidity sensor farmers can keep track and regulate the humidity levels to establish growing conditions for plants, in hydroponic agriculture. [35].

Table 4
Observation of lettuce plant between Standard parameter comparison and Crop recommendation parameters comparison.

Data	Parameter checking	Anomaly detection	Checking Frequency
Crop Recommendation	We can check and compare the parameters with no issue.	Anomalies are seen in regular intervals. In this case, the parameters are too sensitive, and even a slight change causes alerts to the farmer/cultivator, creating a higher workload.	The frequency of checking the parameters is too high. Nutrient levels need to be checked every hour, resulting in more time and effort monitoring and adjusting the system.
Standard Parameter	We can check and compare the parameters with no issue.	Anomalies are not seen in regular intervals. Standard parameters help maintain consistency in adjusting the hydroponic condition, reducing the likelihood of plant stress or nutrient deficiencies.	Anomalies are not observed on a regular basis, reducing the need for frequent checks. It is important to check the hydroponic system regularly in the first week to ensure sensors and monitoring systems are working correctly. Regular checks can also help identify issues that sensors or systems may not detect.

system components and provides remote access for enhanced efficiency and optimal growth conditions.

After the data are extracted from the sensors, the next part will be covered through machine learning. Through careful analysis of the nutrient levels, the best-trained machine learning model will be able to provide recommendations of the most suitable crops to cultivate in the given conditions. It will also recommend if any changes are required or not to provide the best hydroponic solution.

Now that this study has identified the crop from the previous stages, our attention will be on observing the plant in our hydroponic setup. Our objective is to confirm that the parameters are appropriate for the crop's optimal growth using machine learning by analyzing the current parameters. This initial monitoring stage will involve checking the nutrient levels, pH, temperature, and humidity of the nutrient solution and hydroponic environment.

In hydroponic cultivation, proper parameter levels and monitorization are crucial for successful growth. Keeping that in mind, if the parameters are in the right manner the cultivation process can continue in hydroponic condition with those parameters. But if the parameters are not optimal, a second monitoring phase is triggered. In this second monitoring phase, we tend to overcome the changes that will improve the crop's optimal growth in this condition. Every cop has a standard parameter that helps the crops to maintain a steady growth. So to compare the current nutrient levels of the chosen crop to its standard parameters, which help to maintain consistent growth. This enables us to identify any necessary nutrient level adjustments to ensure ideal cultivation. Comparing the parameters with the standard parameter to optimize our model's performance instead of using the same crop recommendation dataset. This helps to maintain constantly recommended parameters for a long-term process so that the parameters do not need to change quite often.

This study conducted a simple lettuce cultivation test to assess our model's efficiency by comparing standard parameters with the crop recommendation dataset. Table 4 shows the result.

During the cultivation of lettuce plants, this study initially involved manual checks of the hydroponic conditions, typically 5-6 times a day, which reduced to 3-4 times a day during the growing phase. However, by implementing standard parameters for system adjustment, authors were able to optimize the settings and minimize the need for manual monitoring. Although our proposed approach involves iterative automated monitoring and checking, due to limited resources and budget constraints, this study was unable to fully implement and validate the IoT section for automatic monitoring and recommendation of necessary changes. Nonetheless, we successfully demonstrated the efficacy of manual data collection, which allowed us to monitor the lettuce plant. By leveraging machine learning techniques (as shown in Fig. 12[a]), this study achieved robust growth and a healthy lettuce plant. To support the cultivation process, this study procured a nutrient solution specifically formulated for hydroponic cultivation (Fig. 12[b]), containing all the necessary NPK ingredients required for lettuce growth. Although further research is required to fully automate the monitoring and recommendation system, our findings highlight the significance of standard parameters in ensuring consistent and successful lettuce cultivation.

4. Result and discussion

The results of our study demonstrate the effectiveness of an AIOT-based automated monitoring and recommendation system in hydroponic conditions. This study conducted validation tests on lettuce plant using both NFT and Tower Garden methods, with limited resources available. Selecting the lettuce plant for our study came after considering its short growth cycle, ranging from 4 to 8 weeks. This allowed us to gather data and draw conclusions quicker than with other varieties of crops. Lettuce also has relatively a simple nutrient requirement which made it easier for us to manage the hydroponic nutrient solution effectively. Throughout this work process, our team manually handled system parameters such as temperature, pH levels, humidity conditions and nourishment needs that are essential in fostering proper development of lettuce plant. With precise regulation practices implemented during experimentation phases resulted in positive improvements on overall fitness measures relating to the progression of the lettuce plants. Moreover, closely monitoring lettuces' physical attributes designated ideal harvesting times when they grew within lengths between 20 to 30 centimeters; green leaves resonated well displaying their healthy state consistently. Besides that, the leaves were 7.5 to 15 cm long, showing off both crisp and tender texture forming a balance moisture-crunch ratio throughout. Additionally, this involved applying machine learning techniques aimed mainly to provide crop recommendations and referring the right parameters for suitable crop. By comparing the monitored parameters against established standard values, our system was able to recommend suitable crops for cultivation. Moreover, it determined the best combination of parameters and nutrient solutions tailored to the specific crop requirements. The Random Forest algorithm, which we employed for crop recommendation, achieved an impressive accuracy rate of 97.5%.

