DE-42 (EE) Suleiman, Iqra, Ibtesham, Shahab

Design and Implementation of a Hydroponic Automated System for Indoor Agriculture

COLLEGE OF
ELECTRICAL AND MECHANICAL ENGINEERING
NATIONAL UNIVERSITY OF SCIENCES AND TECHNOLOGY
RAWALPINDI
2024

COLLEGE OF ELECTRICAL AND MECHANICAL ENGINEERING

DE-42 EE

PROJECT REPORT

Design and Implementation of a Hydroponic Automated System for Indoor Agriculture

Submitted to the Department of Electrical Engineering

in partial fulfillment of the requirements for the

degree of

Bachelor of Engineering

in Electrical 2024

Sponsoring DS:

Submitted By:

M. Suleiman Faisal
Iqra chanar
Ibtesham Ali Asad
Shahab khan

CERTIFICATE OF APPROVAL

It is to certify that the project "Design and development of an automated hydroponic system for vegetable growth" was done by NS M Suleiman Faisal, NS Iqra Chanar, NS Ibtesham Ali Asad and NS Shahab Khan under the supervision of Dr. Saifullah Awan and Dr. Danish Hussain. This project is submitted to Department of Electrical Engineering, College of Electrical and Mechanical Engineering (Peshawar Road Rawalpindi), National University of Sciences and Technology, Pakistan in partial fulfillment of requirements for the degree of Bachelor of Engineering in Electrical Engineering.

Students:

1. **M Suleiman Faisal**

   NUST ID: ____________________ Signature:_______________

2. **Iqra Chanar**

   NUST ID: ____________________ Signature:_______________

3. **Ibtesham Ali Asad**

   NUST ID: ____________________ Signature:_______________

4. **Shahab Khan**

   NUST ID: ____________________ Signature: _______________

Approved By:

Project Supervisor: ____________________ Date: _____________

Dr. Saifullah Awan

DECLARATION

We hereby declare that no portion of the work referred to in this Project Thesis has been submitted in support of an application for another degree or qualification of this of any other university or other institute of learning. If any act of plagiarism found, we are fully responsible for every disciplinary action taken against us depending upon the seriousness of the proven offence, even the cancellation of our degree.

1. **M Suleiman Faisal** Signature:_______________

   NUST ID: ____________________

2. **Iqra Chanar** Signature:_______________

   NUST ID: ____________________

3. **Ibtesham Ali Asad** Signature:_______________

   NUST ID: ____________________

4. **Shahab Khan** Signature: _______________

   NUST ID: ____________________

COPYRIGHT STATEMENT

ACKNOWLEDGMENTS

We are grateful to the ALLAH Almighty who provides all the resources of every kind to us, sothat we make their proper use for the benefit of mankind. May Allah keep providing us with all the resources and the guidance to keep helping humanity.

We would like to start off by giving a heartfelt appreciation to our supervisors, Dr. Saifullah Awan, and Dr. Danish Ali. Their firm support, guidance and encouragement made us come a long way in this project.

Our journey together has been both intellectually enriching and inspiring, thanks to our teammates – M. Suleiman Faisal, Iqra chanar, Ibtesham Ali Asad, and Shahab Khan –. Their diligence, cooperation, and unwavering support throughout this project have significantly contributed to our academic growth and created a truly memorable experience.

We would also like to express our gratitude to our families for their unwavering support and faith in our abilities. Their constant encouragement has been a driving force behind our efforts.

Finally, we are grateful to everyone who was involved in this project either directly or indirectly. Their contributions have been integral to the successful completion of our project.

ABSTRACT

This study presents the design and implementation of a smart hydroponic system for indoor agriculture, leveraging the capabilities of Arduino and Raspberry Pi for real-time monitoring, alarm generation, and deficiency detection in lettuce plants. The system incorporates pH, TDS (Total Dissolved Solids), temperature, and humidity sensors interfaced with Arduino for continuous monitoring of environmental parameters crucial for plant growth. Live data from these sensors are streamed to a website, providing users with instant access to vital information regarding the growing conditions.

In case of parameter deviations beyond predefined thresholds, an alarm system is triggered to alert users, ensuring timely intervention to maintain optimal growing conditions. Additionally, Raspberry Pi 5 is utilized for deficiency detection in lettuce plants through image processing techniques. A trained model, utilizing a dataset, enables the Raspberry Pi to identify nutrient deficiencies in plants, enhancing proactive management strategies.

The hydroponic system facilitates plant growth by automatically regulating nutrient levels through the dispensation of nutrients into the water reservoir. A motor-driven system ensures efficient circulation of water throughout the setup, optimizing nutrient delivery to the plants. Furthermore, photosynthesis lights are employed to provide adequate illumination for plant growth, promoting healthy development.

By integrating Arduino and Raspberry Pi technologies, this smart hydroponic system offers a comprehensive solution for indoor agriculture, enabling remote monitoring, early detection of issues, and automated management of growing conditions. This research contributes to the advancement of precision agriculture, fostering sustainable and efficient cultivation practices in controlled environments.

SUSTAINABLE DEVELOPMENT GOALS

Considering all the possible sustainable development goals the following are directly/indirectly associated with our project:

SDG 2: Zero Hunger: The Hydroponics System enhances food production efficiency and ensures a stable supply of nutritious food. This innovative agricultural approach maximizes yield in limited spaces, uses water efficiently, and reduces dependency on traditional farming, which can be affected by climate change and soil degradation. By increasing access to fresh vegetables and promoting sustainable farming practices, the hydroponic system plays a crucial role in achieving food security and eliminating hunger worldwide.

SDG 9: Industry, Innovation, and Infrastructure: The design and development of an automated hydroponic system for vegetable growth aligns with SDG 9 by enhancing agricultural infrastructure, promoting high-tech industrialization, fostering innovation, and supporting sustainable practices. These systems optimize space, water, and resource use, contributing to efficient and resilient food production, economic growth, and technological advancement.

Table of Contents

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS

Acronyms

FN	Fully Nutrient Lettuce
N	Nitrogen Deficient Lettuce
K	Potassium Deficient Lettuce
P	Phosphorus Deficient Lettuce
pH	Power of Hydrogen
TDS	Total Dissolved Solids

Structure of the Thesis

The thesis is structured as follows:
Chapter 1 introduces the project, outlining the background, objectives, and significance.

Chapter 2 reviews the literature on hydroponics, indoor agriculture, and automation technologies.

Chapter 3 describes the methodology, including the design and implementation of the automated hydroponic system.

Chapter 4 presents the results of the experiments conducted, analyzing the growth performance of lettuce and the system's efficiency.

Chapter 5 discusses the findings, implications, and potential for future research.

By exploring the integration of automation in hydroponic systems, this project aims to contribute valuable insights into sustainable agricultural practices, ultimately supporting efforts to meet the growing global food demand in an environmentally responsible manner

Chapter 1-Introduction

1. 1 Background

The contemporary agriculture world is filled with an array of challenges for outdoor farmers who are working with finite resources, encouraging to the search for more efficient alternative growing methods. As the world will be in the mind of global demographic growth, which is expected to pass the mark of 9. According to the United Nations with 7 billion adding up as a total by 2050, the demand for fresh fruits and vegetables increases crazily worsening the pressure on the conventional farm practices. To begin with, multiple transitions including those like climate change, soil degradation and water scarcity add the existing challenges for the traditional type of farming leading to extreme conditions.

Reasons underlying these challenges include reliance on limited spaces and resources. Nowadays, hydronic farming is widely adopted as a viable solution. Hydro culture, a soil-less plant growing technique usually utilizes advanced networks of tubes and pipes that provide nutrient solutions to plants is an effective alternative to farming. Through a technique known as hydroponics, the plant roots are nourished by the direct delivery of water and nutrients to them, thus enabling proper resource utilization, helping to cut waste, and allowing cultivation throughout the year in a controlled, consistent environment. As NFT (Nutrient Film Technique) is one of the several hydroponic techniques, it is a simple but highly efficient method in growing greens as lettuce.

Over the years, the adaption of hydroponic agriculture emerged like an inevitable force against some factors such as urbanization, changing consumer habits, and technological progress. And as the vertical farms and rooftop garden and indoor cultivation facilities continue to rise, hydroponics is now the most common as a medium-saleable and sustainable approach to provisioning fresh and local produce to meet the growing demands of our generation.

1. 2 Motivation

The stimulus for choosing hydroponic NFT as the focus for this study is a mix of two interests in those areas: the consequence of sustainable agriculture and technical innovation. As food safety, environmental deterioration and excessively intensive depletion of land resources pose a real threat to conventional farming, it is high time that scientists and policy makers started looking for and promoting smarter alternatives that not only work economically but also protect and preserve the environment.

Besides agricultural and technology converging, methods for increasing productivity, efficiency, and resilience may thus be gotten out in food production systems. Through the applications of sensors, data analytics, and automation technologies, hydroponic NFT farming creates the possibility of going beyond the current consumers and crops production methods. This study intends to use these technology breakthroughs to help solve critical problems of hydroponic farming and provide an ongoing drive to make food systems to be resilient and long-lasting.

1. 3 Problem Statement

Moreover, despite hydroponic NFT farming has enormous positive influences, it still suffers several problems that must be solved urgently to make it as a main crop choice. These challenges include:

1. Optimization of Resource Usage: Minimalizing energy, water, and nutrient wastes by increasing the efficiency of aquaculture through the application of hydroponics technology. Although hydroponic systems are already known to generate lower levels of resource use compared to traditional soil-based farming methods, there still exists further scope for devising smart nourishment systems, better water recycling system and of course ways to use energy more efficiently.

2. Disease Management: The task of preventing plant diseases and keeping them at bay is one of the major issues that hydroponic NFT type of farming is dealing with. In the controlled hydroponic systems, diseases can propagate quickly and can lead to severe health problems for crops, may be causing considerable decreases in productivity. Perfectly for effective hydroponic farming operations, disease management techniques by either early detection, integrated pest management, or biosecurity measures, as they need to be long-term applied, are indispensable.

3. Scalability and Affordability: One of the challenges that we face is designing and monitoring cost-effective and scalable indoor hydroponic NFT farms that can be applied for small-scale growers and individuals who live in the city. Although some scaled hydroponic operations have been successfully utilized in commercial agriculture, there is a gap in affordable and deliverable technologies that are applicable to all the stakeholders including small scale producers and community projects.

Tackling this problem requires multidisciplinary outlook incorporating knowledge and skills from, say sciences of agriculture, engineering and data science. This study is envisioned to provide the development of innovative solutions to these challenges and, as such, contribute to the advancement of hydroponic crops farming and engagement of sustainability principles, as well as address the problem of the adoption of new technology-driven approaches through their incorporation to the process of food production.

