Artificial Intelligence Based Soilless Agriculture System Using Automatic Hydroponics Architecture

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Abstract. The conventional practices of farming vegetables are inherently associated with the shortage of vegetables due to its seasonal nature, limited farming land and continuous demand. The introduction of artificial means of vegetable production is labor-intensive because of the processes involved in this paper an Artificial Intelligence (AI) based Nutrient Film Technique (NFT) hydroponics system will be designed to mitigate the shortage of vegetable production and minimizes labor. AI will be coded into the ATMEGA328P microcontroller using C++ to provide the required automatic control necessary for the NFT pumps and valves, while Attention Commands (AT) will be used for the interfaced Sim900 Global System for Mobile Communication (GSM) modem for sending Short Message Service (SMS) to the farm operator in case of any malfunction. The improved NFT is found to maximize farmland sine layers of plants can be arranged on one another at a given distance apart, which varies from plant to plant. The AI minimizes human intervention and provides exact mixing and supply of balanced nutrients to plants for fast growth and healthy plants. Continuous production throughout the year using precise AI techniques was designed. Therefore, an improved user-friendly NFT was achieved by utilizing AI embedded in a microcontroller.

Keywords: Artificial intelligence · Microcontroller · Hydroponics · NFT · Soilless agriculture

1 Introduction

With the advancement of technology in various aspects of our daily lives which aims to improve our standard of living, the need to find a suitable technological solution to the endearing increase in dwindling supply of agricultural products became imminent. With

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the plant rapid increase in industrialization, which in turn results in the reduction of fertile farmlands and urbanization resulted in the overtake of most of the nearby farmlands. Therefore, a solution was developed termed as hydroponics which allows for vegetables and other farm produce to be grown anywhere even in cities as an alternative to conventional agriculture. This is so to meet the daily food requirements in the community [1]. Conventional farming practice is faced with several problems that need to be improving to mitigate with the shortage of seasonal food, fix size of farmland and lack of balanced nutrients for plant growth [2].

This paper aims at providing the solution to continuous production throughout the year, providing the plants with an automatic mixing of the required nutrients elements in the desire proportions and deliver the exact requirements to the plant roots. The stated factures will be addressed using artificial intelligence (AI) embedded in ATMEGA328P. The automation will be carried out using an embedded system, which will be preprogrammed with a suitable mixing formula for the plant to be served. Some degree of freedom will be given which will enable a preset through the graphical user interface (GUI). The GUI will provide flexibility in adjusting the mixture proportions of the nutrients for various stages of plant growth.

The rest of this paper is structured as follows. Section 2 covers the background of the hydroponics; Sect. 3 discusses the design overview and the process flow of the proposed NFT system was explained in Sect. 4. Section 5 provides the conclusion.

2 Background of Hydroponics

The background of the hydroponics is provided in the subheadings to enable a clearer understanding of the proposed design.

2.1 Introduction to Hydroponics

Hydroponics is a type of agricultural system under the subset of hydro-culture. It is known as a method whereby plants are grown in the absence of soil, by using mineral nutrient solutions in a water solvent. The roots of the plant can either be directly exposed to the nutrient solution or can be supported by inert materials [3]. As a result of the nature of hydroponics, plants can be grown all through the year. Figure 1 shows the Sample of the proposed hydroponics system, whereby variety of vegetables are planted in layers. This configuration leads to space maximizing to about three times the size of the land. The plant grown through hydroponics are healthy and free from pests.

2.2 Advantages of Hydroponics to Conventional Soil Agriculture

With the increasing indulgence of researchers in hydroponics agriculture, results have been obtained which shows that hydroponics is very advantageous in various respects, in terms of crop output, expenses, use of resources, etc. Besides the fact that it makes plant cultivation possible in any environment, research has also shown that plants grown with hydroponics are bigger, stronger, healthier, more nutritious, and increased yield of plant produce. Hydroponics also reduces the use of resources, about 70% less water