Despite the manual monitoring process, a user-friendly web-based framework has been developed (Fig. 13) that facilitates easy data input and access to recommended crops. This framework enables users to check the optimality of parameters for specific crops, providing a practical and user-centric solution. Another motive for this framework is to present a graphical user interface to the user for this whole method. When connected to IoT sensors the data will automatically transfer to the hosting website using Bluetooth Serial Communication and will feel the parameters accordingly. In this case, a demo has been shown in Fig. 13[a,b,c,d].

These results highlight the substantial improvements in crop quality that can be achieved through continuous monitoring and machine learning-based recommendations in hydroponic environments. By harnessing the power of technology, it can be optimized the growth conditions and ensure the production of high-quality crops. Overall, our study demonstrates the successful integration of AIOT-based monitoring and recommendation systems in hydroponic cultivation. Hydroponics' future looks promising, due to the blend of precise monitoring, machine

(a) Lettuce plant grown in hydroponic condition.

(b) Nutrient solution A+B

Fig. 12. Lettuce Plant and Nutrient Solution.

learning procedures and an easy-to-use interface. This combination sets the stage for productive crop yield with good quality.

5. Conclusion

This study demonstrates the effectiveness of an AIOT-based automated monitoring and recommendation system in hydroponic conditions in our country. A real time validation test is conducted using lettuce plant using both NFT and Tower Garden methods to analyze the whole process manually and compare with the system to evaluate the performance of the model. For crop recommendations an impressive accuracy has achieved using Random Forest algorithm. Authors developed a user-friendly web-based framework that can recommend crops for suitable input parameters. In this study, authors showcased the value of integrating IoT sensors and machine learning practices for overseeing crops along with their apt conditions in hydroponic settings specifically NFT and Tower Garden systems. Using data derived from nutrient solutions allowed us to constantly observe essential factors impacting plant health and growth. The use of IoT sensor integration presents an opportunity for live-time data harvest which facilitates quick identification if there are any shifts away from ideal conditions needed for plants' development. Implementation of machine learning methods helped in creating a crop recommendation system based on given parameters while also applying those compiled parameters as suggestions towards accomplishing improved growth rate success within hydroponic environments. This system offers vital foresight empowering cultivators to make knowledge-based decisions thereby optimizing their produce yield. The results of our study highlight the potential of AIOT, a new trending technology in revolutionizing hydroponic farming. By leveraging these technologies, the accuracy and efficiency of plant monitoring can be enhanced, leading to improved crop management practices.

Experimental result of this study clarifies that hydroponic system is suitable for our environment and in urban area it is a better choice rather than traditional cultivation. Furthermore, the ability to detect anomalies and promptly address them contributes to reducing crop losses and maximizing resource utilization.

It is important to acknowledge that while this research has yielded promising outcomes, certain limitations should be considered. The effectiveness of the crop recommendation system heavily relies on the quality and accuracy of the input data collected by the IoT sensors. If authors can get more features and data based on the hydroponic environment this model can be trained with more options which will surely improve the model's accuracy. Besides that, electric power consumption and pricing are other two matters which should be considered as well. The various components of the system require a continuous power supply to operate effectively. On the other hand, the installation and setup of the system, including the purchase of IoT sensors, and other necessary equipment, can be costly. Additionally, maintenance and replacement costs for these components may also contribute to higher operational expenses. Minimizing power consumption through the use of energy-efficient equipment or optimizing the system's design and exploring cost-effective alternatives, implementing efficient resource management strategies, and assessing the long-term benefits of the system are potential ways to mitigate this to enhance this approach.

In conclusion, our research underscores the potential of IoT sensor integration and machine learning techniques in revolutionizing hydroponic farming. By providing real-time monitoring, anomaly detection, and crop recommendation, this approach holds promise for enhancing crop yield and sustainability in hydroponic systems. As advancements in technology continue to evolve, this study anticipates further developments and applications of IoT and machine learning in the field of precision agriculture, driving innovation and enabling more efficient and sustainable farming practices. Our future work will focus on refining data collection methodologies and exploring additional parameters to improve the precision and reliability of the system.

CRediT authorship contribution statement

Md Anisur Rahman: Formal analysis, Data curation. **Narayan Ranjan Chakraborty:** Supervision, Resources. **Abu Sufiun:** Writing – original draft, Visualization, Validation. **Sumit Kumar Banshal:** Writing – original draft, Supervision, Conceptualization. **Fowzia Rahman Tajnin:** Writing – review & editing.

(a) Web-based application for crop recommendation.

(b) Crop Recommendation Result

(c) Web-based application for Parameter recommendation.

(d) Parameter Recommendation Result

Fig. 13. AIOT based Web Application.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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