VISVESVARAYA TECHNOLOGICAL UNIVERSITY
"JNANA SANGAMA", BELAGAVI -590 018.

2022 – 2023

A Project Report (Phase - I)
on

"An Approach towards Development and Analysis of a Smart Aeroponic System"

Submitted in partial fulfillment for the award of the degree of
BACHELOR OF ENGINEERING
in
ELECTRONICS & COMMUNICATION ENGINEERING

Submitted By

CHETHAN S	[1JB19EC022]
INDUPRIYA B	[1JB19EC029]
KRUTHI N	[1JB19EC041]
MANJUKISHORE P	[1JB19EC050]

Under the guidance of
Dr. Chandrappa D N
Professor and Head, Dept. of ECE

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

SJB INSTITUTE OF TECHNOLOGY
#67, B G S HEALTH AND EDUCATION CITY
Kengeri, Bengaluru-560 060.

||Jai Sri Gurudev||

Sri Adichunchanagiri Shikshana Trust ®

SJB INSTITUTE OF TECHNOLOGY

BGS Health & Education City, Kengeri, Bengaluru-560 060.

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

CERTIFICATE

Certified that the project work phase – I entitled ***"AN APPROACH TOWARDS DEVELOPMENT AND ANALYSIS OF A SMART AEROPONIC SYSTEM"*** carried out by CHETHAN S **[1JB19EC022],** INDUPRIYA B **[1JB19EC029],** KRUTHI N **[1JB19EC041],** MANJUKISHORE P **[1JB19EC050]** are bonafide students of **SJB Institute of Technology** in partial fulfilment for the award of **"BACHELOR OF ENGINEERING"** in **ELECTRONICS AND COMMUNICATION ENGINEERING** as prescribed by **VISVESVARAYA TECHNOLOGICAL UNIVERSITY, BELAGAVI** during the academic year **2022 – 23**. It is certified that all corrections/suggestions indicated for internal assessment have been incorporated in the report deposited in the departmental library. The project report has been approved as it satisfies the academic requirements in respect of project work phase – I prescribed for the said degree.

Dr. Chandrappa D N	**Dr. K V Mahendra Prashanth**
Guide & Head	**Principal**
Dept. of ECE, SJBIT	**SJBIT**

Name of Examiners **Signature with Date**

1.

2.



ACKNOWLEDGEMENT

I would like to express our profound grateful to **His Divine Soul Jagadguru Padmabhushan Sri Sri Sri Dr. Balagangadharanatha Mahaswamiji** and His Holiness **Jagadguru Sri Sri Sri Dr. Nirmalanandanatha Swamiji** for providing me an opportunity to be a part of this esteemed institution.

I would also like to express our profound thanks to **Revered Sri Sri Dr. Prakashnath Swamiji,** Managing Director, SJB Institute of Technology, for his continuous support in providing amenities to carry out this project (Phase – I) in this admired institution.

I express our gratitude to **Dr. K V Mahendra Prashanth**, Principal**,** SJB Institute of Technology, for providing me excellent facilities and academic ambience which helped me in satisfactory completion of project work (Phase – I).

I extend our sincere thanks to **Dr. Chandrappa D N**, Professor & Head, Department of ECE, for providing us invaluable support and his valuable guidance, suggestions and cheerful encouragement during the entire period of my project work (Phase – I).

I express my truthful thanks to **Dr. Mahantesh K, Mr. Bhaskar B and Mrs. Uma S,** project coordinators, Dept. of Electronics and Communication for their valuable support.

Finally, I take this opportunity to extend my earnest gratitude and respect to our parents, teaching & technical staff of the department, the library staff and all my friends, who have directly or indirectly supported me during the period of my project work (Phase – I).

Regards,

CHETHAN S [1JB19EC022]
INDUPRIYA B [1JB19EC029]
KRUTHI N [1JB19EC041]
MANJUKISHORE P [1JB19EC050]

DECLARATION

I hereby declare that the entire work embodied in this project report has been carried out under the supervision of Dr. Chandrappa D N, Professor & Head in partial fulfilment for the award of “BACHELOR OF ENGINEERING” in ELECTRONICS AND COMMUNICATION ENGINEERING as prescribed by VISVESVARAYA TECHNOLOGICAL UNIVERSITY, BELAGAVI during the academic year 2022 – 23.

CHETHAN S	**[1JB19EC022]**
INDUPRIYA B	**[1JB19EC029]**
KRUTHI N	**[1JB19EC041]**
MANJUKISHORE P	**[1JB19EC050]**

ABSTRACT

In recent years, the Internet of Things (IoT) has received much attention in the areas of industry and academia. Currently, IoT technologies are being applied in many fields and is changing lives in many areas such as smart homes, smart cities, smart grids, autonomous cars, and the industrial internet. Howbeit, traditional agriculture is still waiting for many changes to occur in networking technology, especially in IoT. Many researchers and engineers are working towards applying IoT technology to traditional agricultural methods. Aeroponics farming is an efficient and effective process for growing plants without using soil. When we apply IoT technology to an aeroponics system, it is expected that there will be many improvements such as decreasing water usage, increasing plant yield, minimizing rate of growth and reducing the workforce. In this paper, we designed and implemented anew automatic aeroponics system using IoT devices. Our system is comprised of three main components: a mobile application, service platform and IoT devices with sensors. The mobile application provides the user a graphical user interface to monitor and adjust the aeroponics system. The service platform is a middleware system that provides information for the mobile application to store the gathered information from IoT devices using sensors within the aeroponics system. The IoT device uses sensors within the aeroponics system to control each pump and access data. Our work is a new application in the agricultural industry and is expected to be a promising application that will help the farmer with increasing productivity in farming and reducing carbon footprint.

TABLE OF CONTENTS

Chapter	Particulars	Page
Acknowledgement		**i**
Declaration		**ii**
Abstract		**iii**
Table of contents		**iv**
List of figures		**v**
List of tables		**v**
1	**Introduction**	6
	1.1 Aeroponics	7
	1.2 The Aeroponic Growing System	8
	1.3 Nutrients used in Aeroponics system	9
	1.4 Internet of Things	10
2	**Challenges, Motivation & Objectives**	12
	2.1 Challenges	12
	2.2 Motivation	13
	2.3 Objectives	13
3	**Literature Survey**	14
4	**Prerequisites: Hardware & Software Requirements**	16
	4.1 Hardware Requirements	16
	4.2 Software Requirements	23
5	**Proposed Methodology**	24
	5.1 The Aeroponic System and sensor Network	24
	5.2 Sensor Types and Monitoring Parameters	25
	5.3 Sensor Working Protocol in the Aeroponic System	28
	5.4 Plant Growth and Root optimization	29
	5.5 Plant Growing System	30
	5.6 Advantages and Disadvantages of Aeroponic System	31
	5.7 Expected Outcome	33
	5.8 Applications	33
6	**Conclusion**	34
7	**References**	35

List of figures

Figure	Particulars	Page
1	**Figure 1.1.1: Different types of farming techniques**	8
2	**Figure 1.4.1: Architecture of 4-layer application layer**	11
3	**Figure 3.1: Sensors and actuators used in aeroponic system**	16
4	**Figure 3.1.1: Arduino Mega 2560**	17
5	**Figure 3.1.2: Temperature and Humidity sensor (DHT11)**	17
6	**Figure 3.1.3: Water level sensor**	18
7	**Figure 3.3.4: LDR (LM393) sensor**	19
8	**Figure 3.1.5: CO2 Sensor**	20
9	**Figure 3.1.6: Water pump**	21
10	**Figure 3.1.7: PH Sensor**	22
11	**Figure 3.1.6: EC Sensor**	22
12	**Figure 3.1.7: LED Lights**	22
13	**Figure 3.1.8: Arduino IDE software**	23
14	**Figure 5.1.1: The aeroponic system using sensor technology**	24
15	**Figure 5.2.1 Aeroponic cultivation control system**	26
16	**Figure.5.3.1: Flowchart of Aeroponic hardware system**	29
17	**Figure 5.4.a: Model of Aeroponic system** **Figure 5.4.b: Root Chamber of Aeroponic system**	30
18	**Figure 5.5.1: Prototype of the setup of aeroponic system**	31

List of Tables

Table	Particulars	Page
1	**Table 5.2.1: Basic monitoring and control parameters in the aeroponic system**	28

CHAPTER 1

INTRODUCTION

By the year 2050, the population of Earth is expected to rise by 3 billion people. Approximately 109hectares of additional traditional farmland will be needed to feed them. It is estimated that 80% of the arable land on Earth suitable for farming is presently in use. Roughly 15% of this land has been rendered unusable for farming due to poor management and climate change has claimed even more. More locally, the produce industry of the US is inefficient and insufficient. Populations in the northeast buy produce for at least 6 months out of the year from farms over 3,000 miles away, according to multiple produce vendors in the area. This product has been engineered to survive the long trip and extend shelf life in local stores. Better quality and tasting locally grown produce are only available for a few months out of the year, and in a relatively limited quantity. Jobs associated with farming are often seasonal, low paying, and with no benefits. Even in the East, these jobs are often occupied by migrant workers. Another issue is that crop yields are highly dependent on weather. A single poor growing season can cause thousands to starve in many areas of the world. In the US, this at minimum causes a significant rise in imported produce resulting in higher prices and dollars leaving the local economy.