1. 4 The Aims of the Research

The primary objectives of this study are as follows:

1. One of the objectives is to make and install a sensor system that can measure 2 or 3 of the environmental parameters (pH, E.C (Electrical Conductivity), temperature, humidity in a continuous manner in a hydroponic NFT system. By the help of the sensor system, we will get uninterrupted data streams which are crucial for near real time control and optimization of growing processes.

2. To place cameras installed with computer vision algorithms for lettering diseases taking place in order to have early detection and diagnosis of diseases affecting lettuce plants. With the help of images taken from direct plant leaves analysis, and visually detecting plant disease symptoms like discoloration, lesions, or general irregularities, the camera system will likely enable early disease intervention, and ultimately prevent disease outbreaks.

3. To design and implement machine learning algorithms in order to analyse data and make decisions by relying on the data called in the live sensors and images with a goal of optimizing farming activities. Through the use of machine learning and optimization methods, these software algorithms will come up with recommendations based on the inputs from the hydroponic NFT system, making the system more effective in areas such as nutrient delivery, irrigation scheduling, and pest control

4. Therefore, the one assessment criterion will be the appraisal of the correlation between the performance of an integrated sensor and camera system and the success in improving crop yielding, quality, and disease resistance in hydroponic NFT farming. An experimentation of high rigor and an assessment of the field trails will be undertaken in the study, and the effect of the newly introduced technologies on the key performance indicators, which are, crop yield, nutrient uptake, disease incidence, and resource use efficiency, will be evaluated.

Via accomplishing these goals, this research aims to providing for a better environment of growing hydroponic and for later easier adaptability of sustainable tools and technologies in food production Collaboratively, the study will work out with its industrial as well as community partners and with academic institutions, so that research findings can be converted into useful solutions for the benefit of farmers, consumers, and the environment.

Chapter 2-BACKGROUND AND LITERATURE REVIEW

The following chapter is devoted to the presentation of the hydroponic farming technology and an overview of the various hydroponic techniques. Moreover, this chapter presents critical literature reviews on hydroponic farming as well.

2.1 Introduction to Hydroponic farming

Hydroponic is defined as the "cultivation of plants in water" [16]. Hydroponic is the science of feeding nutrients to plants so they can reach for their full genetic potential and lead to increased agricultural production. These techniques enable plants to grow more rapidly and require less space for farming. This technique of a closed system allows the growers to conveniently grow plants with ease. Nutrients are supplied to the plants in an efficient way and other environmental factors such as temperature and humidity are also controlled and this helps the plants to grow spontaneously and at a faster rate. Farmers and researchers employ different hydroponic methods. People can adapt these methods easily to their requirements and start growing plants.

2.1.1 Types of hydroponic system

These are the most common types of hydroponic systems applied in agriculture and scientific research. Each of the systems has its own pros and cons, and what system to choose depends on factors including crop type, space availability, and the desired level of automation.

1-Nutrient Film Technique (NFT): NFT stands for Nutrient Film Technique, which is a hydroponic system in which a fine layer of nutrient solution constantly flows above the roots of plants, often in channels or troughs. This system provides a constantly supply of water, oxygen, and nutrients to the roots, resulting in healthy growth and high yields.

NFT systems, in general, are very efficient when it comes to using water and nutrients. They are used in growing leafy greens, herbs, and strawberries.

2-Deep Water Culture (DWC): DWC is a simple hydroponic system where plants are suspended in the solution-filled reservoir aerated with nutrients. The roots of the plants are completely immersed in the solution to enable efficient absorption of nutrients and oxygen.

DWC systems are recognized for their simplicity of assembly and low maintenance, which makes them suitable for both beginners and commercial growers.

3- Ebb and Flow system: Ebb and flow systems comprise of trays or beds stuffed with growing medium, which are intermittently flooded with nutrient solution from the reservoir. Afterwards, the nutrient solution is filtered back into the reservoir, thus enabling the roots to absorb nutrients and oxygen from the medium.

Through this cyclic phenomenon of flooding and drying, the plants have a natural irrigation process that helps their strong root growth and nutrient absorption.

4-Aeroponics: Aeroponics systems are those that suspend plants in a chamber and occasionally mist them with nutrients. The roots are suspended in air and nutrients are provided to them in a fine spray. This results in oxygenation and absorption of nutrients to the maximum.

5- Drip Irrigation: Drip irrigation systems directly delivers nutrient solution to the feet of every plant through a system of tubes and emitters. Solution drips at a rate that is proportional to how much nutrient is required.

Drip systems are automated and adjustable to cater to the unique requirements of different crops, therefore making them a suitable method for both small-scale and large-scale hydroponic farming operations.

6- Wicking System: Wicking systems employ a passive wicking device which is responsible for delivering nutrient solution to the roots of plants. A wick, which could be any fabric strip or rope, channels the solution from a reservoir to the growing medium, where it absorbs the solution into the roots using capillary action.

Wicking systems are simple and cost-effective, as they do not require pumps or electricity; however, they may not be suitable for big-scale or high-density crop production.

"From the variety of hydroponic systems existing, Nutrient Film Technique (NFT) has become one of the popular options for a number of applications." NFT systems provide a set of benefits, which are such as efficient supply of nutrients, proper oxygenation of roots and effortless operation. These systems entail a constant flow of a nutrient solution film in the root environment of plants located inside channels or troughs. Water and nutrients are constantly supplied, resulting in the high rate of root growth, nitrogen uptake, and increased plant growth and higher yield.

The use of NFT instead of other hydroponic methods often depends on its adaptability to specific crops, growing systems, and production purposes. NFT systems are a good option because of their versatility to work with different plant types such as leafy greens, herbs, and strawberries. Moreover, it grabs the attention of newbies and experienced growers with its open-source software and low maintenance systems.

2. 2 Nutrient Film Technique

Nutrient Film Technique or N. F. T. which was devised by Allen Cooper at the Glasshouse

Crops Research Institute in Little Hampton, England [6]. This method is well-liked as it has a simple form. In this method, small vegetable like lettuce etc. are cultivated.

2.2.1 Design and Components:

- Development of a NFT hydroponic system that is efficient requires consideration of several major factors, including:

- Channels or Troughs: These are the essential structures that support the nutrient solution and enable root growth. They are most commonly made of long-lasting materials such as PVC or plastic and their width and length can differ based on the crop demands and the limited space for cultivation.

- Nutrient Reservoir: This is where the nutrient solution is kept for the pumping into the channels. The size of the tank should be sufficiently large to hold enough solution needed for plant growth and it should be installed with a filtration system that can remove all the debris and impurities.

- Pump for Circulation: A dependable pump is needed to guarantee the flow of nutrient solution from the reservoir to the channels. It provides a continuous passage for the solution to flow over the roots and hence a continuous supply of water and nutrients for the roots.
- Growing Medium: The NFT schemes, unlike others, require almost no growing medium such as rockwool or perlite, but still, it is very important for retaining moisture and provides support for the plant roots. The type of growing medium is dependent on attributes including water retention, pH stability and availability.

2.2.2 Nutrient Management

Managing the amount of nutrients in NFT hydroponics is a key factor to enhance the health and productivity of the plants:

- Nutrient Formulation: Nutrient solutions must be cautiously created in such a way that they are able to provide the macronutrients and micronutrients that plants need in balanced quantities. This is mostly achieved by substituting commercial hydroponic nutrient mixes with custom formulations made to meet the particular crop requirements.

- pH Adjustment: The pH levels of the nutrient solution are regularly checked and adjusted, when necessary, in order to maintain a high level of nutrient availability for the plant. Most plants are happiest with a slightly acidic pH of about 5. 5 to 6. 0, and diversion of this limits can cause either nutrient deficiencies or toxicities.

- Monitoring Techniques: Tools including electrical conductivity (EC) measurement and ion-selective electrode (ISE) sensors are employed for nutrient content management and solution control. This equipment gives us much information on the status of nutrients in the system and helps us to avoid nutrient imbalances or deficiencies.

2.2.3 Plant Growth and Yield

The study has revealed that NFT hydroponic systems have a high potential to boost plant growth as well as yield compared to the conventional soil-based cultivation.

- Faster Growth Rates: Plants grown in NFT systems are usually characterized by faster growth rates because of the easy and unrestrained access to water, minerals, and oxygen by the roots. Such fast-tracked growth can lead to shorter crop cycles and higher productivity in general.

- Increased Biomass Accumulation: NFT systems have a vigorous root system development and nutrient uptake that increase biomass and the plant health in the end. This results in higher quality produce yield, which makes NFT hydroponics an appealing choice for commercial growers.

- Crop Versatility: NFT system is very flexible and can accommodate the plant species including leafy vegetables, herbs, strawberries, and tomatoes. This very flexibility enables growers to expand their crop variety by taking into account market requirements and seasonal taste.

2.2.4 Environmental Considerations

The NFT hydroponics system offers various environmental benefits. However, we ought to examine the possible environmental impacts and apply sustainability practices.

- Nutrient Runoff Management: Pollutant runoff from NFT plants is dangerous to waterways and ecosystems if not effectively managed. Methods like recycling nutrient solutions, designing nutrient recovery systems, and use of best management practices can be utilized to reduce nutrient runoff and consequently environmental effects.
- Water Conservation: NFT hydroponic systems by nature are water efficient compared to the traditional soil-based farming methods. Through recirculation of nutrient solutions

and minimizing water loss through evaporation or runoff, NFT systems can assist in preservation of water resources and reduce overall water consumption.

- Pesticide Reduction: NFT systems remove the demand for soil and can significantly reduce the use of pesticides as compared to conventional farming practices. This reduction in the use of chemicals can lead to green environments with less pollution and healthier ecosystems.

This can be done through proper design considerations, proper nutrient management, optimal plant growth and yield, as well as environmental sustainability, which will lead to the development of modern agriculture and the production of quality and nutritious crops.

2.2.5 Commercial Applications

From urban farming to large-scale production, NFT hydroponic systems have taken the agricultural world by storm. Case studies illustrate possible uses of NFTs in a variety of contexts, demonstrating the multiple applications and its efficacy. For example, with urban farming projects, NFT systems are used to maximize the little space available and to produce fresh and nutrient rich fruits and vegetables throughout the year. Such systems are usually part of vertical farming schemes, helping to use the available space of urban real estate optimally with minimum environmental impact.