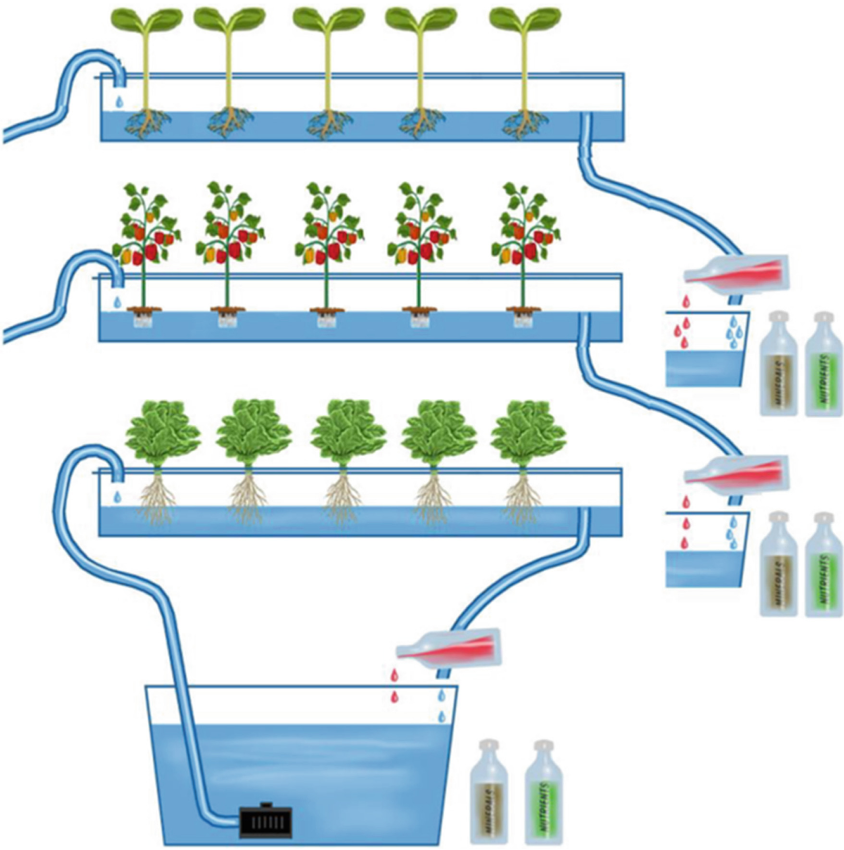

Fig. 1. Proposed hydroponics system.

is needed in hydroponics than in conventional farming [4]. Moreover, there is a high reduction in the use of fertilizers (minimal amounts are needed), the use of pesticides is highly reduced [1, 4]. Other advantages of the system include faster growth rate which results in higher rate of production and complete knowledge of the system in case of any infection in the plant since it is a controlled system [5], the problem can easily be detected. Also, in automated hydroponics, the amount of supervision by the farmer is brought to a minimum and birds cannot get direct access to the plants.

2.3 Types of Hydroponic Systems

There are six (6) basic types of hydroponics systems [6], which include.

- Wick System
- Drip System
- Water Culture System
- Aeroponics System
- Nutrient Film Technique (NFT)

- Ebb and Flow System

New advanced methods are being developed, such as fogponics systems. In this paper, the NFT was adopted because of its driving advantages as mentioned and simplicity. The AI was built in the NFT via the ATMEGA328P to increase efficiency. Figure 2 shows the basic types of hydroponic systems.

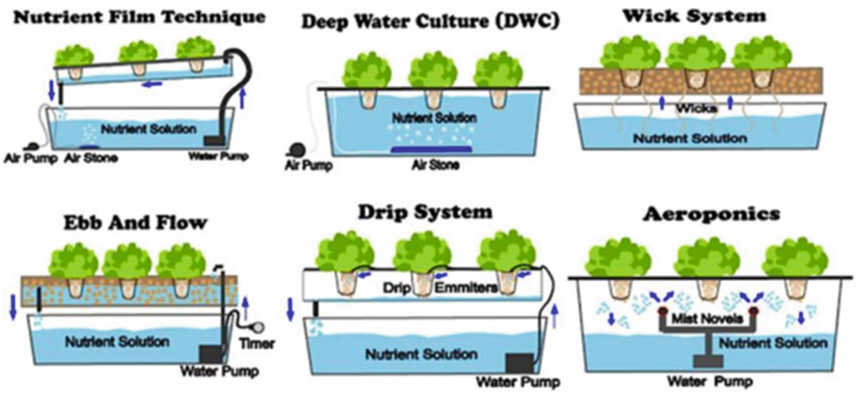

Fig. 2. Conventional setups of basic hydroponic systems [7].

3 Design Overview

The design overview is explained in the following subheadings.