The proposed solution is an integration of currently available technologies in a Controlled Environment High-Rise Farm (CEHRF). The system is based on an aeroponic growing system, chosen for its 90% reduction in water use, 60% reduction in nutrient use, stimulated crop growth, and higher density capabilities as compared to traditional farming. This system is then enclosed in a high-rise building with a transmissive wall, made of corrugated polymer with a light transmission to R-value ratio that is roughly 3 times that of glass. This building is used in conjunction with a high efficiency HVAC system to provide stable, year-round growing temperature and humidity in a series of separate environments specific to each crop type being grown. The supplemental artificial lighting system is based around Luxim's LIFI technology, a highly efficient (120 um/W) full spectrum capable bulb. The growing regimen is designed to provide a year-round continual harvest by offsetting planting times, so that a steady and reliable crop yield can be achieved while providing full-time year-round employment in a safe environment with benefits. These farms can be placed near the populations they are intended to serve, keeping money in local economies. These farms are designed to be co-located with sources of waste heat and/or green energy to maximize benefits. Placement near co-gen plants, or wind farms that the grid can't fully support is ideal, and these locations are more abundant than one might think. Aeroponic literally means "growing in air." An aeroponic system is medium-less in that the roots of the plant are free hanging inside an open root-zone atmosphere. The vegetation zone is separated by the supports used to hold the plants in the top of the unit. Nutrients are mixed in with water in a reservoir basin; this is then filtered and pumped into a pressurized holding tank that is intermittently misted onto the root system. The water droplet size must be big enough to carry the nutrients to the roots in sufficient quantity, but small enough to no immediately precipitate out of the root mass. Unused solution drips down into the base of the unit and is strained, filtered, and pumped back into the reservoir

1.1. AEROPONICS

Aeroponics or air culture uses the application of nutrient dissolved mist over exposed plant roots which enable growth without soil. Aeroponics is usually regarded as a type of hydroponics since water is used as a nutrient dissolution medium. The suspended plant roots are enclosed in a sealed chamber and the plant canopy is exposed to the outside. For small plants the sheath of cell foam is compressed and wrapped around the bottom stem and inserted in to the aeroponic setup. For large fruit bearing plants trellising is used. Trellising is fixation of wooden or metallic supporting frames with the plant body. The plant grows vigorously in an aeroponic system due to the sterile environment and abundant oxygen present in the chamber. The droplet size of a nutrient mist is a crucial element in aeroponics.
An oversized droplet may reduce the oxygen supply.

An undersized droplet may stimulate root hair growth which prevents lateral root growth which influences the efficiency of an aeroponic system. Aeroponic systems are more water resource efficient than hydroponic systems. Another remarkable advantage of aeroponics is the minimal contact between the support structure and plant, due to which unconstrained growth of the plant is possible. The aeroponics system are widely used for NASA space research programs.

The hydro-atomized mist also significantly contributes to the effective oxygenation of the roots. For example, NFT has a nutrient throughput of 1 liter/min compared to aeroponics throughput of 1.5ml/min. The reduced volume of nutrient throughput results in reduced amounts of nutrient required for plant development. Another benefit of the reduced throughput, of major significance for space-based use, is the reduction in water volume used. This reduction in water volume throughput corresponds with a reduced buffer volume. Both of which significantly lighten the weight needed to maintain plant growth. In addition, the volume of effluent from the plants is also reduced with aeroponics, reducing the amount of water that needs to be treated before reuse. The relatively low solution volumes used in aeroponics, coupled with the minimal amount of time that the roots are exposed to the hydro-atomized mist, minimizes root-to-root contact and spread of pathogens between plants

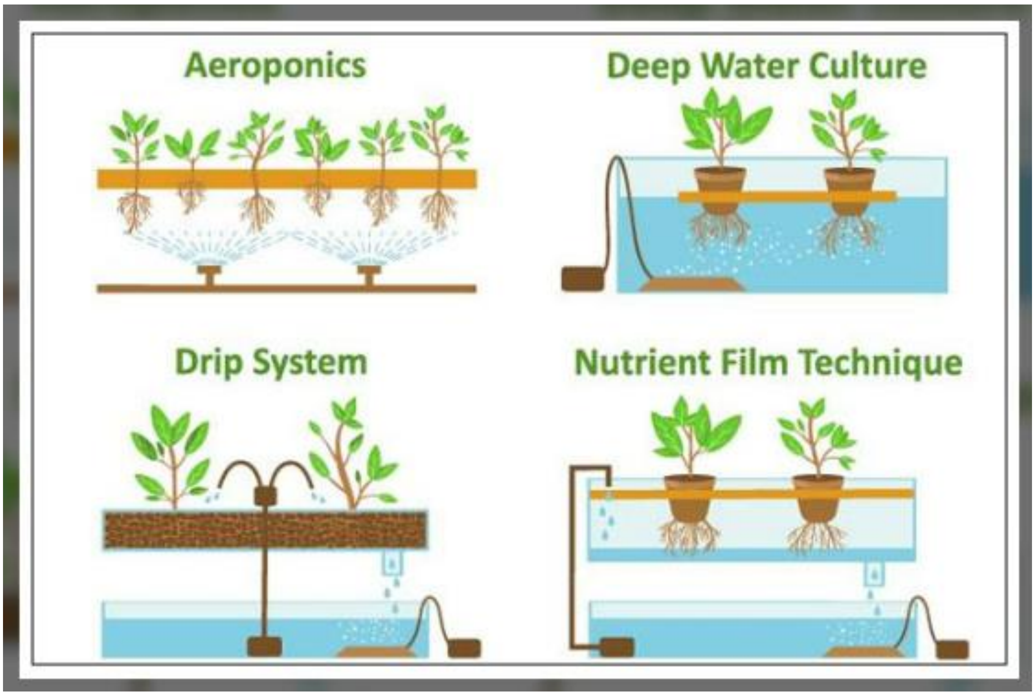

Figure 1.1.1: Different types of farming techniques

1.2 THE AEROPONICS GROWING SYSTEM

The principles of aeroponics are based on the possibility of cultivating vegetables whose roots are not inserted in a substratum (the case with hydroponics) or soil, but in a container filled with flowing plant nutrition. In these containers root can be found in the best condition regarding the best oxygenation and moisture. These conditions allow for better plant nutrition assimilation in a more balanced way, with consequential faster development of the cultivated plant.

Plant containers can be mounted on top of one another and because they are light and handy, they can be easily moved according to agricultural needs. Numerous plants are mounted in vertical columns within a greenhouse or shade house space. Nutrients are allowed to trickle down through the growth columns. Most agricultural plants need direct exposure to the sun during the first vegetative development. Afterwards this direct exposure is no longer relevant. Based on this observation, plant containers are periodically displaced. Young plants are placed at the highest level of the growth column. Afterwards they are progressively lowered utilizing a rotational mechanical system. With the rotation periodically repeated, this permits constant production without any interruption. The Aeroponic system is agriculture with a non-stop production cycle. Plant nutrition is supplied into a closed circuit. Consumption is consequently limited to only the quantities absorbed by the plants, allowing for substantial water savings. For example: to produce a kilogram of tomatoes using traditional land cultivation requires 200 to 400 liters of water, hydroponics requires about 70 liters, aeroponics utilizes only about 20 liters. Because the aeroponic system is a continuous cycle in an enclosed space it reduces agricultural labor into a series of mechanical routine operational tasks which are carried out daily and throughout the year. This enables workers to acquire considerable skill within a short period of time, a few months. In traditional agriculture commercial production is obtained only with skilled workers qualified by many years of experience. The aeroponic equipment is sheltered within greenhouses or anti hail-storm coverings according to the latitude. Climate controls within the greenhouse ensure optimal growing conditions, assuring high yields.

1.3 NUTRIENTS USED IN AEROPONICS SYSTEM

An indoor aeroponics system uses less water and nutrients because the plant roots are sprayed in intervals using a precise drop size that can be utilized most efficiently by osmosis to nourish the plant. Little excess nutrient solution is lost to evaporation or runoff. Plant disease is minimized because the roots are left open to air, avoiding soaking is a stagnant moist medium. Carbon, oxygen and hydrogen are present in air and water. Water may contain a variety of elements according to your local treatment plant additions and should be factored into your final factor, or primary nutrients are nitrogen, phosphorus, potassium and are used by plants in different amounts according to the growth stage. Secondary nutrients are calcium, magnesium, and sulfur, micro-nutrients are iron, zinc molybdenum, manganese, boron, copper, cobalt and chlorine. Complicating the formula more, roots use nutrients as ions in water positively charged cations, or negatively charged anions. An example of a cation is ammonium, NH4+, and an anion nitrate, NO3−, both important nitrogen sources for plants. As plants use the ions, the pH of the solution can change, meaning it can lean too far positive or too far negative. The optimal pH for plant growth is between5.8 and 6.3. In aeroponic system where water and nutrients are recycled.it is important to measure the acid/base or pH measurement to allow plants to absorb nutrients. Aeroponic using spray to nourish roots use much less liquid resulting in easier management of nutrient concentration with greater pH stability.

