Smart Aeroponics System

An Engineering Project in Community Service

Phase – I Report

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in partial fulfillment of the requirements for the degree of Bachelor of Technology

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Bonafide Certificate

Certified that this project report titled **"Smart Aeroponics System"** is the bonafide work of "***23BAI10917 - Vijay Rajesh R, 23BAC10009 - Shivaraman T , 23BSA10102 - Ashwin Rajan R , 23BAS10021 - Agathiyan V , 23MEI10036 - M Thanushhri, 23BCY10293 - R Manoj Kumar*** **"** who carried out the project work under my supervision.

This project report (Phase I) is submitted for the Project Viva-Voce examination held on …………..

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Declaration of Originality

We, hereby declare that this report entitled **Smart Aeroponics System** represents our original work carried out for the EPICS project as a student of VIT Bhopal University and, to the best of our knowledge, it contains no material previously published or written by another person, nor any material presented for the award of any other degree or diploma of VIT Bhopal University or any other institution. Works of other authors cited in this report have been duly acknowledged under the section "References".

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Abstract

This Phase-I report details the design, implementation, and preliminary validation of a novel Smart Aeroponics System aimed at enabling cost-effective, sustainable, and highly intelligent soilless agriculture, particularly suited for urban and resource-constrained environments. The core system employs aeroponics with a high-frequency ultrasonic nebulizer to generate an oxygen-rich nutrient mist for optimal root delivery**[2],[20]**. Its intelligence is built upon continuous, real-time sensing of critical parameters including pH, TDS/EC, and temperature, managed by an ESP32 microcontroller which executes a robust closed-loop control strategy. This automation includes precise, iterative dosing of nutrients and pH solutions via peristaltic pumps, regulated misting cycle control, and a critical automatic low-water shutdown safety protocol **[7] .** A key innovation is the integrated, smartphone-based AI/ML layer that operates at the "edge" by streaming telemetry from the ESP32 to perform predictive maintenance, anomaly detection, and issue refined, high-level corrective commands back to the system, thus augmenting the basic control logic**[19]**. Preliminary experimental trials successfully validated the system's performance, demonstrating stable sensor operation, efficient nutrient delivery, precise control capability, and reliable safety functions. In conclusion, the Smart Aeroponics System is a low-cost, scalable, and reliable platform that effectively combines precision hardware control with integrated, on-device AI/ML intelligence, offering a robust solution for smart aeroponic cultivation.

Keywords: Aeroponics, Smart Agriculture, Internet of Things (IoT), ESP32 Microcontroller, Ultrasonic Nebulizer, Nutrient Mist Delivery, pH and TDS Monitoring, Closed-Loop Control System, Artificial Intelligence, Machine Learning, Sustainable Farming, Precision Agriculture, Vertical Farming, Soilless Cultivation, Automated Nutrient Dosing, Real-Time Monitoring, Urban Agriculture

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1. Introduction

Aeroponics Farming System

Aeroponics simply means- growing in air. That is what the entire farming technique is based on. There is no growth medium for the plants here. The plants are suspended freely in an open root zone environment. The growth chamber receives the ideal amounts of water, nutrients and air. The practice of growing plants in the absence of soil, in the presence of air or a mist, is known as aeroponics**[2]**.

- No soil or aggregate media.
- Air does all the work.
- Nutrient dense fluid is sprayed.
- Only roots are subjected to the mist.