While NFT hydroponics offers growers a lucrative market opportunity in commercial agriculture and greenhouse production by enabling cultivation of high-value crops such as leafy greens, culinary herbs, and specialty vegetables. NFT systems offer a controlled environment that provides optimal conditions for growing, making it possible to have consistent yields and high-quality produce. Also, NFT cultivation allows for very accurate control of nutrient levels, therefore resulting in healthier plants and decreased needs for chemical inputs.

Successful operation case studies of NFTs highlight the economic potential and scalability of this technology. Streamlining production processes, wasting very little of the resources, and increasing crop yields keep the profitability and sustainability of modern agricultural enterprises high by means of NFT hydroponics. Furthermore, the availability of fresh, locally grown foods which are free of pesticides and contaminants to the consumer lead to the improvement of their health and well-being.

2.2.6 Future Directions and Innovations

The current research is geared towards solving the challenges and developing the technology to meet the dynamic needs for agriculture practice. The innovations including the vertical farms where the NFTs are stacked vertically to increase production and minimize the land use have immense prospect for having maximum production efficiencies and minimizing the land use. The possibility of year-round farming in controlled environments makes vertical farming ideal especially for urban areas where farm land is not usually available.

Integration of hydroponics with aquaponics is another innovative approach to the development of NFT hydroponics, creating a fish farm which supplies plants with nutrients simultaneously. In aquaponics, fish waste provides nutrients to plants while plants, at the same time, clean the fish's water. Closed-loop system that minimizes environmental degradation, maximizes resource use and offers a sustainable solution for food production.

The development of advanced sensor technologies, which include wireless monitoring systems and data analytics, will greatly boost the efficiency, productivity, and sustainability of NFT hydroponic systems. These sensors are equipped with real-time feedback on environmental parameters, nutrient levels, and plant health, which allows growers to control growing factors and to detect issues before the crops' performance is impacted. Consequently, automation of NFT systems leads to remote control and management which, in the end, leads to cost reduction and efficiency increase.

Collaboration between researchers, growers, and industry actors is crucial in fueling innovation and facilitating the widespread adoption of hydroponics NFT. Through the process of information exchange, practice exchange, and technology support, stakeholders will develop the skills needed to deal with the global issues such as food security, resource scarcity, and climate change.

2.2.7 Conclusion

Lastly, NFT hydroponic systems can be regarded as a revolutionary method of modern farming as it offers many advantages in terms of productivity, resource efficiency, and environmental sustainability. With help of hydroponics and by embracing innovative technology, NFT systems have an exciting future to transform agriculture and modern world problems.

Via tactical deployment and ongoing research, NFT hydroponics may provide a more resilient and sustainable food system by allowing access to nutritious and fresh produce for both present and future generations. With the vision set towards the future, collaboration, innovation, and commitment to sustainability will play a vital role in actualizing the full potential of NFT hydroponics and reshaping the future of agriculture.

2.3 Disease detection by camera integration

This technology is a great means of monitoring plant health in real-time and detecting problems before they have even appeared. Such camera systems are installed within hydroponic setups to capture detailed images of plant foliage and root systems. Such systems process images captured with the help of advanced image processing techniques, such as machine learning algorithms, to detect even the slightest changes in plant physiology indicative of nutrient deficiencies, pest infestations, or pathogen infections.

One of the fundamental features of camera integration is its possibility of diagnosing signs of plant diseases or stress way before they become visible. That way, the producer will have time to apply targeted interventions in the form of adjusting nutrient formulations or applying biocontrol agents to prevent the spread of diseases and minimize crop losses. Apart from that, camera systems can provide important information on plant health and growth trends. By constantly monitoring plant development, growers can notice trends and patterns indicating possible underlying problems or environmental stressors. Such a data-based approach allows growers to optimize growing conditions and fine-tune nutrient management strategies for improved overall crop performance. Proactive plant disease detection by cameras not only enhances crop health and productivity but also minimizes the use of chemical inputs and enhances environmentally sustainable farming practices. By cutting down the need for pesticides and fungicides, growers protect the environment from pollution and keep the ecosystem healthy.

In total, camera integration for disease detection is a powerful tool in the modern hydroponic farmer's arsenal. By applying advanced imaging technologies and data analytics, growers can successfully monitor plant health, detect early signs of disease, and adjust growing conditions for maximum crop yield optimization while minimizing environmental impact.

2.3.1 EfficientNetV2

It is the evolution of the EfficientNet architecture, with the aim of increasing the efficiency and performance of deep neural networks. The "B0" and "S" variants describe the different scale or size versions of EfficientNetV2 model where B0 is the base model and S is the small variant developed for edge devices or situations where the computer power is a constraint.

- Compound Scaling: Similar to the original EfficientNet, EfficientNetV2 uses a compound scaling method for balancing network depth, width, and resolution. Consequently, it is capable of better performance with a relatively small increase in the computational requirements. With simultaneous scaling of depth, width, and resolution, EfficientNetV2 becomes effective and accurate, while using fewer parameters and less computational power in comparison to traditional scaling methods.
- Stochastic Depth: EfficientNetV2 implements the stochastic depth which is a regularization method that randomly omits layers in training. This tactic leads to the

prevention of overfitting and yields better generalization performance as a result, especially in deeper networks.

- Efficient Building Blocks: EfficientNetV2 incorporates newly designed building blocks that are more effective and efficient in capturing patterns that are complex. These structural components are meticulously configured to achieve optimal representation while at the same time bear minimal computational expenses.
- Attention Mechanisms: EfficientNetV2 variants with attention employ, for example, SE (Squeeze-and-Excitation) blocks which are adaptive in the feature channels recalibrating. This helps the network to pick out salient features, hence maximizing the network's performance.
- Depthwise Separable Convolutions: Like its predecessors, EfficientNetV2 relies significantly on depthwise separable convolutions. These convolutions thereby bring down the number of parameters and computation costs by factorizing the traditional convolutions into depthwise and pointwise convolutions.
- Smaller Variants (e. g., EfficientNetV2-S): Alongside the base model (B0), EfficientNetV2 also offers smaller variations like EfficientNetV2-S that are tailored for deployment on edge devices or scenarios with limited computational resources. Often, these smaller variations are the result of better accuracy versus trade-offs such as reduced model size and inference latency.

2. 4 Previous Work

Studies of different scholars and scientists using many methods of hydroponic farming have proven to be efficient in terms of quantity and quality of food. In this section of the paper, we touched upon some of the current studies carried out by different researchers.

In [7], the authors invented a system using Arduino Uno, Wifi shield, Relay, Temperature sensor, Electrical conductivity sensor, Ph sensor, Solenoid sensor and Ultrasonic sensor. They created android mobile app to control the system and deal with it. The system notifies via mobile app if any values captured by sensors exceed the threshold value. Through the use of these commands required to actuators can be transmitted.

In [8], authors have built a system with Arduino Uno microcontroller and wifi module ESP-8266 which also uses Raspberry Pi 2 Model B microcomputer as webserver with the idea of internet of things. They utilized solar powered battery for supplying power to the system. The system is automatic where farmers need to select the right settings for different plants.

In [9], authors developed the embedded system to manage nutrients in the hydroponics. They used back chaining method for decision making in the decision-making process. They relied on the potential of hydrogen sensor, electrical conductivity sensor, temperature sensor, cooling fan and water pump.

In [10], the authors implemented a prototype with Arduino Uno R3, GP2Y0A21 proximity sensor as a water level indicator and TDS sensor as a detector of electrical conductivity of nutrient solution. The system can start watering and add nutrition automatically when the nutrition solution concentration drops below 800ppm.

2.4.1 Comparative Studies

In this section of the paper, we analyzed some previous works done by other researchers and showed our results in a comparative study table.

Table 2.1: Comparative Study Table

SR No.	Author's Name	Proposed system	Device/material used/technique	Advantages of the study	Disadvantages
1	Somchoke Ruengittinu n, Sitthidech Phongsams uan, Phasawut Sureeratana korn	Used mobile application to send notification to users and monitor the system	Arduino Uno, Wifi shield, Relay, temperature sensor, Electrical conductivity sensor, Ph sensor, Solenoid sensor and Ultrasonic sensor	Remote monitoring and controlling system.	Controlling system is not automated
2	Padma Nyoman Crisnapati, Nyoman Kusuma Wardana, Komang	They monitor and control the NFT hydroponic system.	Arduino Uno microcontroller, Wifi module ESP-8266 and also used RaspberryPi2 Model B	Automated system with web server	Complex system

	Agus Ady Aryanto, Agus Hermawan				
3	Anurag Shrivastava a , Chinmaya Kumar Nayak b , R. Dilip c , Soumya Ranjan	Automatic robotic system design and development for vertical hydroponic farming using IoT and big data analysis	Vertical Hydroponic farming	Explores hydroponic systems suitable for vertical farming, addressing the space-saving and resource-efficient	The challenges of vertical hydroponic farming include limited varieties of crops, Disease susceptibility, and Water or nutrient management.
4	Lisa M. Garcia	Aeroponics vs. Drip Irrigation: A Comparative Study"	Aeroponics/ Drip Irrigation	Compares two techniques, with an emphasis on water and nutrient efficiency, critical in resource conservation and sustainable hydroponic practices	Aeroponics can be costlier, complex and energy-intensive compared to the drip irrigation. Drip irrigation may have limitations in terms of water usage and nutrient distribution
5	Emily L. Davis	Comparing Hydroponic Techniques for Crop Growth	Compares various hydroponic Techniques.	Offers a comparative analysis of various hydroponic techniques, aiding growers in choosing the most suitable method for their specific crops.	From the comparison, the disadvantage of each is well known.
6	Robert J. Patel	Nutrient Film Technique (NFT) in Hydroponics: Advancements and Challenges	NFT technique	Focuses on the NFT technique, highlighting its advantage of maintaining a thin nutrient film for effective root	It come with challenges related to maintenance, nutrient balance, and limitation in supporting few types of crops.

				oxygenation, growth.	
7	Yakub Eka Nugraha, Budhi Irawan, Randy Erfa Saputra	Automation system with forward chaining method	EC sensor, Ph sensor, temperature sensor	Implementa-tion of forward chaining method	Slower rate of learning, Depends on given condition

Table 2.2

Data of *Internet of Things-bases Hydroponic*

Journal Research Result on the website www.sciencedirect.com

SR No.	Author's Name	Title	Journal	Year
1	Ibtissame Ezzahoui, Rachid Ait Abdelouahidb Khaoula Taji, and Abdelaziz Marzak	Hydroponic and Aquaponic Farming: Comparative Study Based on Internet of things IoT technologies	Procedia Computer Science	2021
2	Jolan Jamal, Sadoon Azizi, Alireza Abdollahpouri, Nasser Ghaderi, Behrooz	Monitoring rocket (Eruca sativa) growth parameters using the Internet of Things under supplemental LEDs lighting	Sensing and Bio-Sensing Research	2021