THE MAIN NUTRIENTS USED IN AEROPONICS ARE

- Phosphorus
- Potassium
- Calcium

- Magnesium
- Iron
- Manganese
- Boron
- Copper
- Zinc
- Molybdenum

These are the main nutrients used in aeroponic cultivation. The concentration of the above-mentioned nutrients is different for different crops.

1.4 INTERNET OF THINGS(IOT)

As technology develops, it will bring great advantages to human beings in all areas of life. Especially, the development of network technology is changing many areas of our lives such as smart homes, smart cities, smart grids, autonomous cars, and the industrial internet. Smart agriculture systems are an area that would benefit from this technology. By adapting the recent innovations in technology for farming it would add many benefits for farmers and reduce our carbon footprint. The Internet of Things (IoT) is an emerging technology that provides internet connectivity and powerful data analytic capabilities to create a system in which objects in the physical world could be connected to the internet by sensors. However, smart farming is still in its infancy about using IoT devices for agriculture. Aeroponics farming is an efficient and effective process for growing plants without using soil as a medium as well as with little water. We propose a new automated aeroponics system using IoT devices that will help the farmer by increasing productivity in farming. To the best of our knowledge, this is the first work to design and implement automated aeroponics systems using IoT devices.

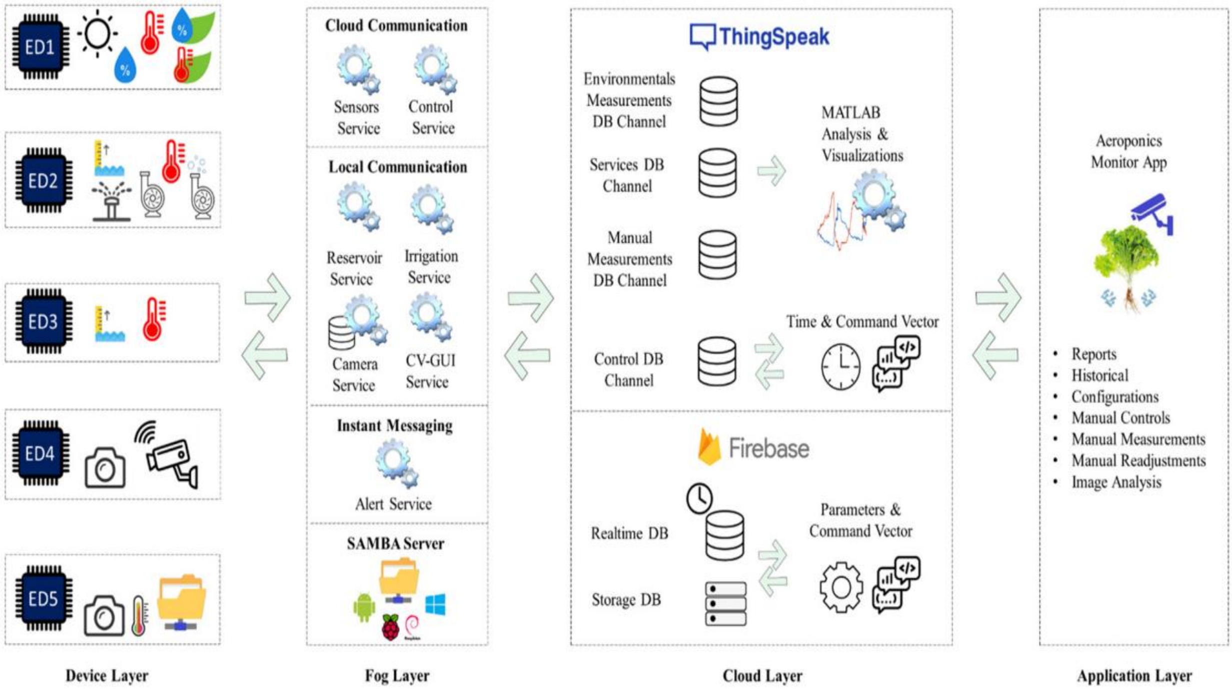

Figure 1.4: Architecture of 4-layer application layer

CHAPTER 2

CHALLENGES, MOTIVATION AND OBJECTIVES

2.1 CHALLENGES

The development of aeroponic systems can be considered as a highly multidisciplinary approach drawing from environmental, mechanical, and civil engineering design concepts and plant-related biology, biochemistry, and biotechnology. Sometimes, specific measurements, schematic view, and control technologies also require abundant knowledge of subjects related to the field of computer science for automatic control systems. This high level of complexity necessarily demands in-depth knowledge and expertise of all involved fields. Furthermore, the electricity connection should be independent of the aeroponic system. Besides, in case of an emergency, additional power sources such as a stand-by generator or battery should always be ready with the system. For those places where power failures are frequent, those areas must need a good generator with an automatic startup system. Considering the initial costs for components and installation, the aeroponic systems with air-assisted and centrifugal atomization nozzle are more expensive than ultrasonic fogger (high-frequency atomization nozzle). In addition, over time, if components are well maintained and used for many years, these higher initial costs can be recovered by reducing the labor costs, minimum inputs of fertilizers and pesticides with significantly higher plant yields.

The system has many potential challenges which could be answered through research studies. Bucksetha et al. (2016) and Stoner and Clawson (1998) revealed that in the aeroponics system the main problem is related to water nutrient droplet size. The larger droplets permit less supply of oxygen availability in the root zone. The smaller droplets produce too much root hair without developing a lateral root system for sustainable growth. Currently, most of the studies on the aeroponics system are based on the growth, yield, and quality of the plant. However, only limited studies had been carried out to determine the influence of various droplet sizes on plant yield and nutrient physio-chemical properties of the nutrient solution. The main potential challenge and drawback of the system is constant power supply throughout the plant growth. Any prolonged rupture of power energy shuts down the nutrient supply and contributes to permanent plant damage. The mineralization of the ultrasonic transducers requires attention and may be prone to potential components failure.

2.2 MOTIVATION

- The declining availability of natural resources like water and arable land, unpredictable weather patterns and changing climates, and an exponentially growing population
- With one in nine people still living in destitute hunger, the world awaits the next phase of the agricultural revolution.
- Quick and disease-free plants are obtained as the roots of the plants are exposed to air and they can easily absorb the required oxygen level. However, the roots can also be sterilized by using mist on the roots to further prevent plant diseases.
- 100% safe and environmentally friendly. They conserve water and reduces the amount of human labor involved

2.3 OBJECTIVES

- To create a fully automated aeroponic system that will reduce the need for human interference to the maximum possible extent.
- To eliminate seasonal dependency due to controlled and regulated environment and to reduce mutation in plants due to increase in UV-index over the period.
- To collect and process the data and display it to the user through a web interface, which will also be used to allow the user to monitor the aeroponic system.
- The specific objectives of this project involve accomplishing goals which are specific to system, and which would greatly improve the system from those that are already available.

CHAPTER 3

LITERATURE REVIEW

Several projects were implemented based on hydroponics system, which is the motivating idea behind the aeroponics system. The first person is W. Carter in 1942, who had done research on air culture growing and proposed a method of growing plants in water vapor to facilitate the examination of roots. L.J. Klotz in 1944, discovered vapor misted citrus plants in a facilitated environment for his research about the diseases of citrus and avocado roots.

G.F. Trowel in 1952, grew apple trees in a spray culture medium. In 1957, F. W. Went who first mentioned the air-growing process as “aeroponics” and grew coffee plants and tomatoes with air-suspended roots and applied a nutrient solution to the plants roots. By the early start of 1975, scientists and researchers were involved in developing their first aeroponics system. In 1978 Isaac Nir described an aeroponic system that automated the spraying of mist at the root of the plants and was one of the very firsts of its kind. The apparatus was very simple in comparison to the sophisticated apparatus available in the present market.

The first commercial aeroponic device was introduced by GTi in 1983. It was known by the name Genesis Machine. GTi's device came with an open-loop water driven apparatus, controlled by a microchip, and delivered a high pressure, hydro-atomized nutrient spray inside an aeroponic chamber. The Genesis Machine was simply connected to the water faucet and an electrical outline in 1997, Richard Stoner II founded Agri House, an Agri-biology company, which along with research inputs from NASA produced the Genesis Series Aeroponic System. The system used hydro-atomizing spray jets to deliver mist with a droplet size of less than 50 microns which is just about the ideal size. Digital timers were used to spray mist at regular intervals.

One of the very first aeroponic systems to use ultrasonic foggers was the Aeroponic Growth System invented by Richard W.Zobel and Richard F. Lychalk in 1998 . This system produced fog using ultrasonic foggers and delivered it to the root making it more effective than any of the preceding inventions. Project XGEN by Shyamal Patel and Dr Lance Erickson in 2011 produced a device that was much more sophisticated and modern than the previous apparatuses. This project made extensive use of sensors such as gas sensors, water sensors, and pH sensors to monitor the physical conditions within the system. The idea of transmitting data from an aeroponic system to a computer was first seen in the Aeroponic Growing System which was designed for potato production by Irman Idris and Muhammad Ikshan Sani in 2012.