3.1 Nutrient Film Technique

In this paper, the Nutrient Film Technique (NFT) was used in combination with AI. It was chosen because it is simple to implement, and its design arrangement allows for easy automation and maximizing land usage as well as AI is incorporated as the highest and full automation approach [8]. The NFT is also called the continuous-flow solution culture because nutrient solution constantly flows passes the roots and is drained back to the reservoir from where it is pumped again. Figure 3 shows the features of the adopted NFT [9].

The NFT system is simple, and it eliminates some of the challenges of other setups [11]. Because of its continuous flow, no timer is required for the submersible pumps. It also does not require any growing medium i.e., inert materials used in other setups. The NFT makes used of only plastic baskets to support the plant and the roots are immersed directly in the nutrient solution passing through the channel. Despite its advantages, the NFT system has shortcomings such as susceptibility to power outages and pump failures. Once any of the two happens, then the roots become dry shortly. Due to the critical of the said shortcomings, the AI was deployed to address the problems by triggering alarm of unpleasant frequencies to alert the operator and an immediate Short Message Service

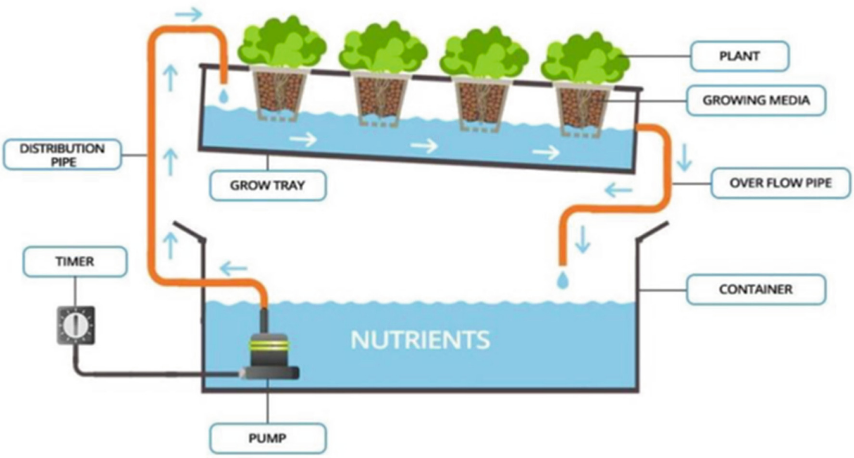

Fig. 3. The basic setup of the NFT system [10].

(SMS) will also be sent for urgent response. Figure 4 shows the NFT plant grow trays using PVC materials and film channels for the planting. The PVC was selected because they are lighter than other hydroponic system materials like steel, and moreover they are not toxic and soluble.

Fig. 4. PVC pipes for NFT plant grow tray and film channel [12].

3.2 Nutrient Solution Mixture

The basis of hydroponics is the replacement of the natural soil with a suitable nutrient solution that contains all the plant needs. Research has shown that the plant needs about 16 elements for growth [13]. These include carbon, hydrogen, oxygen, phosphorus, potassium, nitrogen, sulfur, calcium, iron, magnesium, boron, manganese, copper, zinc, molybdenum, and chlorine. These nutrients can be gotten from water, air, and fertilizers or by getting liquid solutions of the individual elements. The major elements however are

Nitrogen N, Potassium K and Phosphorous P [14], hence they will be used in this paper and their required mixture will be done via AI in the percentage ratio of 7%-9%-5% of N-P-K respectively.

The correct and precise composition percentages of these elements are required for the nutrient mixture else it may result in distortion, deficiencies, and death of the plants. The compositions vary at various stages of plant growth and vary for individual plants. The nutrient solution mixture is therefore a very key aspect of hydroponics hence precise is placed in maintaining the nutrients compositions, the solution's pH value and electrical conductivity always. Hence an artificial intelligence-based control is employed to enable the exact process.

3.3 Plant Reservoir

The plant reservoir is a container that is specially designed or any container that could serve the purpose of holding a required volume of nutrient solutions. It also houses the air pump, air stone, EC sensor, pH sensor, submersible nutrient pumps and other components. Figure 5 shows the plant reservoir.

Fig. 5. Plant reservoir [15].

3.4 Submersible Pumps

These are pumps that can be powered electrically and can be controlled by the control unit equipped with AI. The pumps are driven by a direct current (DC) motor, which is controlled by the AI. They are used to deliver the nutrient solution by pumping the required solution as instructed by the AI from the reservoir to the plant tray (Fig. 4) and pump nutrient element solutions from their various tanks into the reservoir. Figure 6 shows a submersible DC pump.