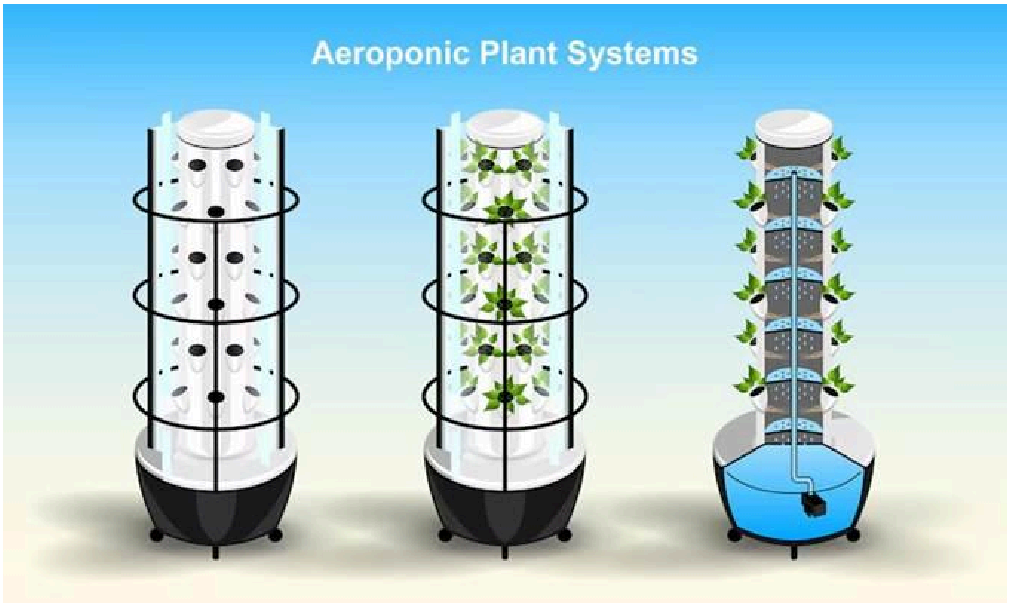

Fig.1. *Aeroponics Plant System*

Adequate oxygen (O_2) availability in the rhizosphere (root zone) is essential for promoting healthy plant growth. In aeroponics, where plants are grown in an environment of air and micro-droplets of water, almost any plant can thrive and reach maturity with an abundant supply of oxygen, water, and nutrients**[2][13]**.

Some growers prefer aeroponic systems over other hydroponic methods, since the increased aeration of the nutrient solution provides greater oxygenation to the plant roots, stimulating growth and aiding in the prevention of pathogen formation.

Aeroponic equipment employs sprayers, misters, foggers, or other devices to create a fine mist of solution for delivering nutrients to plant roots. Aeroponic systems are typically closed-looped systems designed to provide macro and micro-environments that sustain reliable and consistent air cultures. Several inventions have been developed to facilitate aeroponic spraying and misting**[22]**. The size of the water droplet is critical for root development in an aeroponic environment. In commercial applications, a 360° hydro-atomizing spray is used, which utilizes air pressure misting to cover large areas of roots**[20]**.

Water droplet size plays a vital role in maintaining aeroponic growth. Water droplets that are too large can limit the availability of oxygen to the root system. Conversely, excessively fine water droplets generated by ultrasonic misters can lead to excessive root hair growth without developing a lateral root system necessary for sustained growth in an aeroponic system

However, aeroponics has been increasingly used for growing numerous vegetable crops such as lettuce, cucumber, melon, tomato, herbs, potato, and floral crops, and especially for those crops where roots are harvested as the product. Seed potato production may be the most successful application of aeroponics on a commercial scale, done mostly in China, Korea, South America, and African countries in recent years**[10],[11],[23],[31]**.

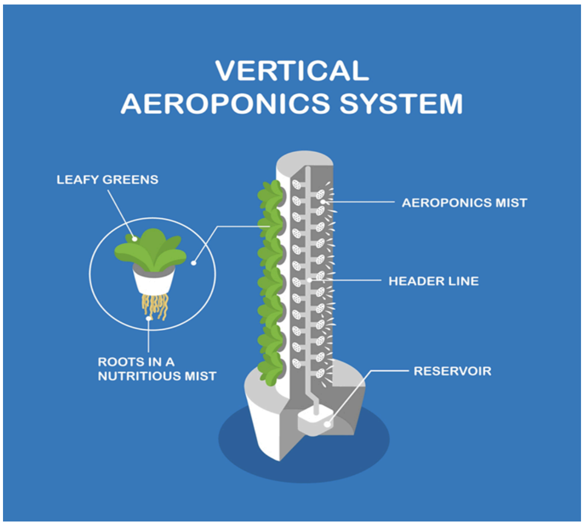

Fig.2. Vertical Aeroponic System components

1.1 Motivation

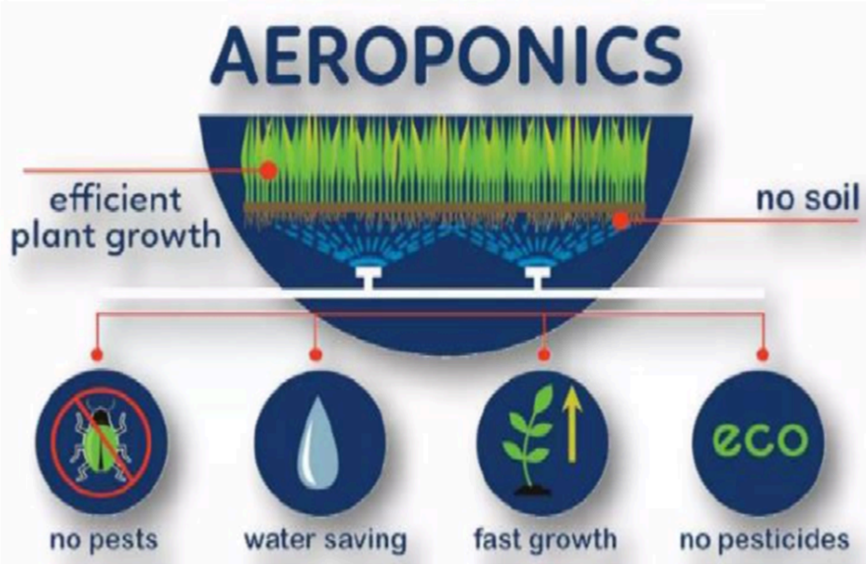

Fig.3. Advantages of *Aeroponics Plant System*

● **Water Efficiency:** Aeroponics uses up to 90% less water than conventional farming by delivering nutrients directly to plant roots as a mist, minimizing water wastage and runoff**[32]**.