This system was an upgrade to the project XGEN as it, in addition to the monitoring system, included a regulatory system. An aeroponic system built by J.L.Reyes et al. was very similar to project XGEN in the way that it included a greenhouse system to main the atmosphere of the shoot system. However, this project monitored the electrical conductivity of the nutrient solution unlike the case with project XGEN.

An aeroponic system developed by Jing Liu and Yunwei Zhang in 2013 was among the first systems to include a temperature regulator. A P Montoya et al.'s Automatic aeroponic irrigation system was a much-improved version of the previous aeroponic systems. The system included a greenhouse system, pH sensors, EC sensors, temperature and humidity sensors, ultrasonic range finders, and water flow sensors to monitor the system constantly. Moreover, real time data was logged and streamed to a web server making data mining and analysis possible. An aeroponic system that could be used in the space was built by V. Arenella et al. in 2016.

There are multiple proposals in the literature referring to IoT architectures used inintelligent agriculture; among the most recent are AREThOU5A, AgriSens, IRRISENS,Agro-IoT, SWAMP and a proposed four-layered architecture by Kour in 2020, each referring to soil agriculture. Kamienski et al. propose SWAMP, a generalized architecture oriented to the intelligent management of irrigation for agricultural systems on the ground incorporating different interconnection strategies between its elements to address the problems of communication in greenhouses on a large-scale using fog nodes in the soil with Lora WAN routers. Its architecture is made up of five layers, which include the sending of information to end users, distribution models for irrigation, use of drones for vision inspection, data analysis models in the cloud fog nodes using as references the relative humidity of the soil, databases, security for data acquisition, sensors, actuators, and weather reports, among others.

Based on the literature reviewed by Kour et al. from 2015 to 2020 and related to the advances and development of agriculture, the authors show, as a conceptual representation, a reference to IoT architecture for agriculture made up of six layers (Agro-IoT), including: a perception layer for sensors, actuators, wireless nodes, etc.; a network layer that encompasses the communication protocols, software middle layer, application layer for data analysis and prediction; a user layer where results are directed to farmers, experts in the area, the supply chain and industries. With the aim of monitoring low-scale greenhouses in real time, optimizing resource use, the early detection of diseases, identification of crop species, optimization of irrigation facilities and effective use of pesticides and fertilizers, the authors propose an IoT architecture for solar precision agriculture with four layers, including: a sensory layer, a network layer considering IoT nodes and base stations; a decision layer involving server services, workstations, work and knowledge base; an application layer involving how researchers, experts and farmers receive the information.

CHAPTER 4

PREREQUISITES: HARDWARE AND SOFTWARE REQUIREMENTS

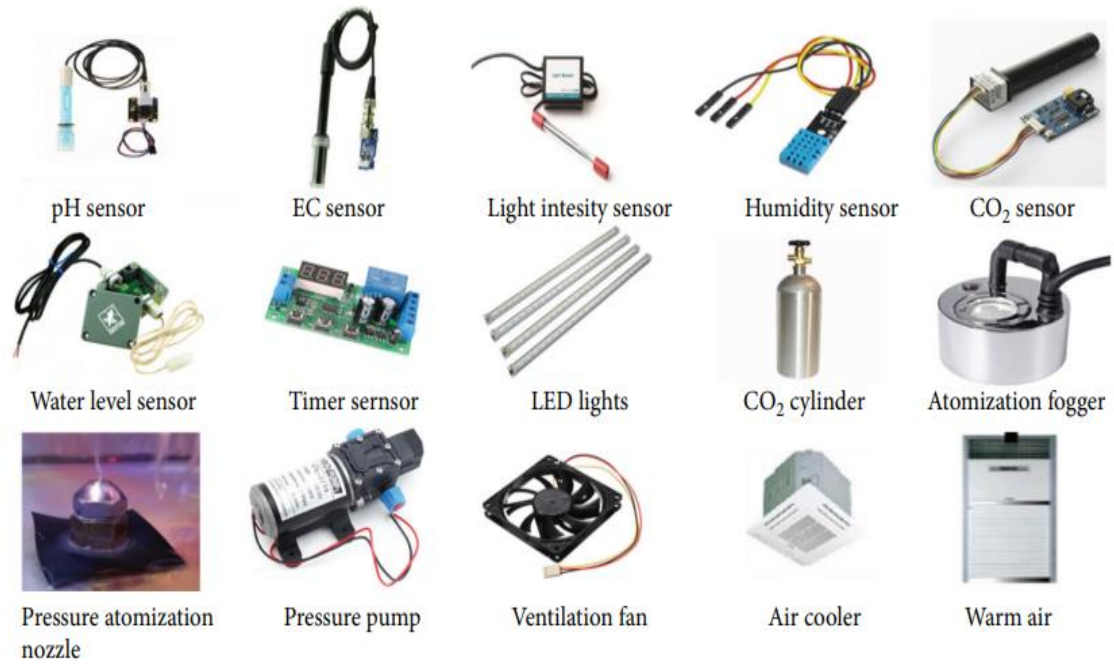

Figure.3.1: Sensors and actuators used in aeroponic system

4.1 HARDWARE REQUIREMNETS

- **Arduino Mega 2560:** The microcontroller board like "Arduino Mega" depends on the ATmega2560 microcontroller. It includes digital input/output pins-54, where 16 pins are analog inputs, 14 are used like PWM outputs hardware serial ports (UARTs) – 4, a crystal oscillator-16 MHz, an ICSP header, a power jack, a USB connection, as well as an RST button. This board mainly includes everything which is essential for supporting the microcontroller. So, the power supply of this board can be done by connecting it to a PC using a USB cable, or battery or an AC-DC adapter. This board can be protected from unexpected electrical discharge by placing a base plate.

Figure 3.1.1: Arduino Mega 2560

- **Humidity sensor (DHT 11):** Aeroponics is the technique of cultivating plant by providing the water nutrient small spray in the air. Thus, the humidity is another important parameter of aeroponic growth chamber environments, and its control is recognized to be very important for significant plant growth. In the aeroponic system, the plant gets all available moisture in the growth chamber. Moreover, if the growth chamber has too high or less moisture content, both conditions will create many problems for the plant. Accordingly, an accurate and precise means of testing moisture content in the growth chamber will help farmers to monitor their crops and provide a suitable growth environment for the plant. Wang et al. reported that a humidity sensor is a device that detects and measures water vapor present in the air within a room or enclosure. At present, humidity sensors are widely used in medicine, agriculture, and environmental monitoring. However, the most used units for humidity measurement are relative humidity. The development of humidity sensors has shown remarkable progress because of using various types of sensing materials in recent years. The sensing materials used in humidity sensors can classify into ceramics, polymers, and composites. The humidity sensor could be placed in the growth chamber to maintain the moisture level. If the moisture level becomes less than the plant requirement, the sensors will forward the signals to atomization nozzles to perform their work. This is a temperature and humidity sensor connected to Arduino at digital pin 10. Relaying on ambient temperature and humidity levels, the fans run by DC motors and the water sprayers are turned on by the microcontroller.

Figure 3.1.2: Temperature and Humidity sensor(DHT11)

- **Water level sensor:** Aeroponics is the method of plant cultivation by providing a small mist of the nutrient solution in the growth chamber. Thus, there is no use of soil; just water is required to cultivate the plant throughout the germination to harvest time. Therefore, the water nutrient solution reservoir is one of the major components of the aeroponic system which should be monitored throughout the growth period. In the conventional aeroponic system, the farmer checks the water nutrient level in the nutrient solution reservoir, and if he finds water level less than the desired level, he maintains accordingly. However, by adopting precision agriculture techniques, the farmer will be able to monitor and control water nutrient levels through intelligent methods such as wireless sensors. The water nutrient level sensors detect the liquid level in the reservoirs and facilitate operators in collecting water nutrient level data in real time. The sensors will alert the operator about any potential property damage that results from any leaks and also allow you to know when a container is nearly empty.