3	Rui Suo, Wenqi Wang, Yidong Ma, Longsheng Fu, and Yongjie	Effect of different root lengths for retaining freshness of hydroponic lettuce	Journal of Agriculture and Food Research	2021
4	Younes Abbassi And Habib Benlahmer	The Internet of Things at the service of tomorrow's agriculture	Procedia Computer Science	2021
5	Wenqi Wang, Yidong Ma, Longsheng Fu, Yongjie Cui, and Yaqoob Majeed	Physical and mechanical properties of hydroponic lettuce for automatic harvesting	Information Processing in Agriculture	2020
6	Vaibhav Palande, Adam Zaheer, and Kiran George	Fully Automated Hydroponic System for Indoor Plant growth	Procedia Computer Science	2018
7	Taji Khaoula, Rachida Ait Abdelouahid	Architecture design of monitoring and controlling of IoT-based aquaponics system powered by solar energy	Procedia Computer Science	2021
8	Shanhong Zhang, Yu Guo, Shuai Li, Zhixin	Investigation on environment monitoring system for a combination of hydroponics and aquaculture in greenhouse	Information Processing in Agriculture	2020

9	Divas Karimanzira, and Thomas Rauschenbach	Enhancing aquaponics management with IoT-based Predictive Analytics for efficient information utilization	Information Processing in Agriculture	2019
10	Manlio Bacco, Paolo Barsocchi, Erina Ferro, Alberto Gotta, and Massimiliano Ruggeri	The Digitization of Agriculture: A Survey of Research Activities on Smart Farming	Array	2019
11	Ondrej Kainz, František Jakab, Miroslav Michalko, Miroslav Hudák, and Rastislav Petija	Enhanced approaches to automated monitoring environmental quality in non-isolated thermodynamic system	IFAC-PapersOnLine	2019

Chapter 3: Methodology

This chapter introduces the method that was used in the implementation of the "Hydroponic farming NFT for lettuce production" project. In this case, the method involves the hardware setup, sensor calibration, software implementation, dataset preparation, model training, evaluation, deployment, and real-time inference process. preparation, model training, evaluation, deployment, and real-time inference process.

3.1 Hardware Setup

The following hardware components were used:

3.1.1 Block diagram

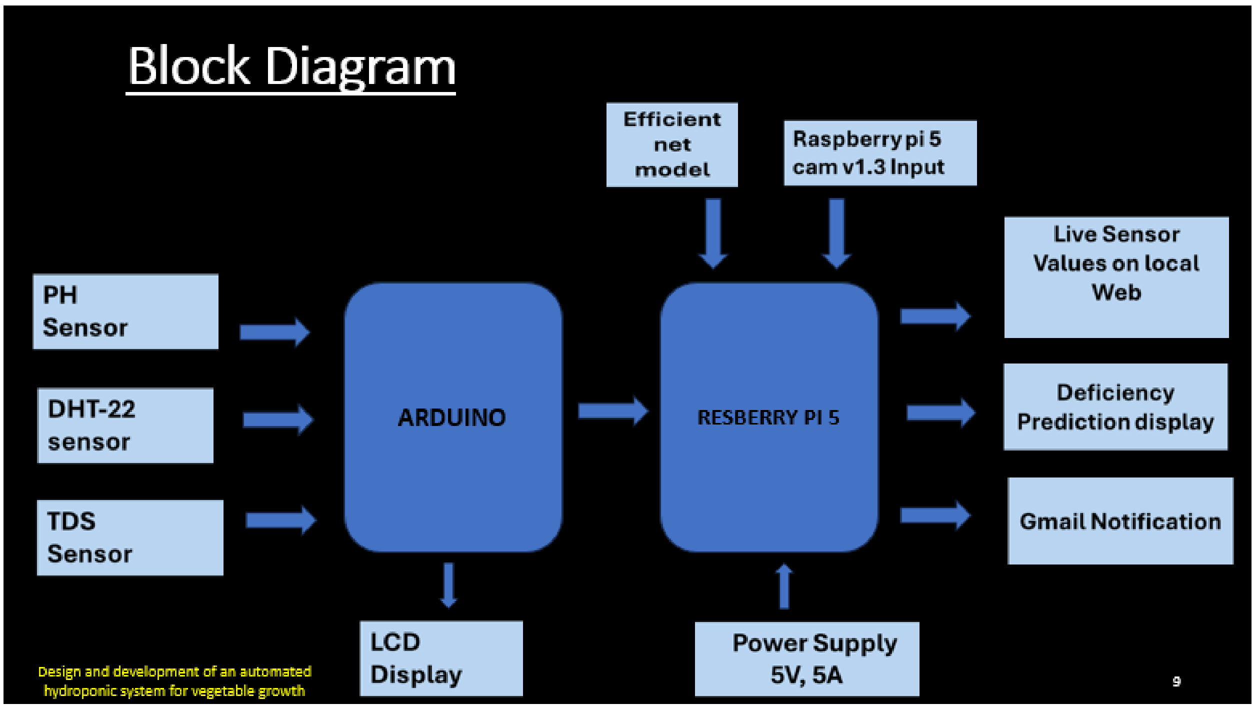

Figure 1 Block Diagram

3.1.2 Raspberry Pi 5:

The Raspberry Pi 5 is the core of the project and serves as the central processing unit that controls the whole system, carries out tasks like data processing, control and interfacing with the hardware components.

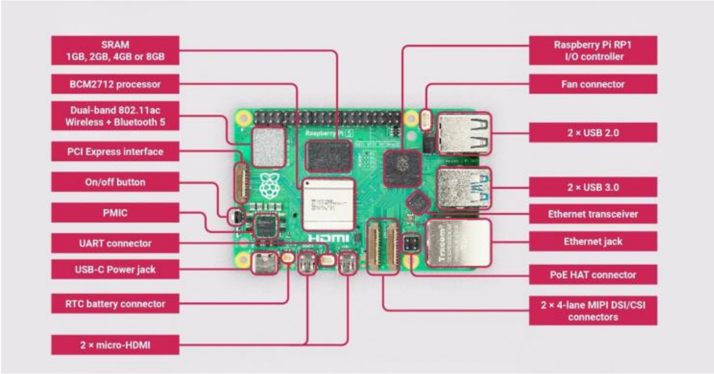

Figure 2 Structure of Raspberry Pi 5

3.1.2.1 Hardware Specifications

The Raspberry Pi 5 – part of the Raspberry Pi family of single-board computers – has powerful hardware features that can be used in a variety of applications, e.g. IoT, robotics, and embedded systems. Some key specifications include:

1- Processor: Having a strong ARM-based processor which is not only capable of processing heavy computations but also of constantly multitasking.

2- Memory: Adequate RAM for processing the multiple processes simultaneously and storing the data temporarily.

3- I/O Ports: Different GPIO (General Purpose Input/Output) pins for connection with the outside world's hardware components and sensors.

4- Connectivity: In-built Wi-Fi and Ethernet communication with other devices and networks.

Storage: The microSD cards provision for onboard storage, facilitating data storage and retrieval.

5- Data Processing: With the aid of sensors such as DHT-22 temperature/humidity sensor, pH sensor, and TDS meter, Raspberry Pi 5 performs data processing. It undertakes this analysis to monitor the environmental conditions within the hydroponic system and to guarantee appropriate growing conditions for lettuce plants.

6- Control: Through GPIO pins, the Raspberry Pi 5 controls various hardware components such as the water pump for nutrient solution circulation, Raspberry Pi Camera for image capture and other actuators or devices in the hydroponic arrangement.

7- Interfacing: It acts as the bridge among hardware components and software modules, where communication and data exchange are accomplished. For instance, it shows sensor readings to the software system for further processing and analysis.

8- Compute Power: The Raspberry Pi 5 is capable of doing machine learning algorithms for tasks like disease detection in lettuce plants which is based on image analysis it definitely increases intelligence and autonomy of the system.

9- Scalability: The modular system can be scaled and expanded through the Raspberry Pi ecosystem. Along with that, new sensors, actuators, or computational units can be added as easily as the system's operations are scaled up to meet changing requirements.

10- Versatility and Flexibility:

The versatility of Raspberry Pi5 allows to adapt it to different hydroponic farming system, meeting different configurations, scales and conditions.

This platform has an advantage of being flexible in terms of hardware interfacing, software development, and customization which make it perfect for exploring and implementing agricultural technologies.

3.1.3 DHT-22 Temp/Humidity Sensor

The DT-22 Temperature/Humidity Sensor forms an important part of the hydroponic farming NFT System that is utilized in monitoring the environment to ascertain optimal growth conditions for the lettuce plants.

Figure 3 DHT-22 Temp/Humidity Sensor

1- Purpose:

Temperature Monitoring: The DHT-22 sensor measures the temperature of the nutrient solution as well as the surrounding temperatures within the hydroponic system. Constant monitoring of the temperature is inevitable as it directly depends on the uptake of the nutrients, metabolism, and overall well-being of the lettuce plants.

Humidity Monitoring: In addition to temperature, the sensor calculates the level of relative humidity within the hydroponic space. Humidity works as a regulator of transpiration rates, water uptake, and diseases susceptibility for plants. The humidity monitoring makes sure the right environment for the growth of lettuce is established.

2- Integration into the System

Live Data Acquisition: The Raspberry Pi 5 intercommunicates with the DHT-22 sensor that provides the real-time measurement of the temperature and humidity all the time. Such live data flows are then sent to the central systems for analysis and interpretation.

Data Analysis and Threshold Monitoring: The temperature and humidity data collected in the current time are analysed in a real-time mode to determine their conformance to a predefined level. These standards, set based on acceptable growing conditions for lettuce, are used for evaluating the health condition of the hydroponic environment.

3- Notification System

Threshold Notification: This is done by sending notifications to operators when the temperature or humidity measurements cross the predetermined thresholds. Therefore, these notifications act as early warnings, calling for immediate response to any unexpected change in the environment conditions.

4- Live Value Monitoring

Operators obtain the live temperature and humidity readings from the DHT-22 sensor via online streaming. This real-time tracking of environmental conditions enables them to make decisions on the nutrient solution.

3.1.4 pH Sensor

Sensor pH is an essential component in real time monitoring of pH level of the nutrient solution within the hydroponic system. Getting the pH into a balanced level is crucial for nutrient absorption and overall lettuce health. This sensor enables continuous monitoring of pH level to keep it within the desirable range for lettuce cultivation.