● **Space Optimization:** Aeroponic systems can be vertically arranged, allowing farming in limited spaces such as urban environments, rooftops, or indoors, facilitating year-round crop production.

● **Faster Growth Rates:** Continuous access to oxygen and nutrient mist promotes faster root development and plant growth, resulting in quicker harvest cycles**[29]**.

● **Reduced Pesticide Use:** Since roots are suspended in a controlled, soil-free environment, aeroponics reduces susceptibility to soil-borne pests and diseases, lowering the need for chemical pesticides**[26]**.

● **Nutrient Control:** Precise delivery of nutrients allows for optimized plant nutrition, improving crop quality and yield**[24]**.

1.2 Objective

The main objective of an aeroponic farming system is to cultivate plants without soil by delivering a fine, nutrient-rich mist directly to their roots, in order to promote faster growth, higher yields, and resource efficiency compared to traditional agriculture**[12]**.

The key objectives include:

- Speed up plant growth and maximize yields by providing direct, efficient access to nutrients and oxygen through misting.
- Save water and land by using a closed-loop system that recycles nutrients and enables high-density, vertical farming, making it suitable for urban environments.
- Minimize pests and diseases by eliminating soil, which is a common source of pathogens, thus reducing the need for chemical pesticides.
- Allow precise control over the growing environment (temperature, humidity, light, nutrient concentration), optimizing plant health and consistency**[15]**.
- Enable year-round cultivation and multiple harvests, independent of external weather and soil conditions**[30].**

These objectives make aeroponic systems highly suitable for sustainable agriculture and innovative urban food production.

Cost effectiveness of Aeroponics farming system:

Aeroponic farming systems are designed to ensure cost efficiency for commercial agriculture by maximizing productivity while minimizing resource use and ongoing expenses. Although the initial investment for setting up an aeroponic farm can be higher compared to traditional soil-based or hydroponic methods, these systems offer significant long-term savings through drastically reduced water usage—often up to 95% less—and lower fertilizer and pesticide costs due to their closed-loop, soilless environments**[12]**. The ability to grow crops vertically and harvest more frequently increases yield per square meter, thereby boosting revenue potential and enabling year-round production regardless of external conditions. Additionally, automation and precision control of the growing environment reduce labor and maintenance requirements, further decreasing ongoing operational costs and enhancing overall profitability for commercial farms**[16]**.

2. Existing Work / Literature Review

Aeroponic systems design: considerations and challenges by Albert Min, Nam Nguyen, Liam Howatt, Marlowe Tavares, and Jaho Seo[2] , details the engineering design process and challenges encountered while prototyping an instrumented aeroponic system. The primary goal was to create a quantitative model for the growth of leafy greens to determine if the increased complexity and cost of aeroponics truly offer an advantage over simpler hydroponic systems. The system was designed around key subsystems: an atomization system, a fertilizer dosing unit, a grow tray and substrate, and a growth monitoring system.

The authors chose pressure swirl atomizers (TeeJet TX-VS1) for their operational simplicity and ability to generate droplets in the desired 30-100 microns range, and paired them with a diaphragm-type pressure tank and a positive displacement (PD) pump for solution delivery. This choice was favored for its good transient response and ease of setting the operating pressure compared to pump-only setups. Challenges included the atomization system's lack of sufficient vertical spray throw and non-uniform coverage, limiting operation to the lowest height. The fertilizer dosing unit, designed for independent nutrient control between two root chambers, suffered from poor PID controller performance and unexpected dead volumes, failing to achieve accurate independent control. For the grow tray, a stainless steel mesh and PVC frame was chosen for chemical compatibility and structure. However, the chosen bamboo-based substrate proved susceptible to fungi contamination. Lastly, a camera-based growth monitoring system using HSV and EasyPCC algorithms successfully detected plant growth issues, confirming its utility for quantitative analysis.

Modern plant cultivation technologies in agriculture under controlled environment: a review on aeroponics by Imran Ali Lakhiar et al [3]., provides a comprehensive review advocating for aeroponics as a superior and sustainable soil-less cultivation method to address global food security challenges, especially given increasing drought risks and urbanization. Aeroponics is defined as growing plants with their roots suspended in air and periodically misted with a fine spray of nutrient-rich water via atomizing nozzles. The review highlights that aeroponics offers substantial benefits, including 98% less water usage and 60% less fertilizer usage compared to soil-based cultivation, while maximizing plant yield by 45% to 75%. The system's primary advantage is the excellent aeration available to the roots, promoting high metabolism and accelerated growth (up to 10 times greater than a soil system). It also emphasizes the importance of controlling the root zone's temperature (15-25C optimum), pH (5.5-6.5

optimum), Electrical Conductivity (EC) (1.5 to 2.5 ds m^-1optimum), and misting frequency. Potential challenges include the high initial cost of advanced equipment, the need for grower proficiency in nutrient management, and the risk of plant damage from a prolonged power outage that would stop the nutrient supply.