Figure 3.1.3: Water level sensor

- **Light intensity sensor:** Photo Resistor or LDR(LM393) As we know, all vegetable plants and flowers require large amounts of sunlight, and each plant group reacts differently and has a different physiology to deal with light intensity. Some plants perform well in low light intensity and some in high light intensity. However, the aeroponic system implements indoor conditions, so it is necessary for the farmer to provide sufficient light quantity of at least 8 to 10 hours a day to grow the healthy plant. Artificial lighting is a better option to present enough intensity to produce a healthy plant. In the conventional aeroponic system, the control of the light quantity present in the growth chamber is mostly done by the farmer through observing the plant condition. However, it is a time consuming and challenging task for the farmer to provide the required light concentration accurately. It could be a better option to use intelligent agriculture techniques to monitor the light intensity in the aeroponic system. The light sensor is an electronic device which is used to detect the presence or non-presence of light and darkness. There are several types of light sensors including photoresistors, photodiodes, and phototransistors. These light sensors distinguish the substance of light in a growth chamber and increase or decrease the brightness of light to a more comfortable level. Light sensors can be used to automatically control the lights such as on/off. By adopting the sensor network in aeroponics, the farmer could be able to monitor light intensity without any human interference. Because the sensors will perform all work such as if the light intensity in the growth chamber will be less than the required light quantity for plant growth, the sensor will automatically forward the signal to the LED light to turn on until the light quantity reaches to the desired level. This is a light sensor connected to Arduino at pin number A1. This sensor is utilized to keep track of the light falling on the system to maintain the 16:8 ratio of light and darkness. Depending on the threshold value of this sensor the Arduino is going to turn on the LED Bulb when it finds more darkness than the essential amount.

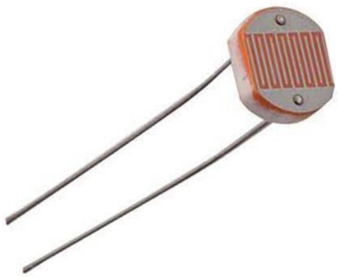

Figure 3.1.4: LDR (LM393)

- **Temperature Sensor (DHT 11)**: In the aeroponic system, the temperature is one of the critical factors significantly determining plant growth and development. A reduction in temperature below the optimal conditions often results in suboptimal plant growth. A different cultivar requires a different temperature level for the photosynthesis process and growth, which can advance the plant growth stage. It will eventually bring us substantial economic benefits. In the aeroponic system, the optimum growth chamber temperature should not be less and more than 4 and 30° C, respectively, for successful plant growth. The temperature fluctuations of aeroponic growth chambers can significantly affect the root growth, respiration, transpiration, flowering, and dormant period. Therefore, temperature sensors can be used to monitor the temperature fluctuations of the aeroponic system. At present, temperature sensors are used in many applications like environmental controls, food processing units, medical devices, and chemical handling. The temperature sensor is a device mainly composed of a thermocouple or resistance temperature detector. The temperature sensor measures the real-time temperature reading through an electrical signal. The sensors collect data about temperature from a particular source and convert the data into an understandable form for a device or an observer.

- **CO2 Sensor:** The appropriate oxygen concentration in the root environment is crucial to keep the root metabolism in nutrition solution. The available oxygen concentration for the root environment is a hugely significant factor since low concentrations affect the root respiration, nutrient absorption, and, consequently, the plant growth [66]. Thus, the CO2 sensor could be used to monitor the carbon dioxide fluctuations in the aeroponic growth chamber. A carbon dioxide sensor is an instrument which is used for the measurement of carbon dioxide gas concentration. pH sensor EC sensor Light intensity sensor Humidity sensor Atomization fogger CO2 sensor CO2 cylinder Pressure atomization Pressure pump Ventilation fan Air cooler Warm air nozzle Water level sensor Timer sensor LED lights Figure 5: Sensors and actuators used in an aeroponic system. Journal of Sensors 9 [99] reported that CO2 sensors are used to measure indoor air quality in a building to perform demand-based ventilation. However, the CO2 sensor data measuring range is in between 500 and 5000 parts per million. There are two main types of the CO2 sensors which include no dispersive infrared carbon dioxide sensors (NICDS) and chemical carbon dioxide sensors (CCDS), whereas the NICDS detected CO2 in a gaseous environment by its characteristic absorption and composed of an infrared detector, an interference filter, a light tube, and an infrared source. However, the CCDS of sensitive layers are based on polymer or heteropoly siloxane with low-energy consumption.

Figure 3.1.5: CO2 Sensor

- **DC Water Pump:** This pump is controlled along with a single channel relay. It is used to check the water level employing the above-mentioned water level sensor in the main water tank and it falls to a certain level then this pump is triggered to fill up the main water tank from the external tank.

Figure 3.1.6: Water pump

- **EC and pH Sensor:** In the aeroponic system, the plant productivity is closely related to nutrient uptake and the EC and pH regulation of the nutrient solution. The EC and pH concentration of the nutrient solution affects the availability of nutrients to plants. The pH and EC concentrations are controlled to prevent barrier growth. Their measurement is essential because the solubility of minerals in acidic, alkaline, and ion concentration of all the species in solutions is different and the solution concentration changes with solubility. The unmonitored EC and pH concentration of the nutrient solution will quickly lead to a situation where plants cannot absorb the essential nutrients, if not corrected this will eventually lead to harmful plant growth and poor productivity. Thus, the EC and pH concentration of the nutrient solution is a critical parameter to be measured and controlled throughout plant growth. Moreover, in the conventional aeroponic system, the EC and pH value of the nutrient solution is mostly monitored manually by performing laboratory analysis or using advanced equipment which is a time-consuming process. For instance, when the EC of the nutrient solution decreased or increased, the control of nutrient solution concentration is mostly achieved by adding more high concentration nutrient solution or the fresh water, respectively, to the nutrient solution to maintain the EC level to the prescribed target range. Similarly, for pH, an acid solution and an alkali solution are used to control the pH fluctuation of the nutrient solution within a specified target range. However, these conventional methods are time-consuming and challenging tasks for the farmer to maintain the EC and pH value at the desired range accurately. In addition, the EC and pH sensor could be used to deal with the above challenges.

Figure 3.1.7: PH Sensor

Figure 3.1.6: EC Sensor

- **LED LIGHT:** This is managed along with a relay switch of a single channel. If the value of the photoresistor goes below the threshold level of 150 then the LED Bulb turns on and provides the necessary, light. As the coriander plant is required to be kept in sunlight for 16 hours and under dark night for 8 hours, this condition is maintained by these LED lights.

Figure 3.1.7: LED Lights

4.2 SOFTWARE REQUIREMENTS

- **Arduino IDE**: The IDE used to code the Arduino microcontroller. It depends on Java Processing Software and functions admirably on Windows, Linux, and Mac conditions. The product is open source.

Figure 3.1.8: Arduino IDE software

CHAPTER 5

PROPOSED METHODOLOGY

The implementation of aeroponic system using IoT requires some software and hardware components, and they all are described below:

5.1 THE AEROPONIC SYSTEM AND SENSOR NETWORK:

In recent years, early fault detection and diagnosis using an intelligent agricultural monitoring system is considered as the best tool to monitor plants without any complicated operations and laboratory analysis which required domain expertise and extensive time. The development of these convenient features has attracted much attention in agriculture. The system is based on a wireless sensor network which comprises a data server, a wireless convergence node, a plurality of wireless routers, and a plurality of wireless sensor nodes.

However, the wireless sensor nodes are used as the signal input of the intelligent agricultural monitoring system and are used to collect each selected parameter of farming operations to be monitored. Park et al. stated that wireless sensor network-based systems could be a significant method to fully automate the agriculture system, because the sensors provide real- time significant information and believed to eliminate the considerable costs of just wiring. Another study by Kim said that in agriculture, sensor network techniques help to improve existing systems installed in the greenhouse efficiently and smoothly by forwarding real-time collected information to the operator through the radio signals.

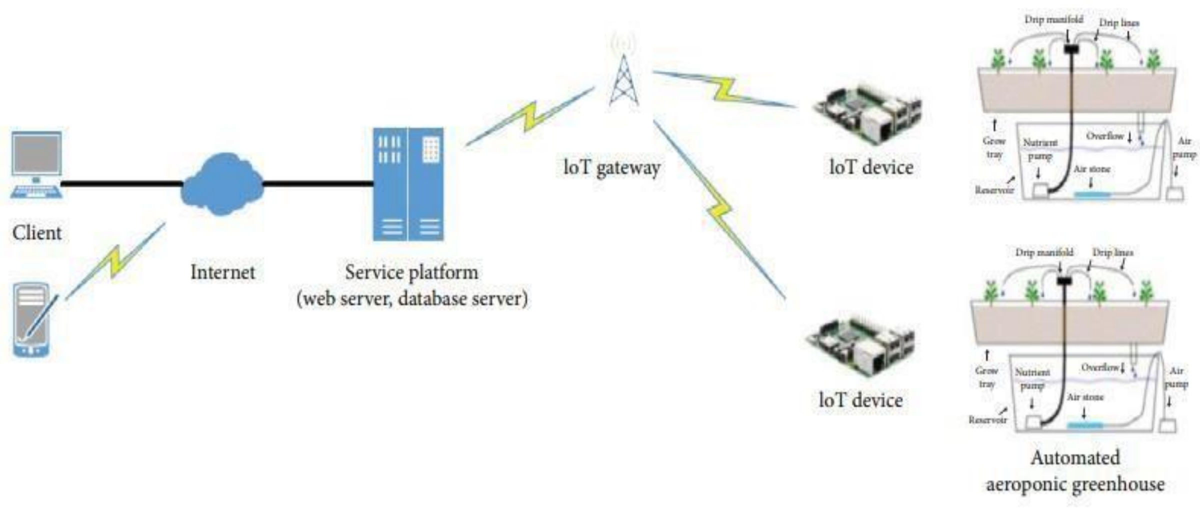

Figure 5.1.1: The aeroponic system using sensor technology by Kerns and Lee

The system optimizes the transmission protocols more accurately and quickly and maximizes the application of energy to save energy and reduce the consumption. Pala and team. suggested that the utilization of artificial intelligence techniques in the aeroponic systems could lead not only to find early fault detection but also to fully automate the system without any or small interventions of human operators. The aeroponic system could gain more popularity among local farmers by deploying this technique in a system for monitoring and controlling purposes. However, it will conserve resources and minimize impacts on the environment. The farmers could start to understand their crops on a micro scale and be able to communicate with plants through accessible technology. Therefore, in this article, we explored how wireless sensing technologies wove into the aeroponic system. Thus, the primary motivation of this review article was to provide an idea about different intelligent agriculture monitoring tools used for early fault detection and diagnosis for plant cultivation in the aeroponic system. Additionally, it would be helpful for the local farmer and grower to provide timely information about rising problems and influencing factors for successful plant growth in the aeroponic system. The adoption of intelligent agriculture monitoring tools could reduce the concept of unsuitability for the amateur.