Figure 4 pH Sensor

1- Integration into the System

Live pH Monitoring: The pH sensor is connected to the Raspberry Pi 5 system to monitor continuously the pH value of the nutrient solution. The sensor provides real time pH readings which can help monitor and react to undesirable changes on a timely manner.

2- Data Transmission: The pH sensor sends the live pH figures to the central system, where they are worked out and analysed in an on-the-spot manner. These readings are used as crucial feed for decision-making algorithms and setting thresholds.

3- Optimal pH Range: The system is designed to keep the pH of the nutrient solution in the range which is optimal for growing lettuce, usually pH range of 5. 5 and pH 6. 0. The thresholds here are dependent on the optimal nutrient availability and uptake levels of the lettuce plants.

4- Threshold Logic: If the pH measurements are outside of the specified range, the system then notifies operators or stakeholders. Little deviations from the optimal range can be interpreted as either an acidic or alkaline imbalance in the nutrient solution, which can undermine plant health and development.

5- Live Notifications: Operators get live alerts specifying the status of pH levels in the nutrient liquid. Such alerts act as measures, triggering immediate steps for the adjustments of pH levels to ensure the most suitable environment for the growth of lettuce plants.

3.1.5 TDS Meter

The TDS meter determines the total amount of dissolved substances present in the nutrient solution, which directly leads to the growth and health of the lettuce.

Figure 5 TDS Meter

1- Sensor Specifications

This experiment uses a TDS meter that measures the electrical conductivity (EC) of the nutrient solution, which is then converted to TDS values in parts per million (ppm).

For lettuce, the optimal TDS range is 700 to 900 ppm, or a EC range of 1. 4 to 1. 8 mS/cm.

2- Hardware Connection

The TDS meter is connected to Arduino microcontroller through analog input pins.
The Arduino reads the analog signal from the TDS meter which is equivalent to the conductivity of the solution.

3- Data Processing

The Arduino converts the raw data from the TDS meter, which is an analog signal, to digital values representing the TDS in ppm. The data that has been processed is then sent to the Raspberry Pi 5 through a serial connection.

4- Data Transmission and Monitoring:

The Raspberry Pi 5, working with Node-RED, obtains the TDS data from the Arduino.
This data is processed by Node-RED which displays live values on the web interface, providing real-time monitoring of the nutrient concentration.

5- Threshold Monitoring and Notifications:

The TDS value is continuously monitored by Node-RED and is kept within the optimal range for lettuce (1. 4 to 1. 8 mS/cm). TDS (Total Dissolved Solids) values when lower than this range Node-RED instigates an alert system.
An email notification is sent to the addresses specified using the email node of Node-RED which informs the user of the need to adjust the nutrient solution.

3.1.6 Raspberry Pi Camera v1. 3

The Raspberry Pi Camera v1. 3 integrated in the hydroponic farming NFT system to create live images from the lettuce plants. Such images are then processed using an EfficientNet predictive model to discern whether any diseases affect the lettuce. This integration offers a solution for the real-time monitoring and early warning of plant diseases. Therefore, it is very essential for a good crop growth, which informs the user of the need to make adjustments to the nutrient solution.

Figure 6 Raspberry Pi Camera v1. 3

1- Specifications

The Raspberry Pi Camera v1. 3 its 5-megapixel sensor helps in capturing high-quality photos at 2592x1944 pixels. It captures videos at 1080p30, 720p60 and 640x480p 60/90 resolutions, therefore ideal for high resolution imaging required for disease diagnosis.

2- Hardware Connection

The camera module is wired to the CSI connector on the Raspberry Pi 5. The connection is built by securely plugging the camera's ribbon cable into the CSI port and making sure it is properly aligned and connected.

3.1.7 Water Pump

The water pump is a fundamental element of the nutrient solution circulation in the hydroponic system.

Figure 7 Water pump

1- Circulation of Nutrient Solution

The water pump continually pumps and circulates the nutrient-rich solution from the reservoir through the PVC pipes and back to the reservoir. This way, lettuce plants are assured of the constant flow of nutrients and oxygen which is highly required for their healthy growth.

2- Maintaining Flow Rate

The pump is calibrated in such a way that it ensures a desired flow rate without causing any stagnation or allowing uneven distribution of nutrients. A constant flow rate is very important to avoid the root rot and to grant each plant an identical number of vitamins.

3- Integration with Control System

The pump is connected to the control system being controlled by Arduino and Raspberry Pi. The flow rate can be adjusted and the operation times can be adjusted based on the real-time data of sensors (such as pH and TDS meters) to optimize the nutrient delivery based on plants' needs.

3.1.8 PVC Pipe Structure

The PVC pipe structure will be the foundation of the hydroponic NFT system. It maintains the whole system and ensures the constant feed of the nutrient solution. Key aspects include:

Figure 8 PVC Pipes

1- Framework Design

The construction is arranged to ensure the stability of the plant holding cups or to serve as a channel for the nutrient solution. PVC pipes are arranged slightly sloping for the solution to flow by gravity, from inlet to the outlet.

2- Customization and Scalability

The modular structure of PVC pipes makes it easy to modify and expand. New pipes can be installed to increase the capacity or the existing ones can be amended to fit in confined spaces. This flexibility helps to tailor the system to fit various growing environments.

3- Ease of Maintenance

PVC one of the durable and easy to clean material, this makes the maintenance process a simple process. Periodic cleaning avoids clogging and the overgrowth of alga or other contaminants, which makes nutrient solution flows freely without diseases.

3.1.9 Plant Holding Cups

The plant holding cups are integral parts of the hydroponic system that protect and sustain the lettuce plants. The condition of plants depends on the right design and utilization of containers. Details include:

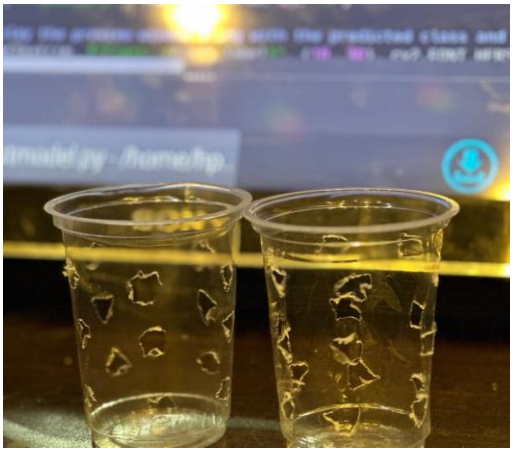

Figure 9 Holding Cups

1- Support and Stability

Each cup provides strong support to the lettuce plant thus allowing its roots to curve into the solution in which the plant is planted. The cups will be cut to the same diameter as the drilled holes on the PVC pipe in order to prevent the plants from falling.

2- Root Exposure and Aeration

The cup design has exposed roots immersed in nutrient solutions and well aerated at the same time. This equilibrium is essential for the intake of elements and oxygen flow resulting in the healthy development of root system and overall growth of the plant.

3- Material and Durability

The cups are made from food-grade plastic so that the acid does not get in contact with any toxic materials. Furthermore, they are strong and reusable and hence they are the low cost option in hydroponic system for long term use.

3.1. 10 Nutrients

Figure 10 Nutrients

To achieve optimum lettuce growth in our hydroponic NFT system, we are taking advantage of the MasterBlend Lettuce Formula NPK 8-15-36, which we use. MasterBlend fertilizers are usually used in two environments: hydroponics and soil gardening, mainly by the commercial growers. This custom formula is intended to cater for the nutritional requirements of hydroponic lettuce crops and is used in tandem with Epsom Salt and Calcium Nitrate to make a balanced, water-soluble nutrient solution.

3.1.10.1 MasterBlend Lettuce Formula NPK 8-15-36

The MasterBlend Lettuce Formula is a nutrient-rich formula designed specifically for lettuce plants growth and well-being. The formulation is highly concentrated and completely water-soluble, allowing nutrients to be easily absorbed by plants.

Total Nitrogen (N): 8%

Nitrate Nitrogen: 7. 5%

Ammoniacal Nitrogen: 0. 5%

Available Phosphate (P2O5): 15%

Soluble Potash (K2O): 36%

Magnesium (Mg) (Total): 0. 49%

Water Soluble Magnesium: 0. 49%

Boron (B): 0. 20%

Copper (Cu): 0. 02%

Chelated Copper: 0. 02%

Iron (Fe): 0. 40%

Chelated Iron: 0. 40%

Manganese (Mn): 0. 20%

Soluble Manganese: 0. 20%

Molybdenum (Mo): 0. 01%

Zinc (Zn): 0. 05%

Chelated Zinc: 0. 05%

1- Preparation of Nutrient Solution
In order to avoid nutrient lockout and to make sure that all nutrients are accessible for the plants, the right order and procedure for the nutrient solution mixing should be followed. The incorrect mixing of the elements causes precipitation, which makes these nutrients unavailable for plants.

The order of mixing and the exact procedures applied while preparing the nutrient solution play a big role in preventing nutrient lockout and ensuring the availability of all nutrients to the plants. Improper blending of the components may result in flocculation and the prevention of nutrient absorption by plants. Do not shade the three substances directly. Each reagent should be dissolved separately in water and them combined.

2- Directions for seedlings & young plants

Dissolve 11 grams MasterBlend:

6. 5 grams Epsom Salts - Dissolve after the master blend.

8. 5 g Calcium Nitrate - Sprinkle after the Epsom salt.

3- Directions for Mature Plants

12 grams MasterBlend - Stir and dissolve.

7 grams Epsom Salt - Sprinkling thoroughly after the MasterBlend.

12 grams Calcium Nitrate - Dissolve after Epsom Salt has completely dissolved.

3- Mixing Procedure

Weighing Components:

Measure out the needed amounts of MasterBlend, Epsom Salt, and Calcium Nitrate with a reliable and precise scale accurate to grams.

Dissolution Process:

Take MasterBlend and dissolve it in the full amount of water (5 gallons). Shake the solution until the fertilizer is dissolved completely. Epsom Salt to the solution, and keep stirring until the Epsom Salt is completely dissolved. Lastly, add Calcium Nitrate and stir until the solution is clear and all the components are completely dissolved.

4- Maintaining Solution

Keep a close check on the pH levels and total dissolved solids in the nutrient solution by maintaining them within the ideal range for lettuce development. Adjustments might be required following the results from the pH and TDS sensors informational system.

3.1.11 Water Container

Holding reservoir for the nutrient solution.