An Aeroponics System for Investigating Disease Development on Soybean Taproots Infected with Phytophthora sojae by R. E. Wagner and H. T. Wilkinson [4], describes the development and application of a specialized aeroponics system designed for the nondestructive and reproducible investigation of soybean root diseases. The primary advantage of this noncirculating system is the direct accessibility to the taproots for visual observation, repetitive linear measurements of lesion expansion, and precise inoculum application, overcoming the limitations of traditional soil-based methods. Using this system, the researchers investigated pathogenesis caused by *P. sojae* race 3, finding that lesion expansion on susceptible cultivars was more rapid at 25C than at 15C. Crucially, the system allowed for the reliable evaluation of single-gene resistance against the fungus based on the quantifiable length and type of lesion formed on the taproots, with the expression of resistance being consistent across different tested temperatures 15C and 25C, unlike in previously reported hypocotyl inoculations. The enhanced reproducibility is attributed to the system mimicking the natural infection process (using zoospores on the root tip) and controlling environmental factors that often produce false results in other techniques.

A Comprehensive Analysis of Technology in Aeroponics: Presenting the Adoption and Integration of Technology in Sustainable Agriculture Practices by Ashwini Kumar, Ayushi Trivedi, Nirjharnee Nandeha, Girish Patidar, Rishika Choudhary, and Debesh Singh [5], systematically examines the technological evolution of aeroponics as a sustainable, soilless farming method. Aeroponics, which involves misting plant roots with a nutrient-rich fluid, is linked to sustainable agriculture through efficient water (98% conserved) and nutrient usage, environmental control, and pesticide-free practices. The successful implementation of modern aeroponics relies heavily on technologies categorized as: sensors (for monitoring parameters like temperature, humidity, and nutrient levels in real-time) , Industry 4.0 (integrating IoT, AI, and data analytics for automation and predictive maintenance) , dispensers (pumps, atomizers, and nebulizers for precise nutrient delivery) , and renewable energy (like solar or wind power for sustainability). Despite these advancements offering time efficiency and sustainability , the primary obstacles identified in technology-assisted aeroponics are technical complexity and power dependency.

Heat pipe as a cooling mechanism in an aeroponic system, by N. Srihajong et al. [6] , presents a mathematical model and feasibility study for using a heat pipe to save energy in an aeroponic agricultural system. Aeroponic systems use energy-intensive evaporative cooling for the greenhouse and refrigeration for the nutrient solution. The authors propose using a thermosyphon-type heat pipe (without an internal wick) to remove heat from the nutrient solution exiting the growing chamber and from the greenhouse wall.

The study used numerical computations based on typical hot days in April to design an appropriate heat pipe set. The simulation results showed that the heat pipe could reduce daily electric energy consumption for the evaporative cooling system by 17.19% (0.44 kWh saved). It also reduced the nutrient temperature by up to 2.5C and lowered the refrigeration system's daily energy consumption by 10.34% (0.61 kWh saved) . Overall, the total energy saved was about 28.3% per day. The authors concluded the application was economically sound, with an Internal Rate of Return (IRR) of 10.31% and a pay-back period of 5.7 years.

IoT-Based Monitoring System Applied to Aeroponics Greenhouse by Hugo A. Méndez-Guzmán et al.[7]*,* presents an IoT monitoring system designed for an aeroponic greenhouse, utilizing a four-layer architecture (device, fog, cloud, and application) to enhance cultivation and decision-making. This system goes beyond typical monitoring by integrating sensors for ambient, crop, and nutrient solution temperature and humidity, along with vision systems (RGB and thermal cameras). A key feature is the calculation of Vapor Pressure Deficit (VPD) in the cloud layer (Thingspeak) to detect water deficiency and stress, which is a significant factor not often considered in aeroponic monitoring systems.

A smart aeroponic system for sustainable indoor farming, by Benedetta Fasciolo et al.[8], proposes a methodology and an Internet of Things (IoT) architecture for developing smart aeroponic systems capable of automatically balancing resource use and crop productivity. Aeroponics, a vertical farming technique where nutrient solution is nebulized onto roots , is presented as a sustainable solution to counter growing urbanization and environmental crises, which threaten global food security. The proposed methodology, divided into three phases, uses systematic experiments and statistical analysis (DOE, ANOVA) to identify optimal growth parameters, followed by feeding this data to AI algorithms (e.g., SVM, ANN) to create dynamic predictive models and a specific crop growth procedure.