Fig. 6. Submersible Electric Pump [16].

3.5 EC Sensor

The EC meter known as the electrical conductivity meter is a meter used to measure the electrical conductivity of solutions. The EC meter is especially useful in hydroponics to determine the number of nutrients, salt, or other impurities present in the nutrient solution [17]. The standard unit for measuring electrical conductivity is milli-Siemens per centimeter (mS/cm). For a typical hydroponic nutrient solution, the value of electrical conductivity is around 2.0 mS/cm.

The EC meter returns the value of its readings of the electrical conductivity of the nutrient solution to the control unit where the AI will decide considering the value of the readings whether the nutrient solution in the reservoir needs to be changed. Though the EC meter can measure the strength of the nutrient solution, but it cannot give the nutrient balance of the solution and cannot also read the strength of non-ionic compounds such as carbon compounds [17], hence the introduction of the AI as an improvement measure ahead of research of its kind.

3.6 pH Sensor

The pH meter is also important for this research work. It is used to measure the hydrogen-ion activity in water-based solutions, indicating its acidity or alkalinity expressed as pH, which is useful in hydroponics agriculture [17]. Its readings are necessary because the pH value in the reservoir must be maintained at a balance in growing plants [18]. Hence, the control unit of an automatic hydroponics system takes the inputs of the pH meter and applies measures where necessary to balance the pH value. This is mostly done by adding a chemical pH balancing solution. In most hydroponics systems the optimum pH range is within 5.8–6.2 [19].

3.7 Oxygenation of the Nutrient Solution

After the proper composition of the nutrient mixture in the reservoir, another important task to be done is the oxygenation of the nutrient solution. This is necessary because the plant needs a proper amount of oxygen to breathe otherwise it dies out. There are a couple of methods used to oxygenate the nutrient solution. Some hydroponic users adopt the use of hydrogen peroxide, which is not amazingly effective. It creates dissolved oxygen which has a short life and is not well circulated. Also, O2- is created which can damage healthy plant cells [20].

A better oxygenation approach is to introduce natural air to the reservoir, which reacts with the solution to form enough dissolved oxygen (DO) molecules needed by the plant. This is done by using air pumps and air stones to aid in better circulation of the dissolved oxygen molecules. Supplementary, stirring pumps can be added for better circulation.

3.8 Air Pumps and Air Stones

As discussed in the section above, one other important aspect of implementing a successful hydroponics system is the oxygenation of the nutrient solution. This is done using air pumps and air stones. What the air pump does is pump air into the nutrient reservoir, when the air meets the water; it diffuses into the water which supplies it with oxygen to undergo oxygenation. The air pump pumps air through a plastic tube or pipe to the bottom of the reservoir where its end is attached to an air stone as shown in Fig. 7 and Fig. 8. The purpose of the air stone is to catalyze the oxygenation reaction by passing out the pumped air in the shape of small size bubbles for the effective circulation of air into the nutrient solution to form dissolved oxygen, which is needed by the plant roots.

Fig. 7. Air pumps pumping air through air stones [21].

Fig. 8. Air Stones [22].

4 Process Flow of the NFT System

Pump P3, P4 and P5 are controlled via the AI, which is embedded in the ATMEGA328P to supply nutrients (Nitrogen, Phosphorous, and Potassium) in the required proportions to the reservoir. Water and are pumped via P6. From the reservoir, a nutrient pump (P7) is used to pump the nutrients to the nutrient film channel which is maintained at a fixed slope to achieve a constant and desired flow rate. After the nutrient solutions have passed through the roots of the plants it is then returned to the reservoir where it will be pumped up again. 'AT' commands are used for the Global System for Mobile Communication (GSM) modem Sim900, which is cooperated to establish communication via SMS to the operator when malfunction occurs. This describes the unique character of the proposed improved NFT system, whereby nutrients solutions are reused, and wastage is eliminated, and the roots are constantly supplied with adequate amounts of water, oxygen, and nutrients. It can also be seen from the schematic diagram shown in Fig. 9 that two sensors (meters) are used, the EC meter and pH meter. These two (M1 and M2) meters determine the pH level of the nutrient solution and the electrical conductivity, respectively. If the values fall below a certain threshold at which the solution does not deliver proper nutritious content to the plants, the current solution will be drained to the waste reservoir through valve S2, and new nutrients will be pumped and mixed in the reservoir [20]. The repetition of the entire process is done via AI. Proposed NFT system was explained in Sect. 4. Section 5 provides the conclusion.