Figure 10 Water container

3. 2 Sensor Calibration

Calibration of sensors is very important to the system of hydroponics to decrease the measurement error. It is necessary to perform a calibration process for the sensors to give accurate readings that are needed in order to maintain the required climate for the lettuce plants.

3.2.1 pH Sensor Calibration

1- Preparation of Calibration Solutions

The standard solutions preparation was the starting point of the calibration process. Typically, pH 4. 0, pH 7. 0, and pH 10. There are 0 buffer solutions in the process. On the other hand, the deionized is neutral with a pH of near about 7 as the baseline. 0.

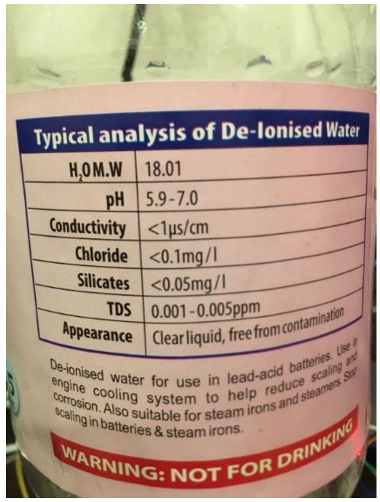

Figure 11 De-Ionised Water

2- Initial Calibration

The sensor was immersed in deionized water; then the reading was taken. The output of the sensor had to match exactly the pH value of deionized water, which is generally at pH 7. 0. This step serves to fix the sensor reading at the baseline level.

3- Verification

To determine the satisfactory of the calibration, the sensor was tried in a pH 7. 0 buffer solution. The readings were rechecked to be certain that the sensing devices provided the correct pH value for the buffer solution. If need be, more refinements were done.

3.2.2 TDS Sensor Calibration

1- Preparation of Calibration Solution

Tap water and Deionized water has been used for the calibration in the beginning. The TDS (total dissolved solids) level was assessed, using a reference meter as a starting point and having a TDS of 0 ppm, was used for chiral calibration to obtain a reference point of Tap water and Deionized water respectively.

	TDS (ppm)
Tap Water	130 - 400
Reverse Osmosis	5 - 6
Deionized Water	1
Bracton Distilled Water	1.3

Figure 12 Tap water and De-Ionised Water measurements

2- First Calibration with tap water

The sensor was submerged in the water sample and the measured value was calibrated to agree with the TDS value obtained by reference electrode. This step neutralizes the usual tap water impurities.

3- Second Calibration with Deionized water

The sensor had been put in deionized water. Any value above 0 ppm is adjusted to 0 ppm so that the sensor correctly detects lack of dissolved solids in pure samples of water.

Overall Calibration Process:
The calibrated sensors were interfaced into the hydroponic system, and using the Arduino and Raspberry Pi, they were able to monitor and control data in real time. The calibration of the pH and TDS sensors ensured that the correct readings were provided. Therefore, the nutrient solution could be maintained in the optimal ranges required for lettuce growing. Building in a long-term maintenance plan that included regular calibration checks helped to make the system more precise, dependable, and efficient in the long run.

With carrying out these strict calibration measures we made sure that our sensors were accurate and therefore provided a trustworthy data that helped us to manage growing conditions for the lettuce plants in the hydroponic NFT system appropriately.

3. 3 Software Implementation

We utilized the Node-RED software in order to form the software elements of the project. This graphical programming helped to integrate the hardware components, data processing, and communications among the different modules. Node-RED implementation gave rise to a user-friendly and flexible system for the hydroponic NFT setup control. The next part gives instructions on implementing Node-RED software in the project.

3.3.1 Integration and Data Processing

Node-RED was used as a core system to interface various software constituents such as sensors and controllers and to process the data they generate.

1- Sensor Data Input

The Arduino was connected to the sensors which would read pH, TDS, temperature and humidity values and send data to the Raspberry Pi. Node-RED ran on Raspberry Pi serving as the server and receiving and processing the sensor data.

2- Actuator Control

The Node-RED program was configured to turn the actuators on and off in accordance with the readings from the sensors, with the goal of delivering the right conditions to the plants.

3.3.2 Flow Chart Design

For the development of the flow charts, the visual programming interface of Node-RED was utilized to define the data processing and control logic. Every flow chart operated in a hierarchical way to handle various sectors.

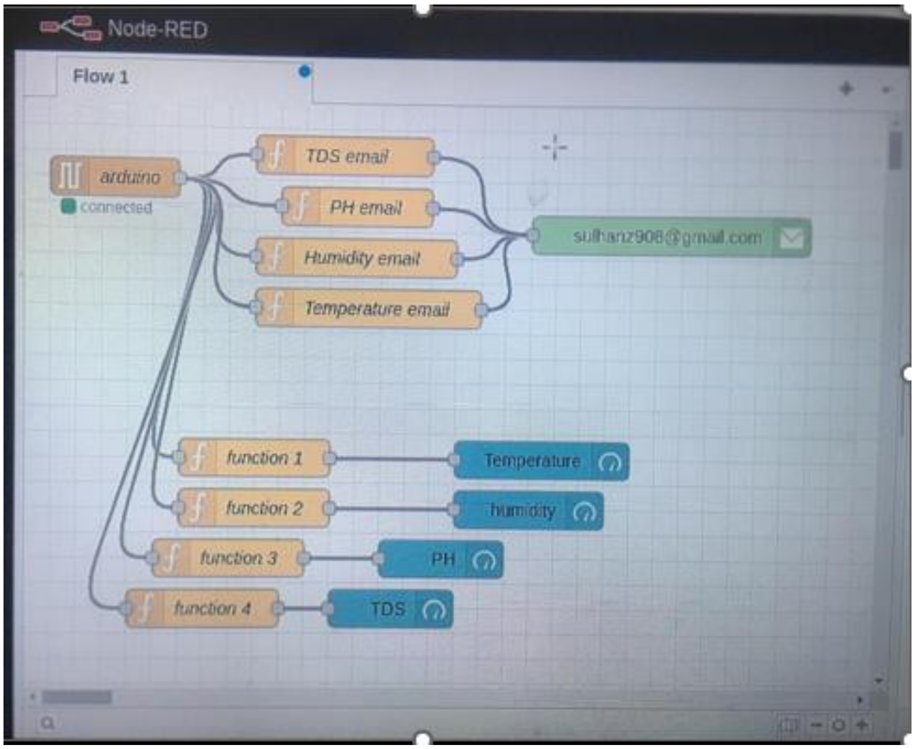

Figure 13 flow Chart of Node-RED

3.3.3 Threshold Monitoring and Notifications

1- TDS Monitoring

The flow chart was designed to constantly monitor the (Total Dissolved Solids) TDS values. If the TDS exceeded or fell below the optimum scale of 1. 4 to 1. The measured value was 8mS/cm and the system triggered an email notification to alert the operator.

2- pH Monitoring

It also had a flow chart for (pH). When the pH value deviated from the optimal range for lettuce development an email was sent as a notification.

3- Humidity and Temperature Monitoring

We designed individual flow charts for humidity and temperature for the monitoring purpose. If these environmental parameters went over the thresholds, Node-RED provided notifications so quick reaction.

4- Email Notification System

Node-RED's native nodes were configured to deliver email notifications via Gmail. Each sensor was associated with the data flow that used conditional logic to check if the readings fall inside the accepted limits. If any of the reading failed to stay within the defined range, the system used to compose and send an email notification automatically.

As an example, the TDS chart flow included a node in which the current TDS value was compared to the threshold value (1. 4 to 1. 8 mS/cm). Of the value was outside this range, the flow chart made the email node operational which sent the alert to the designated email address.

Example Flow Chart Descriptions:

TDS Flow Chart:

Input Node: Receives TDS information from the sensor.

Threshold Check Node: Compares the TDS value to the established parameters.

Notification Node: If TDS value is more than or less than the threshold limit, this node sends an email.

3.3.4 Real-Time Dashboard

1- Live Data Display: Charts and numbers in real-time for pH, TDS, temperature, and humidity, respectively.

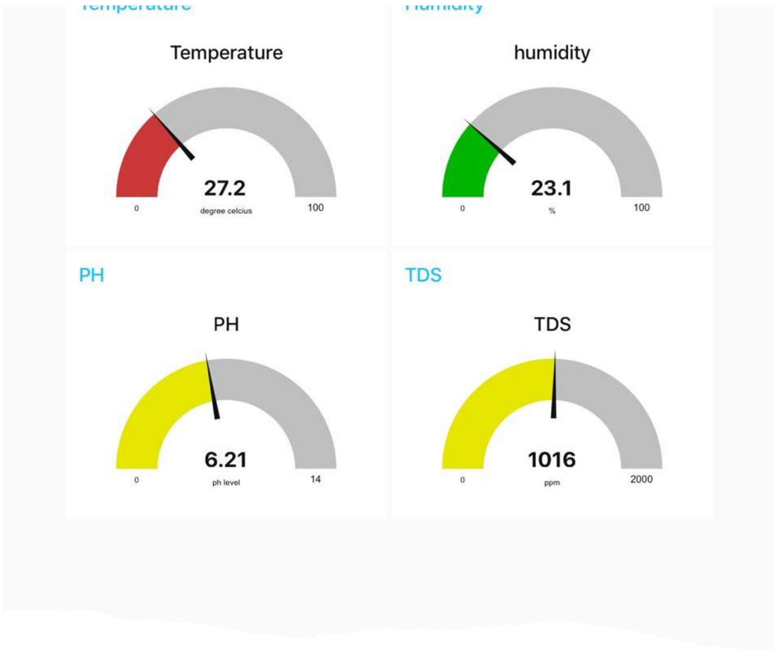

Figure 14 Live values on Web

2- Alerts Section: A section that will display alerts/notifications that have been sent out when the values exceed the threshold.

Figure 15 Notification Alert

3. 4 Disease Detection System

The disease detection system for our hydroponic farming project was developed to identify nutrient deficiencies in lettuce plants based on images captured by a digital camera and processed through image processing and machine learning algorithms. The following sections describe the process for creating the dataset, data augmentation, training models, evaluating models, and deploying models.

3.4.1 Dataset Preparation

The dataset for the detection of diseases was carefully selected for the model to accurately classify different nutrient deficiency in the lettuce plant.

1- Data Collection

Images of lettuce plants were collected and categorized into four classes: FN lettuce, P deficient lettuce, N deficient lettuce and k deficient lettuce.