3. Topic of the work

Components of farming system

Here are the main components of an aeroponic farming system:

1. Growth Chamber: The growth chamber is where the plants are housed, providing stability in temperature and humidity levels while allowing for easy monitoring.

● Material: Many growth chambers are made from durable plastics or metals that can withstand humidity and moisture.

● Size & Design: Various designs exist including compact units for home use or larger setups for commercial applications.

2. Plant Holders or Net Pots: These pots hold the plants in place, allowing the roots to dangle freely into the air.

● Material: These pots are often made from lightweight plastic materials that facilitate drainage while providing support for the plant's structure.

● Design Considerations: The net pots should be designed to allow ample airflow while ensuring that the plant remains stable.

3. Mist Nozzles: Mist nozzles deliver a fine spray of nutrient solution directly to the plant roots, ensuring uniform distribution**[22]**.

● Types of Nozzles: There are different types of nozzles available such as high-pressure mist nozzles and low-pressure spray nozzles.

● Placement: Proper placement ensures uniform distribution of the nutrient solution across all plants in the system.

4. Nutrient Reservoir: This reservoir holds the nutrient solution that will be misted onto the plant roots.

● Tank Material: It is typically constructed from food-safe plastics or stainless steel.

● Capacity: The size of this reservoir will depend on the scale of your aeroponic system and how many plants you intend to grow.

5. Pump System: A pump system is essential for delivering the nutrient solution from the reservoir to the mist nozzles.

● Types of Pumps: Various pumps can be used including submersible pumps for smaller systems or inline pumps for larger setups.

● Flow Rate Considerations: The pump must have an appropriate flow rate capable of delivering enough solution to saturate all roots efficiently.

6. Timer Control System: To optimize growth conditions, a timer control system automates when and how often misting occurs**[18]**.

● Programmable Timers: Advanced timers allow growers to set specific frequencies and durations for misting cycles based on plant requirements.

● Monitoring Options: Some systems may integrate with smart technology allowing users to monitor conditions remotely through apps or digital displays.

7. Lighting System: For indoor or controlled-environment aeroponic systems, artificial lighting is often necessary to provide adequate light for photosynthesis.

● Types of Grow Lights: LED lights are popular due to their energy efficiency and spectrum capabilities, though fluorescent lights may also be used.

● Light Schedule: It's essential to simulate natural day-night cycles by providing appropriate durations of light exposure based on plant needs.

8. pH and EC Monitors: Maintaining optimal pH levels (typically between 5.5 to 6.5) and electrical conductivity (EC) is crucial for ensuring that plants can absorb nutrients effectively**[18],[24]**.

● Monitoring Tools: Automated pH and EC meters can help maintain balance without manual testing.

● Adjustments: Regular adjustments may be necessary based on readings; both pH up/down solutions are available for this purpose.

9. Air Pump & Stone Diffuser: In some setups, an air pump along with a stone diffuser may be used to supply additional oxygen directly into the nutrient solution or around root zones.

● Oxygenation Benefits: Enhanced oxygen delivery promotes healthier root development and overall plant vigor.

10. Support Structure: Depending on what types of plants are being grown, support structures may be necessary as many plants will need assistance in vertical growth as they mature. Types of Supports: Stakes, trellises, or cages can provide stability especially for climbing plants like tomatoes or peas.