5.2 SENSOR TYPES AND MONITORING PARAMETERS:

In this review study, we reviewed the previous work done on the aeroponic system using wireless sensor network technique. We found that the primary objective of a wireless sensor network system for the aeroponic system is to control the growth chamber climatic condition as per the crop data sheet. However, the basic principle of the aeroponic system is to grow the plant by suspending it in the closed, semi closed, or dark environment in the air with artificial provided support. In the system, the plant stems, leaves, and any fruit grow in a vegetative zone above the suspension medium, and roots dangle below the suspension medium in an area commonly referred to as a root zone.

Generally, closed cell foam is compressed around the lower stem and inserted into an opening in the aeroponic growth chamber, which decreases labor and expense. However, trellising is used to suspend the weight of cultivated plants. Ideally, the environment is kept free from pests and diseases so that the plants grow healthier and more quickly than other plants grown by techniques. Furthermore, the key to the success and high yields of air gardening is a scientific grade monitoring of the conditions and accurate control of the growing environment. Each plant yields and needs a different environmental condition for growth.

However, the plant growth is mainly influenced by the surrounding environmental and climatic variables and the amount of water, and the fertilizers supplied by irrigation. There is a requirement to monitor and control liquid nutrient parameters in a narrow range of preferred values for optimal growth. The parameters include nutrient temperature. If the parameters drift outside the desired range, the plants can be harmed. Besides, there are some additional parameters which can be adjusted to further optimize growth, such as air temperature, relative humidity, light intensity, and carbon dioxide (CO2) concentration. Idris and Sani reported that the one solution to solve the problems of monitoring and controlling the growing conditions in the space environment is by applying some sensors. The sensor can detect and monitor several parameters such as temperature, humidity, and light intensity.
Aside from the sensors, there is also a requirement for the actuators to distribute nutrients and water to plant roots or lower stems. The sensor collects the information of the various environmental conditions and forwards the signals to the actuator to take place and produce the outcome for the collected information to know the status of that parameter. The actuator can control the environment changes. The sensors store information that analyzes the environment and identifies the location, object, people, and their situations. The sensor provides multiple contributions in various domains that depend on a variety of attributes and variants in time.

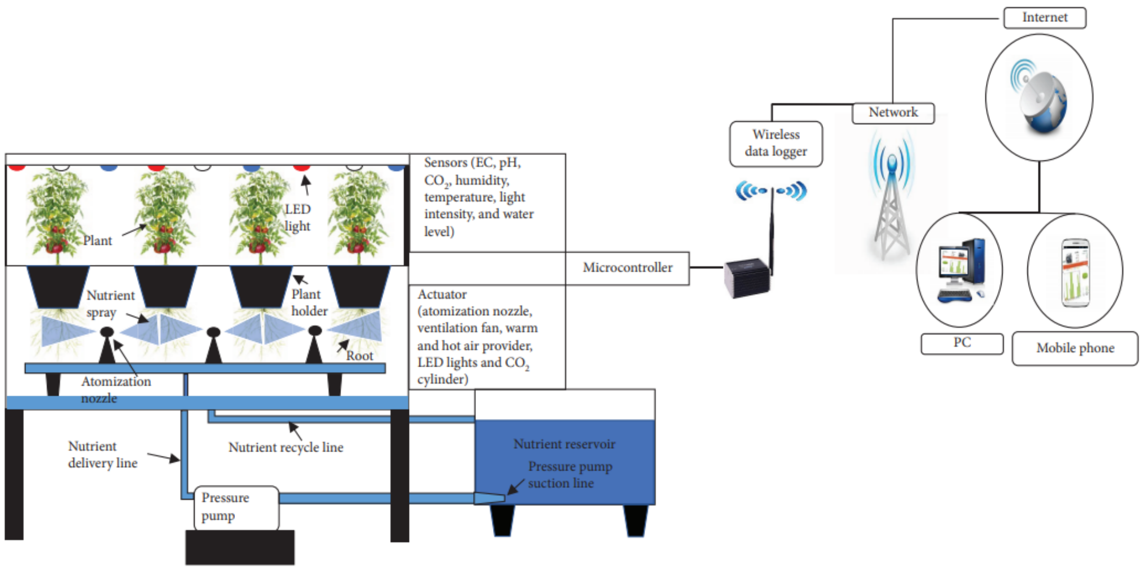

Figure 5.2.1 Aeroponic cultivation control system

No.	Parameters	Common value	Instruments
1	Nutrient atomization	Mist/spray/aerosol/droplet size at high pressure from 10 to 100, low pressure from 5 to 50, and ultrasonic foggers from 5 to 25 microns, respectively	Atomization nozzle (high and low pressure, atomization foggers)
2	Growing medium	Plant holder	Any artificial root supporting structure
3	Desirable pH of the nutrient solution	The pH value depends on the cultivar (onion 6.0–7.0, cucumber 5.8–6.0, carrot 5.8–6.4, spinach 5.5–6.6, lettuce 5.5–6.5, tomato 5.5–6.5, and potato 5.0–6.0)	pH measuring device
4	Humidity	Provide 100% available moisture	Humidity measuring device
5	Temperature	Optimum 15° C–25° C and should not increase to 30° C and less than 4° C	Temperature measuring device
6	The lights	The light inside the growth box must be dark enough	Cover the growth chamber with locally available material
7	Atomization time	Depends on the cultivar growth stage	Manually operating the system with timer
8	Atomization interval time	Depends on the cultivar growth stage	Manually operating the system with timer

Table 5.2.1: Basic monitoring and control parameters in the aeroponic system

5.3 SENSOR WORKING PROTOCOL IN THE AEROPONIC SYSTEM

Today, the world demands automatic tools to do most of the work for them without bothering its user for doing some tasks. So, the concept is all about a very high level of automation system which will be independent of its users to a very great extent, reduce human efforts, and save all kinds of resource utilization, as monitoring and controlling will be done by computers leaving very few easily manageable tasks for humans, and it will interest more people to join this field.

Moreover, the monitoring and control system for the aeroponic system mainly consists of following sections which include the aeroponic system, data acquisition, controlling the equipment, data transmission module, cloud data processing server, social communication platform, and mobile application. The data acquisition module is placed in the aeroponic system or near the growth chamber to collect the real-time information from selected parameters (temperature, light intensity, humidity, nutrient solution level, atomization quantity) and transmit the gathered data to the control and management center. However, the control and management section refer to the central processing unit (CPU) of the system.