4.1 Control Unit

The ATMEGA328P was used due to its inherent advantages in addition to being easy to program using Arduino development boards [23]. It is also the main component of the control unit where the intelligence was coded in it using the C++ and AT commands. The DC motor switches use to control the water, nutrient and air pumps are controlled by the ATMEGA328P. The DC motors are interfaced with the I/O ports through a switching circuit. The ATMEGA328P controls the switching circuit following the intelligence

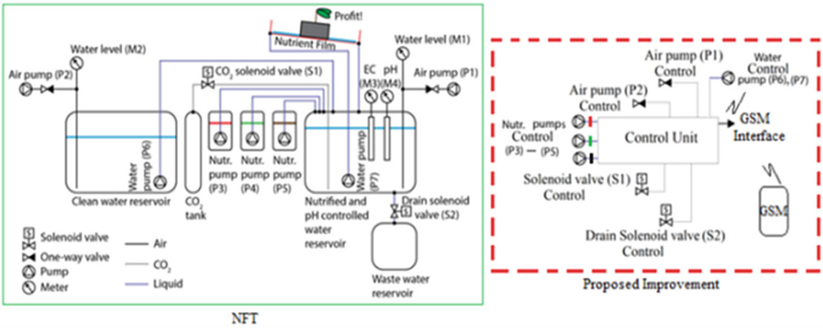

Fig. 9. Artificial intelligence process flow schematic for an NFT hydroponic system

embedded in the coding. Figure 10 shows the pins configurations and ports for the ATMEGA328P.

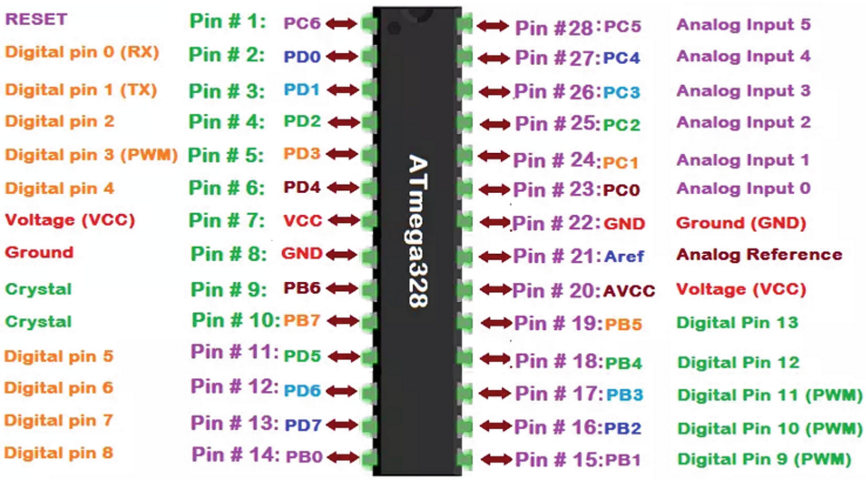

Fig. 10. ATMEGA328P pin configuration [24].

4.2 Display Unit (16 × 2 LCD)

The 16 × 2 liquid crystal display (LCD) was used to provide visualization of the percentage of the composition mixture of the nutrient solution. The quality of the current nutrient solution in the reservoir as measured by the EC and pH sensors and which mixture type is currently in use are displayed for easy monitoring.

4.3 Mixture Types

The diverse types of composition mixtures of the nutrients to form solution are referred to as the states. There are three States A, B and C. These states are included in other to improve the versatility of the system by giving the user the freedom to choose from diverse types of mixtures. These states A, B and C denote different composition mixtures of nutrients required for various stages of plant growth from germination to full growth. The states are selected by pushing dedicated button switches which inform the controller that a state has been selected and that the nutrient mixture should be done accordingly. Figure 11 shows the Proteus schematic circuit diagram for the control.