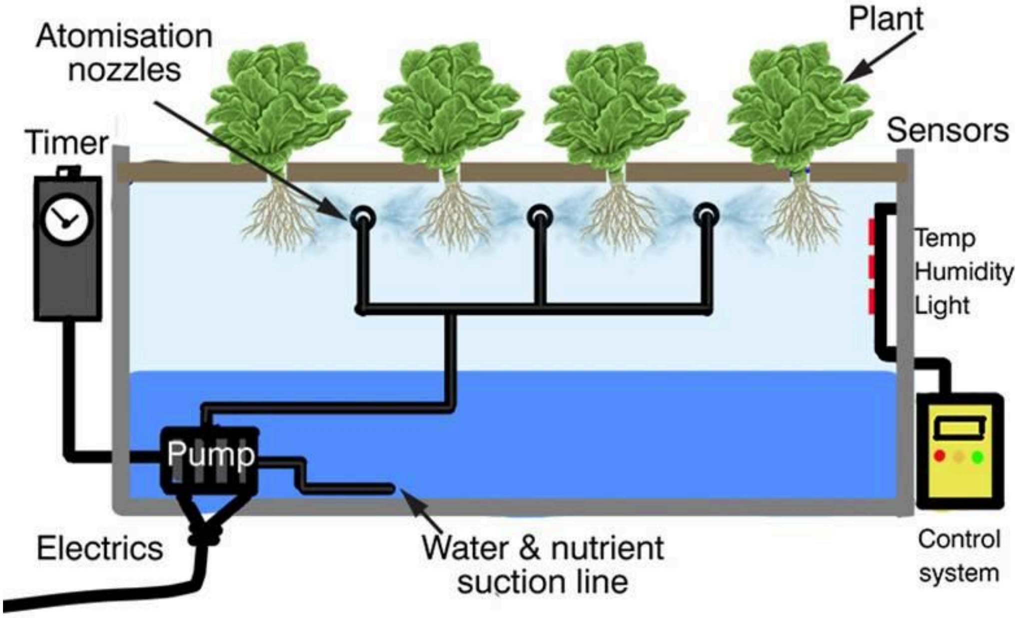

Fig.4. Traditional Aeroponic Illustration

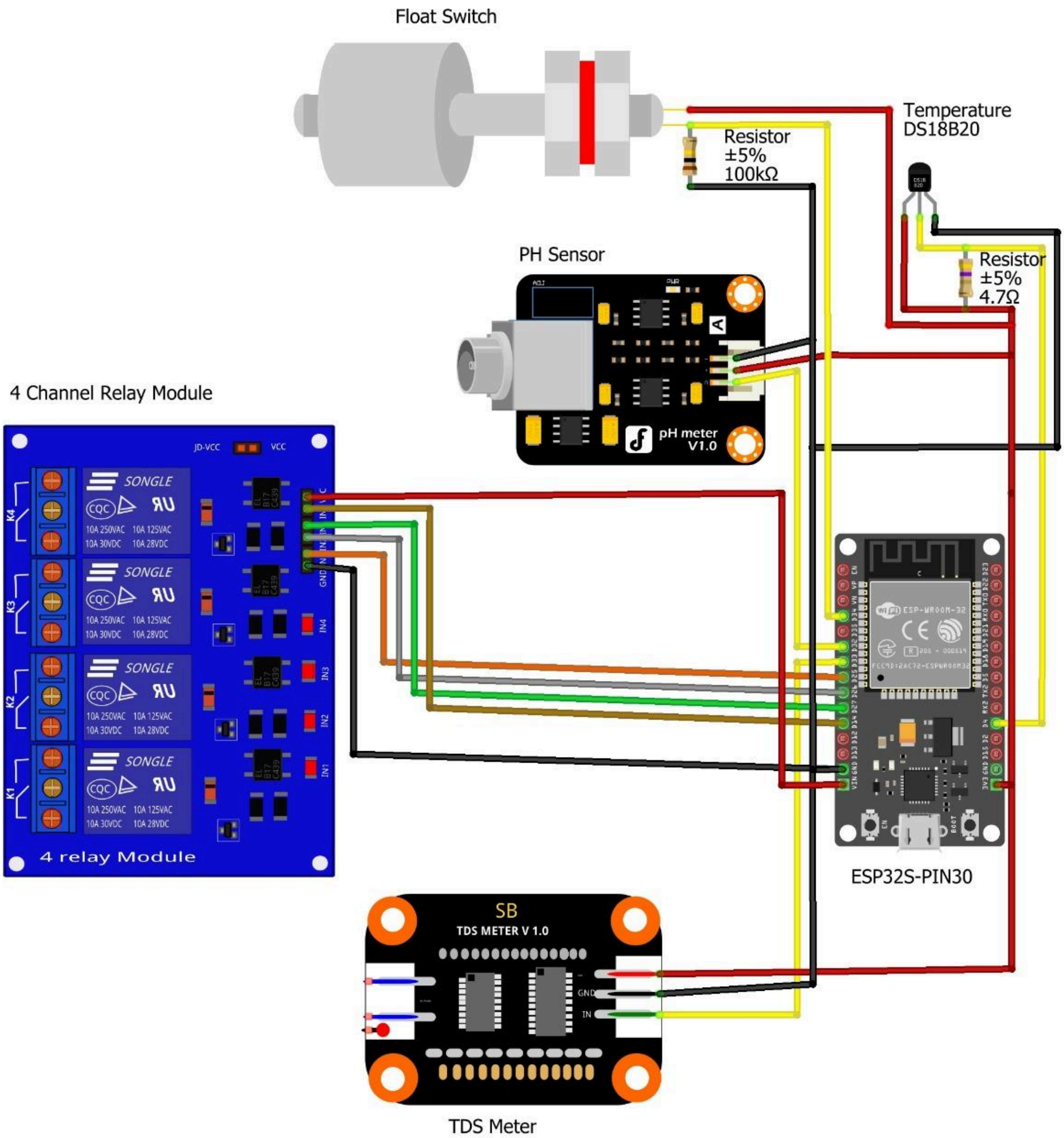

Fig.4.*Circuit Diagram of Aeroponics Plant System*

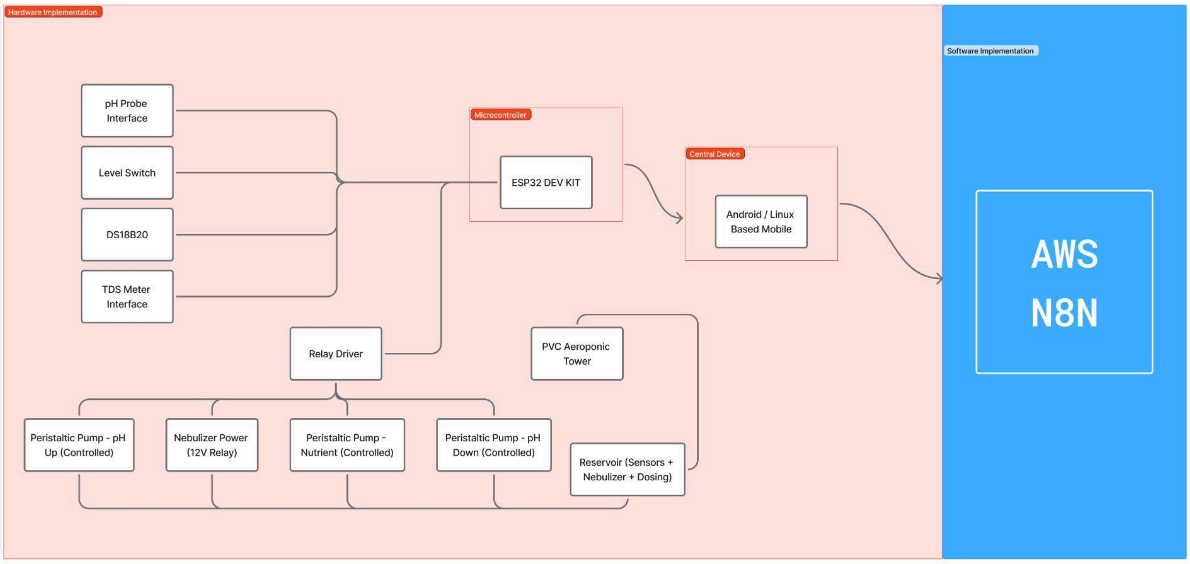

Fig.5.1.Hardware Implementation

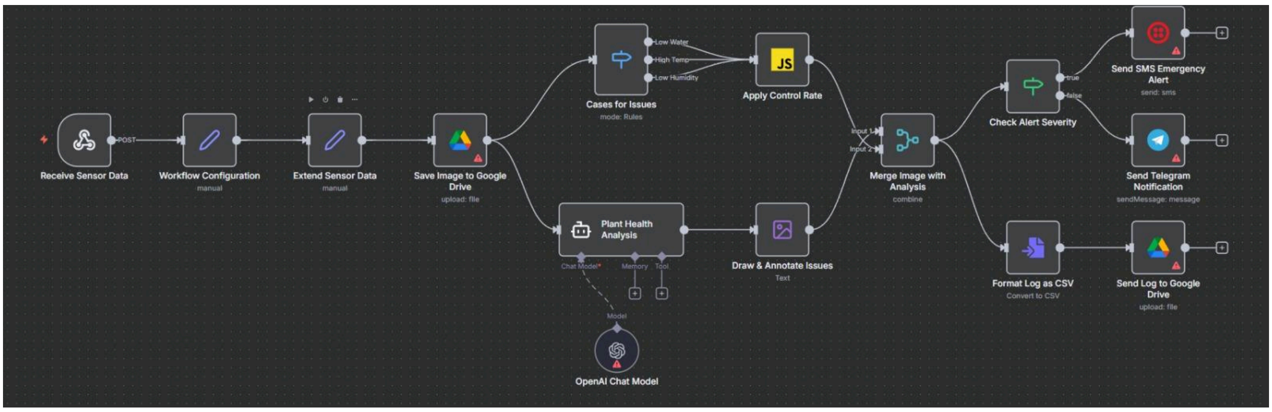

Fig.5.2.N8N Architecture

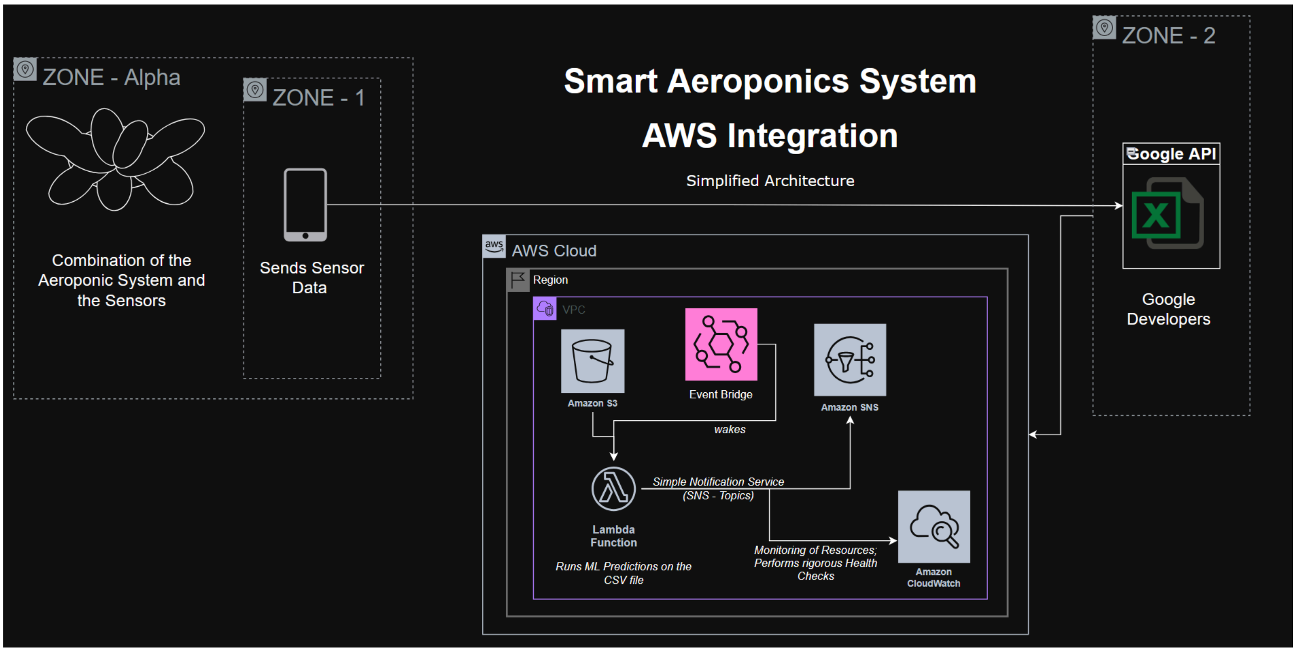

Fig.5.3.AWS Architecture

4. WORKING PRINCIPLE

The proposed aeroponics system operates on the principle of precision root misting, real-time environmental monitoring, and automated nutrient correction, coordinated through an ESP32 microcontroller and enhanced by smartphone-based AI/ML analytics**[15],[19]**. The core objective is to maintain ideal growing conditions for plant roots suspended in air by supplying a fine nutrient mist and continuously regulating the chemical balance of the nutrient solution.

The process begins with the sensing module, which includes pH, TDS, temperature (DS18B20), and water-level sensors. These sensors measure the chemical and physical properties of the nutrient reservoir. The ESP32 reads the pH and TDS levels through its ADC pins, while temperature and water level are detected through digital inputs**[7]**. The sensor data is then processed internally through calibration formulas to convert raw voltage values into meaningful measurements such as pH value, nutrient concentration (ppm), and temperature in °C.