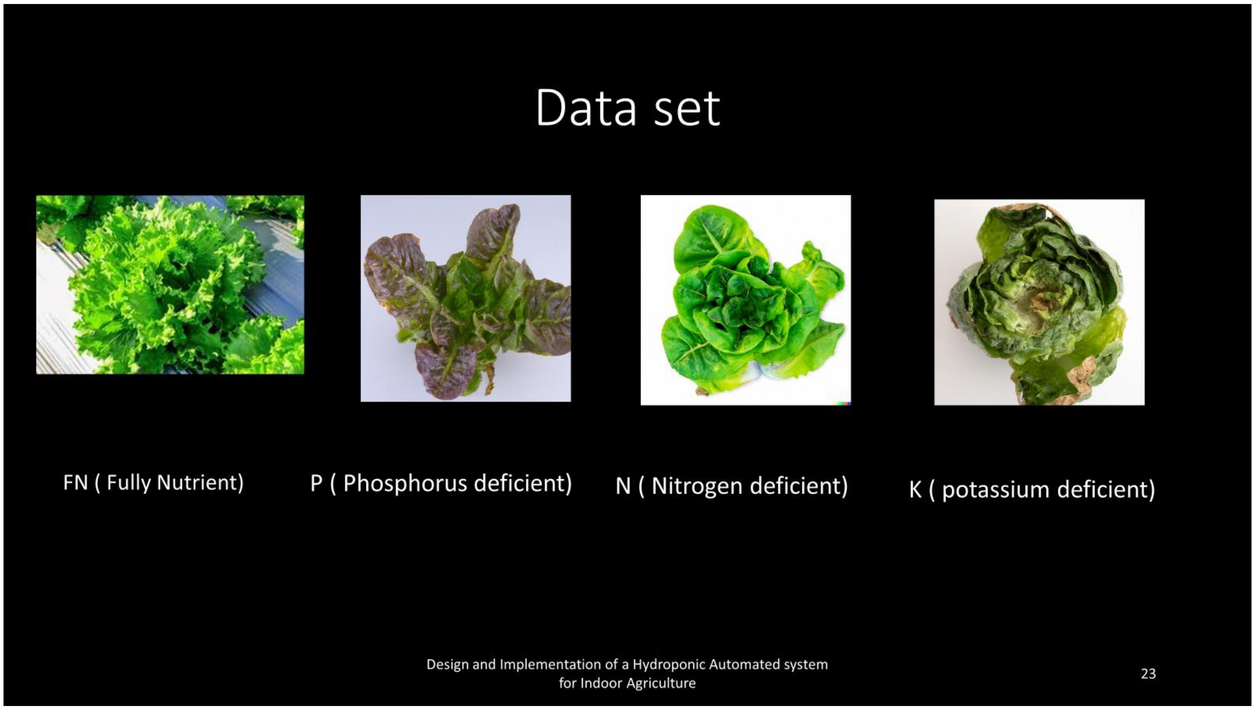

Figure 16 Classes of Images

2- Data Split

The collected images were split into training and validation sets.

Training Set: 90% of the images were employed in training the model.

Validation Set: Another 10% of the images were kept aside for testing the performance of the model.

3- Organization

Images were then placed in respective directories based on their classes. This organization made the training process less time-consuming and chaotic.

3.4.2 Data Augmentation

Data augmentation methods were used to improve the model's generalizability and avoid overfitting. These techniques brought in variability and contributed to better generalization of the model to unseen data.

Augmentation Techniques:

1- Rescaling: Normalizing the pixel values to the range of 0 and 1.

2- Rotation: Images that have been randomly rotated to different angles.

3- Shifting: Horizontal and vertical translation of images.

4- Zooming: Picking images and randomly zooming in on them.

3.4.3 Model Training and Configuration

EfficientNetV2 B0 and S architectures were used for training the image classification model.

1- Optimization

All the models were trained with the Adam optimizer that is considered efficient and has an adaptive learning rate.

2- Loss Function

The loss function Sparse Categorical Cross entropy was employed to manage the multi-class classification scenario.

3- Training Process

Epochs: The models were trained for 100 epochs to achieve convergence and optimal performance.

Batch Size: An appropriate batch size was selected considering the computational capacity to train quickly and effectively.

3.4.4 Model Evaluation

The models were tested extensively after training to test their effectiveness and accuracy.

1- Accuracy and Loss Curves: Plotted over the training epochs to represent the learning curve and performance of the model.

2- Confusion Matrices: Obtained to assess the classification accuracy for each class by demonstrating the true positives, false positives, false negatives, and true negatives.

3.4.5 Model Deployment

The Raspberry Pi 5 was used for real-world inference with the trained models to generate live input images using the Raspberry Pi Camera v1. 3.

1- Model Conversion

The trained models were saved in. h5 format and then converted into TensorFlow Lite format. This conversion was necessary to prepare the models for deployment using the Raspberry Pi device that has limited resources.

2- Inference

Raspberry Pi 5: Raspberry Pi Camera v1. 3, acquired real time images of the lettuce plants.

The images were passed through the deployed EfficientNetV2 models to predict the nutrient status of the plants. The system also returned the class prediction (FN, P, N, or Ph) along with the probability of classifying the correct class to prevent delays in addressing Nutrient deficiencies.

3. 5 Real-time Inference

Inference plays a vital role in our hydroponic farming NFT platform as it helps in monitoring and responding to the nutrient deficiency in lettuce plants in real-time. This section describes the configuration of Thonny IDE for loading models and running inference, PiCamera2 initialization and real-time image capturing, preprocessing of captured frames, inference process, and handling predictions.

3.5.1 Thonny Integration

For model loading and inference, Thonny IDE was employed as it allows executing TensorFlow lite models.

1- Model Loading

TensorFlow lite models pre-trained for deployment on resource-constrained devices were loaded into Thonny environment.

2- Tensor Allocation

Tensors for the model were pinned in memory for faster inference. These tensors acted as the input and output placeholders for feeding data to and from the model.

3- Camera Initialization

The piCamera2 Python library to access the Raspberry Pi camera module was instantiated for real-time image acquisition.

3.5.2 Configuration

PiCamera2 was set to capture images at the required resolution and framerate that is compatible with real-time processing. Resolutions frames per second and exposure controls were tweaked to maintain image quality and efficiency.

1- Initialization

The camera was set to begin recording live images from the Raspberry Pi Camera v1. 3. This initialization process guaranteed that the camera was always available to take images whenever necessary in the inference process.

2- Preprocessing

Each frame captured from the camera feed was subjected to preprocessing before being passed into the machine learning pipeline.

3- Resizing

Images from the camera were resized and pre-processed to meet the input size required by the TensorFlow Lite model. This helped to resize the input images so that the dimensions of the images were compatible with the requirements of the model to achieve accurate inference.

3.5.3 Inference

The pre-processed images were then sent for inference using the TensorFlow Lite model which facilitated real-time nutrient deficiency detection.

1-Prediction

An application of the TensorFlow Lite model was used to generate predictions from images presented as input. The inference itself was performed by running image data that had been pre-processed through a graph of computations in the model, resulting in probabilities being produced based on different classes.

The visual output of predictions was displayed as soon as they were generated — allowing real-time decisions to be made regarding plant health management.

2- Recognition

From all predicted classes, the class with the highest probability was taken as an indication from the model about what it thought regarding the nutrient status of lettuce plants seen in real time via camera feed. This helped determine actual decisions related to plant health management.

3.5.4 Display

The live camera view displayed images captured in real-time. The overlay text, shown along with the frames, included two elements: the predicted class and likelihood percentage. This innovative visual display immediately communicated vital information regarding the condition of lettuce plants. It allowed easy determination of what action needed to be taken upon identification of nutrient deficiencies during that early intervention stage.

Figure 17 FN lettuce

Chapter 4: Results

The hydroponic system will have the levels of the multiple parameters such as pH, Total Dissolved Solids (TDS), temperature and humidity systematically monitored and presented through the different interfaces for the appropriate interpretation. On the LCD display, the values of these essential parameters can be directly monitored with distinct indications, thus providing instant feedback on the developing conditions. The web interface which allows the users to monitor the hydroponic setup from anywhere as playing a key role remote access to the data.

4.1 Sensors display on LCD

1- Temperature and humidity display on LCD

Figure 18 Temperature and Humidity values

2- pH and TDS values display on LCD

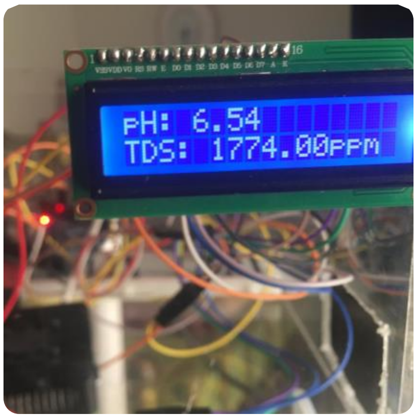

Figure 19 pH and TDS values

4.2 Live values on web

It is possible to combine a camera system into the identification of a lack in the necessary nutrients by providing graphic capabilities reflecting what the condition of the plant is. This feature selects deficiencies for those nutrients are crucial, such as potassium and nitrogen, phosphorus, and as a result, growers can react immediately to issues and change the plan in a timely manner. The captured detail makes it apparent that there are shortcomings which then helps in directing nutrient supplementation for a full row plant development.

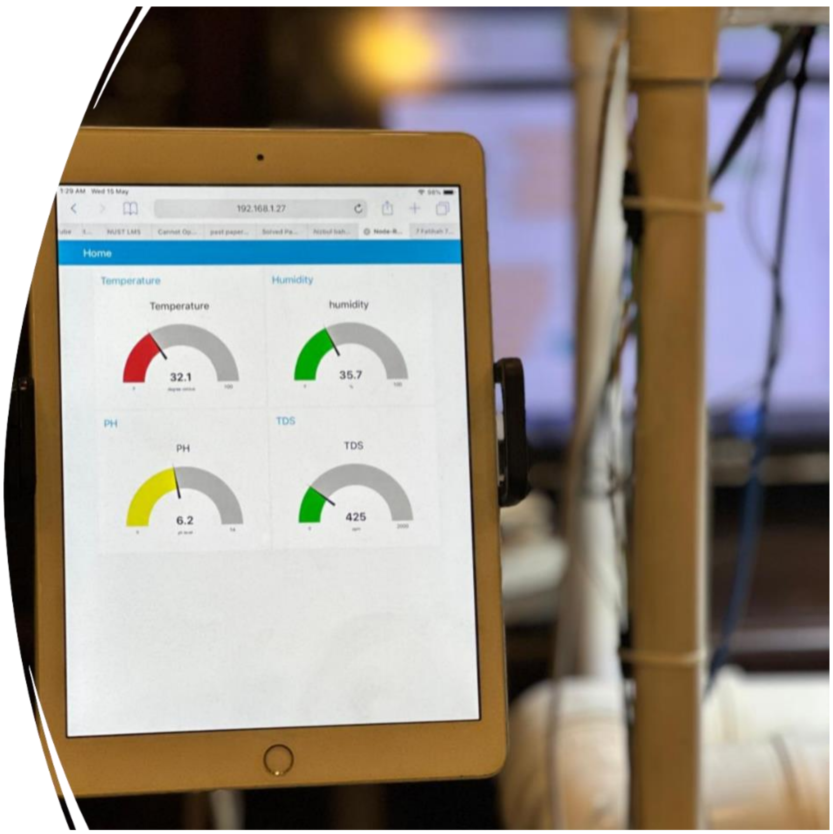

Figure 20 all sensors value on Web

4.2.1 Testing of model with soil grown plants

Case 1- Testing of Fully nutrient lettuce:

Figure 21 FN lettuce

Case 2- Testing of Dried Plant:
We have given no water and no sunlight to this plant for 4 days, so it shows nitrogen deficiency.