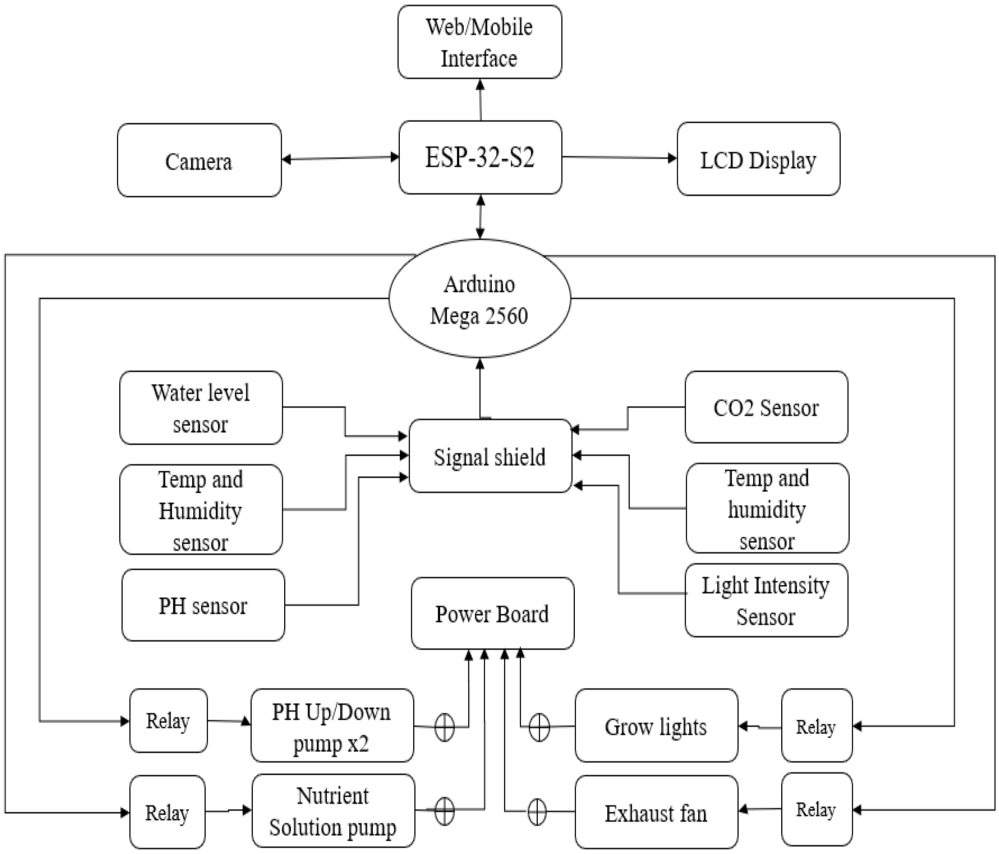

Figure.5.3.1: Flowchart of Aeroponic hardware system

5.4 PLANT GROWTH AND ROOT OPTIMIZATION

In general, the methodology provides a modular “plug-and-play” aeroponic growth system which allows for efficient maintenance and/or expansion of individual modular aeroponic units within the system without interrupting or otherwise disturbing the operation of other individual modular aeroponic units. The present system also configures the positioning and cone angles of the atomizers/misters (referred to herein as "spray nozzles") and the structure of the modular aeroponic units to minimize the occurrence of wet or dry zones within a root zone. The present system also provides an automated system controller that may implement pre-programmed spray operations, monitor, and control the temperature, humidity (i.e., activation of the spray nozzles), CO2 levels, light quality, light intensity, and other suitable plant growth parameters, and initiate alarms in the event of high or low sensor readings, pump failure, pressure loss, water loss, power failure or the occurrence of any other monitored process variable. It will be understood that the components and methods described herein for providing a modular automated aeroponic growth system for plants may be implemented in hardware, software, or a combination of both.

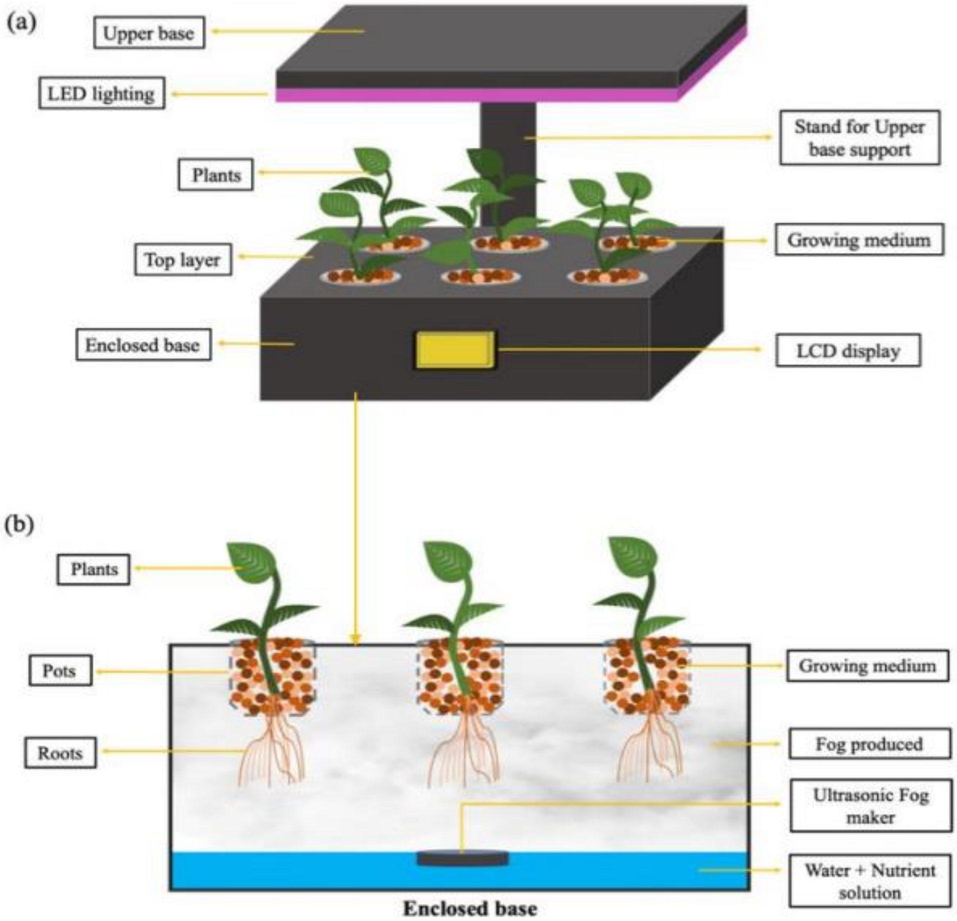

Figure 5.4.a: Model of Aeroponic system
Figure 5.4.b: Root Chamber of Aeroponic system

5.5 PLANT GROWING SYSTEM

As discussed above, the aeroponics system differs from both Hydroponic and in vitro plant growing techniques. Unlike the hydroponic system, which uses water nutrient rich solution as a growing medium and provides essential nutrients for sustaining plant growth. However, it is conducted without any growing medium. In the system, the nursery plants might be either raised as seedlings using specially designed lattice pots or cuttings could be placed directly into the system for rapid root formation. Lattice pots allow the root system to develop down into the growth chamber where it is regularly misted with nutrients under controlled conditions. Zobel et al. (1976) reported that root zone environmental conditions play a significant role in healthy plant growth and attaining the excellent quality of seed production. Siddique et al. (2015) revealed that only an efficient root system provides unobstructed growth space for the plant under atomization conditions. Soffer and Burger (1988) reported that once plants located in the atomization system roots start to get the most favorable root aeration system.

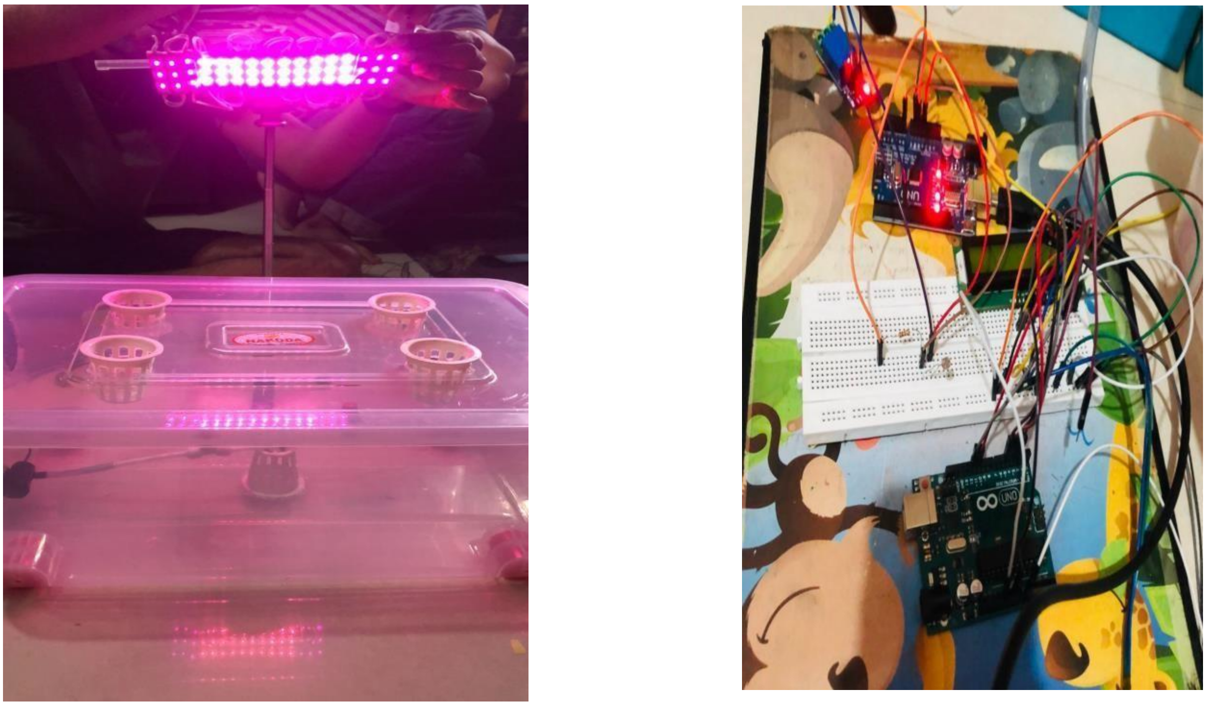

Figure 5.5.1: Prototype of the setup of aeroponic system

5.6 ADVANTAGES AND DISADVANTAGES OF AEROPONIC SYSTEM

5.6.1 ADVANTAGES:

- Fast plant growth – The chief feature of aeroponics. Plants grow fast because their roots have access to a lot of oxygen 24/7.
- Easy system maintenance – In aeroponics, all you need to maintain is the root chamber (the container housing the roots) which needs regular disinfecting, and periodically, the reservoir and irrigation channels. The constant semi-moist environment of the root chamber which invites bacterial growth is the only main drawback of all aeroponic system maintenance.
- Root access – In an aeroponic system, plant roots are easy to see and access. This is useful for

plant scientists and researchers who wish to observe plant roots without impacting plant growth or killing the plant by up-rooting it. This allows for more regular testing and observation.