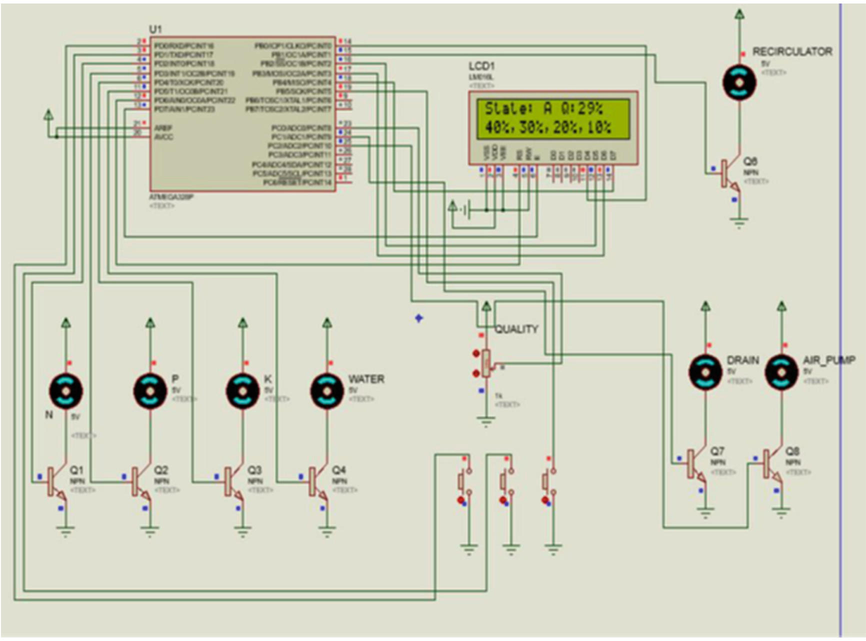

Fig. 11. The schematic diagram for the control circuit of the plan

4.4 Developed Software

Two applications software were used to implement the software aspect of this paper. First, the Arduino Compiler was used to write the program code. Secondly, the Proteus 8 Professional was used to simulate the hardware circuit of the work.

4.5 Arduino Compiler

Arduino compiler is that which uses the C++ programming language. It is commonly used to write program codes for Arduino-based controllers. The Arduino compiler interface is simple and hex files are easily generated and uploaded on the controller in the Proteus environment.

4.6 Proteus 8 Professional

Proteus 8 Professional is an interactive development environment (IDE) developed by Labcenter Electronics. It is used for the development and simulation of electronic circuits. It has the advantages of pre-implementation in loop tests and corrections.

4.7 Simulation

The simulation was conducted on the Proteus IDE before uploading the Hex file to the controller. The following subsystems explain how it is done.

4.8 Brief on How the Simulation Works

Seven DC motors are used in this paper's simulation, the motors represent the following:

N – Nitrogen pump, Water – Water pump, P – Phosphorous pump, drain – Drain valve, K – Potassium pump, Air pump and Recirculation pump. When the simulation is started, it displays the state (i.e., the type of mixture), the quality of the nutrient solution, and the Percentage of N, K and P, respectively. It then pumped water and mixes the nutrients according to the state selected, by pumping their various liquid solutions for specific durations into the reservoir using flow rate. After the nutrient has been mixed in the reservoir, the control circuit triggered the air pump for oxygenation. Since the Nutrient Film Technique is being used that means the nutrient solution is continuously pumped into the film channel. Therefore, the controller is set to pump the nutrient solution into the film channel after every one minute. Assuming one minute is the duration required for the nutrient solution to slide through the plant's root in the film channel and be drained into the reservoir.

The controller always checks, before initiating the recirculation pump, the quality (nutrient value) of the nutrient solution in the reservoir. This quality value is measured by the EC and pH sensors and feedback to the controller, which are represented by a variable resistor in this simulation. If the quality is below 30% the control circuit, then initiates the drain pump to drain this low-value solution and then mix a new nutrient solution into the reservoir then initiates the recirculation pump. This process is repeated continuously.

5 Conclusion

It can be concluded that a soilless agriculture system using the proposed AI enhanced NFT hydroponics system can provide an improvement over the conventional NFT. The improved NFT maximizes farmland, minimizes human intervention, provides fast growth of plants due to balance nutrients at all the time, resulting in healthy plants free from pests, and birds and permits continuous production throughout the year using the precise AI techniques.

6 Limitation and Recommendation

Every good engineering design has some number of limitations, which give room for future improvement to increase its reliability and effectiveness. Some of the future work may include:

i. Physical implementation of the prototype.
ii. Frequent updating the IoT related to this research finding is necessary as technology rapidly changes with time.

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