Figure 22 N deficient lettuce

Case 3- Testing of Dried Plant 2:

We have also given no water and no sunlight to another plant for 4 days; in the result it shows nitrogen and phosphorus deficient.

Figure 23 P and N deficient lettuce

4.3 Stages of Lettuce Growth

1- 1st Day of Seeding:

Figure 24 1st Day of Seeding

2- After 25 Days of Seeding:

Figure 25 25 Day of Seeding

3-1st day on hydroponic system

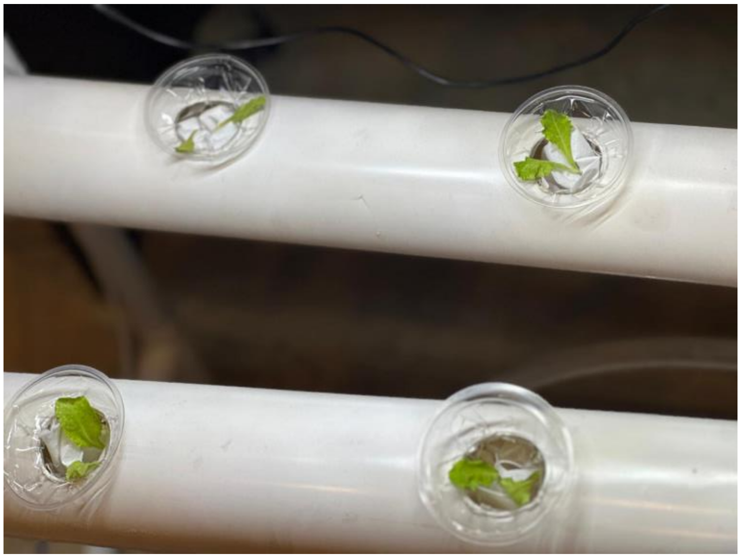

Figure 26 1st Day on Hydroponic System

4-5th day on hydroponic system

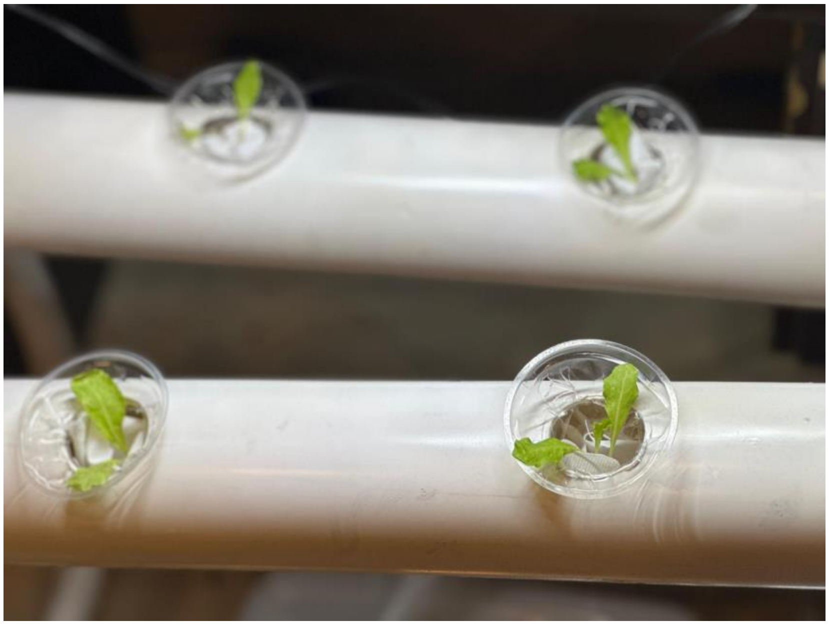

Figure 27 5th Day on Hydroponic System

5- 9th day on hydroponic system:

Figure 28 9th Day on Hydroponic System

6- 12th day on hydroponic system:

Figure 29 12th Day on Hydroponic System

Chapter 5: CONCLUSIONS AND FUTURE WORK

5.1 Conclusion

The hydroponic system created for indoor agriculture is a major step towards precision farming, which combines sensors, data processing and machine learning. The objective was to develop an efficient and dependable mechanism to monitor plant health levels at optimum rates and the results obtained prove its achievement.

5.1.1 Accurate and Real-Time Monitoring

To maintain nutrient concentration, pH levels, temperature, and humidity accurately and continuously, the use of TDS, pH and DHT-22 sensors were perfect. Nutrient deficiencies and environmental stress risks have been reduced by consistently maintaining the plants under optimal growth conditions.

5.1.2 Effective Data Integration and Display

The data transmission and processing were seamless due to the integration of Arduino and Raspberry Pi. Node-RED has also proven to be an intuitive web-based interface for real-time data visualization that is accessible to everybody. It is possible to remotely monitor the hydroponic system using this setup thus interim decision making can happen over a phone call.

5.1.3 Automated Alert System

Automated alerts could notably be realized through Gmail notification feature of Node-RED. Users received prompt notifications whenever readings from the sensors went beyond certain pre-determined thresholds hence enabling them take immediate corrective measures where necessary. This was a big improvement in terms of dependability as well as user’s reactions.

5.1.4 Advanced Deficiency Detection

An important breakthrough was made when we applied EfficientNet V2 B0 model in detecting nutrient deficiency through image processing. The model displayed high rates of accuracy in detecting nitrogen, phosphorus and potassium deficiencies. As such, this allowed for proactive management of nutrients such that plant healthiness is enhanced alongside increased productivity of crops.

5.1.5 Enhanced Productivity

The system can help enhance plant growth and yields to a great extent through the precise monitoring and timely intervention. Recognizing them on time and rectifying them, helps in mitigating losses related to crop production and boosting overall productivity as well.

5.1.6 Resource Efficiency

By accurately measuring nutrient levels and environmental conditions; it ensures that resources such as water and fertilizers are used effectively. This not only reduces waste but also minimizes the environmental impact of indoor farming.

5.1.7 Scalability and Adaptability

It is easily scalable across different types of indoor farming setups since the module design combines readily available components with open-source software. Several plants' species can be accommodated with varying degrees of growth condition customization.

5.1.8 Economic Viability

Automation and precision offered by this system will reduce labor costs while improving crop quality making indoor farming more economically viable. This is particularly beneficial in areas with limited space and resource constraints.

5.2 Future Work

While the system has demonstrated substantial success, there are areas for further improvement and exploration:

5.2.1 Advanced Environmental Monitoring

1- Integration of Light intensity Sensor:

Add light intensity sensors to measure the amount and duration of light exposure to the lettuce plants. The light intensity is very important in photosynthesis and growth of plants and conditions can be monitored in real time to have optimal light conditions for best plant production.

2- Integration of CO_2 Sensor:

Implement CO_2 Sensor to detect the carbon dioxide levels in the hydroponic system. CO_2 is important in the photosynthesis process, and regulating the gas levels can promote plant growth and yield. Continuous analysis of the CO_2 present in the cultivation room makes it possible to regulate the environmental conditions in a timely manner for the healthy growth of plants.

5.2.2 Dynamic Threshold Adjustment

Develop algorithms to optimize the thresholds of various nutrients and environment factors based on the developmental stage of lettuce crops. Adaptive thresholding can be useful for meeting changing nutrient needs of plants or for different stages of plant development or for differing growth conditions.

5.2.3 Automated Nutrient Management

Design outlines for using algorithms for automated nutrient management and dosing using real-time sensor data and machine learning. There are smart systems that can monitor nutrient levels in the hydroponic solution on a regular basis and regulate the addition of nutrients in order to ensure the nutrient solution is always at the optimal levels for plant growth.

5.2.4 Remote Monitoring and Control

Add remote access features to the system so that users can interact with the hydroponic setup over the Internet using a browser or a mobile application. Remote monitoring supports the continuous measurement of plant health indicators and environmental factors and the possibility of controlling and altering processes from a distance with the help of an internet connection.

5.2.5 Multi-Crop Support

Improve the system to enable the growth of other varieties of crops in addition to lettuce. Pilot scale modelling and nutrient management of diversified hydroponic systems with different crop species.

5.2.6 Research on Nutrient Formulations

Research on new compound feeds and supplements with specific nutrient composition for various crops and development stages. Study the application of organic and sustainable nutrient to prevent environmental pollution and improve quality and nutritional value of crops.

REFERENCES

[1] “Early Detection of Casava Plant Leaf Diseases using EfficientNet-B0,” *IEEE Conference Publication | IEEE Xplore*, Feb. 11, 2022.

[2] V. Lakshmi, V. Sai K, J. Sravanthi, K. V. S. S. Vijay, A. Prof, and Students, “Leaf Fungicide Recommendation using EfficientNetV2B0 1,” *JETIR2211370 Journal of Emerging Technologies and Innovative Research*, vol. 9, 2022

[3] Fahad, E. (2024) *Ph meter arduino, ph meter calibration, DIYMORE ph sensor Arduino Code*, *Electronic Clinic*.

[4] “Automated Hydroponic System Build – Projects | Kyle Gabriel.” https://kylegabriel.com/projects/2020/06/automated-hydroponic-system-build.html

[5]“MasterBlend Lettuce Formula 8-15-36 Fertilizer - BULK,” *PowerGrow Systems & Utah Hydroponics*.

[6]Wubetu Barud Demilie, “Plant disease detection and classification techniques: a comparative study of the performances,” *Journal of Big Data*, vol. 11, no. 1, Jan. 2024, doi: https://doi.org/10.1186/s40537-023-00863-9.

[7] M. Hassan, M. Islam, and F. Noor, “Smart Hydroponic System Based On Nutrient Film Technique,” 2018.