- Less need for nutrients and water – because the nutrient absorption rate is higher, and plants usually respond to aeroponic systems by growing even more roots.
- Mobility – Plants, even whole nurseries, can be moved around without too much effort, as all that is required is moving the plants from one collar to another.
- Requires little space – You don't need much space to start an aeroponics garden. Depending on the system, plants can be stacked up one on top of each other. Aeroponics is basically a modular system, which is perfect for maxing out limited space.
- The system reduces the labor cost, consumes less water usage by 98%, fertilizer usage by 60%, pesticide and herbicides usage by 100% and maximizes plant yield.
- The possibilities of multiple harvests of a single perennial crop and accelerated cultivation cycle due to the increased rate of growth and maturation.
- The plant receives 100% of the available carbon dioxide and oxygen to the leaves, stems, roots, and accelerates growth with reducing rooting time.
- The system is not subject to weather conditions. The plants could be grown and harvested throughout the year without any interference of soil, pesticides, and residue.
- It is an environmentally friendly and economically efficient plant growing system.

5.6.2 DISADVANTAGES

- Expensive for long scale production.
- The plant grower must need a specific level of proficiency to operate the system.
- The grower must have the information about the appropriate quantity of required nutrients for plant growth in the system.
- It is important to supply the required concentration of nutrients.
- There is not any solid culture to absorb the excess nutrients if supply excess plants will die.
- The system design material is a little expensive. As the well-designed system requires advanced equipment. It mainly needs constant high-pressure pumps, atomization nozzles, EC, and pH measuring devices, temperature, light intensity and humidity sensors and timer to control the system.

5.7 EXPECTED OUTCOME

- An automated aeroponic system is created which reduces the need for human interference to the maximum possible extent. This system will be fully enclosed and completely detached from the outer environment. Thus, this aeroponic system can be completely monitored and regulated which can greatly reduce the practical problems associated making it a commercially viable solution.
- Since the root of the plant is suspended in the air unlike in geoponics where the root is completely submerged in the soil, the rhizosphere of the plant has greater access to fresh air. This results in the root of the plant being supplied with plenty of oxygen. The presence of oxygen in the rhizosphere stimulates growth while aeration ensures that the chances of pathogen formation are greatly reduced.
- This aeroponic systems can produce healthier and tastier foods. Irrespective of the many benefits of the aeroponic system, numerous logical constraints impede aeroponics from becoming a commercially viable solution.
- This IOT system facilitates the management of an aeroponic greenhouse through the registration of manual procedures, the automation of the irrigation system and the monitoring of environmental variables in cultivation; all this with the support of a visualization tool from an app.
- Allows the integration of smart sensors, in a technological solution based on IoT, that leads to the study of the favorable conditions for the growth of aeroponic crops with remote management.
- The app developed for this purpose allows the visualization of historical variables of temperature and relative humidity in the environment and crops, as well as the level and temperature of the nutrient solution tanks to carry out the adjustment of pH and EC.

5.8 APPLICATIONS

Aeroponics for Earth and space: The nutrient solution throughput of aeroponic systems is higher than in other systems developed to operate in low gravity. Aeroponics' elimination of substrates and the need for large nutrient stockpiles reduce the amount of waste material that needs to be processed by other life support systems. The removal of the need for a substrate also simplifies planting and harvesting (making automation easier), decreases the weight and volume of expendable materials, and eliminates a potential pathogen transmission pathway. These advantages demonstrate the potential of aeroponic production in microgravity and the efficient production of food in outer space.

CHAPTER 6

CONCLUSION

This system will be effective when implemented in aeroponics agriculture. Delivers nutrients directly to the plant roots. Completely programmable technology conserves energy. Closed-loop system conserves water. Conserves water through runoff absorption into roots. Can be combined with hydroponics. Crops are easier to harvest in the absence of soil. Higher density crops optimize output. Reduce labor cost through automation. Produces higher quality food in a controlled environment. Reduced risk of disease and pest infestation in a controlled environment. No need to immerse roots in water which offers more control. Roots are provided with better exposure to oxygen. Scalable systems can range from commercial level to apartment sized gardens. Produces more food with less effort. This can be developed in future for better results. There are many chances for developing systems in future which would be of great development in the field of aeroponics. Thus, this product is better development in present and with certain other development in future.

The main contribution of this report is the integration of smart sensors, in a technological solution based on IoT, that allows the study of the favorable conditions for the growth of aeroponic crops with remote management.

As future work, the proposed architecture for aeroponic crop production will be implemented, monitoring the growth chambers simultaneously, and considering the irrigation frequency and the time interval as study variables regarding the image processing-embedded algorithms on fog layer, for the study of colorimetry, infrared thermography and morphology in the evolution of the crop when considering the leaf and root will be added.

CHAPTER 7

REFERENCES

1 Hati, A.J.; Singh, R.R. Smart Indoor Farms: Leveraging Technological Advancements to Power a Sustainable Agricultural Revolution. AgriEngineering 2021, 3, 728–767.

2 Hassan, S.I.; Alam, M.M.; Illahi, U.; Al Ghamdi, M.A.; Almotiri, S.H.; Su'ud, M.M. A Systematic Review of Monitoring and Advanced Control Strategies in Smart Agriculture. IEEE Access 2021, 9, 32517–32548.

3 Maraveas, C.; Bartzanas, T. Application of Internet of Things (IoT) for Optimized Greenhouse Environments. AgriEngineering 2021, 3, 954–970.

4 Wimmerova, L.; Keken, Z.; Solcova, O.; Bartos, L.; Spacilova, M.A. Comparative LCA of Aeroponic, Hydroponic, and Soil Cultivations of Bioactive Substance Producing Plants. Sustainability 2022, 14, 2421.

5 Lakhiar, I.A.; Gao, J.; Syed, T.N.; Chandio, F.A.; Buttar, N.A. Modern plant cultivation technologies in agriculture under controlled environment: A review on aeroponics. J. Plant Interact. 2018, 13, 338–352.

6 Kamienski, C.; Soininen, J.P.; Taumberger, M.; Dantas, R.; Toscano, A.; Salmon Cinotti, T.; Filev Maia, R.; Torre Neto, A. Smart Water Management Platform: IoT-Based Precision Irrigation for Agriculture. Sensors 2019, 19, 276.

7 Kour, V.P.; Arora, S. Recent Developments of the Internet of Things in Agriculture: A Survey. IEEE Access 2020, 8, 129924–129957.

8 González-Amarillo, C.A.; Corrales-Muñoz, J.C.; Mendoza-Moreno, M.A.; González-Amarillo, A.M.; Hussein, A.F.; Arunkumar, N.; Ramírez-González, G. An IoT-Based Traceability System for Greenhouse Seedling Crops. IEEE Access 2018, 6, 67528–67535.

9 Fernández-Ahumada, L.M.; Ramírez-Faz, J.; Torres-Romero, M.; López-Luque, R. Proposal for the Design of Monitoring and Operating Irrigation Networks Based on IoT, Cloud Computing and Free Hardware Technologies. Sensors 2019, 19, 2318.

10 Mohammed, M.; Riad, K.; Alqahtani, N. Efficient IoT-Based Control for a Smart Subsurface Irrigation System to Enhance Irrigation Management of Date Palm. Sensors 2021, 21, 3942.

11 K.Boopathi Raja M.Srinivasaperumal,M.Jagadesh,T.Prabhu, "Detection and Analysis of Spoofing Attackers in Wireless Sensor Networks", Middle-East Journal of Scientific Research,

12 M.Udhayamoorthi M.Saravanan,T.Prabhu,A.Santhosh Kumar,M.Jagadesh, "Analysis and Implementation of Mean, Maximum and Adaptive Median for Removing Gaussian Noise and Salt & Pepper Noise in Images" European Journal of Applied Sciences,Vol:09,

13 S.M. Swamynathan M.Udhayamoorthi,M.Saravanan,M.Jagadesh,K.S.Mohan," Enhancing QoS in

Wireless Mobile Adhoc Networks with Energy Aware Reliable Routing Algorithm", European Journal of Applied Sciences,Vol.9,Pages:234-238.

14 M Srinivasaperumal, M Jagadesh, T Prabhu, K Boopathi Raja," Detection and Analysis of Spoofing Attackers in Wireless Sensor Networks",Middle east journal of scientific research, Page no:63-67,2016.