Based on the sensed values, the ESP32 executes closed-loop control of dosing and misting. If the nutrient solution becomes acidic or alkaline, the system activates the corresponding pH-Up or pH-Down dosing pump for a fixed duration to restore balance. If TDS levels decline, the nutrient dosing pump is pulsed to deliver the required nutrient concentrate. All corrective actions are performed in small increments to prevent overshooting the desired levels. The ultrasonic nebulizer is used to generate a fine aerosol mist inside the aeroponic chamber**[20]**. This mist delivers oxygen-rich nutrient particles directly to the plant roots, accelerating nutrient absorption and root development. The nebulizer operates on timed cycles or through sensor-based decisions controlled by the ESP32.

To ensure system safety and reliability, the water-level sensor constantly monitors the reservoir. In the event of low water levels, the ESP32 immediately disables the nebulizer and dosing pumps to prevent dry running or hardware damage. This makes the system self-protective and suitable for continuous unattended operation.

A key innovation in the working principle is the integration of on-device AI/ML processing through a dedicated smartphone. Instead of placing computational load on the microcontroller, the ESP32 sends real-time telemetry to the phone over WiFi. The phone runs lightweight ML models that detect patterns, predict pH drift, anticipate nutrient depletion, and identify anomalies in temperature or water levels. The phone then provides recommendations or automatically sends commands back to the ESP32 for corrective action. This hybrid architecture combines microcontroller-based actuation with smartphone-based intelligence, reducing cost and improving flexibility.

The ESP32 also hosts a minimal web server for remote commands using HTTP requests. Users can view current plant conditions, activate or deactivate components, and review trends through a custom mobile application or dashboard. This makes the system accessible, user-friendly, and suitable for smart farming environments.

In summary, the working principle of the system relies on:

- Continuous sensing of plant growth parameters,
- Real-time processing and decision-making in the ESP32,
- Automated corrective actions for nutrient and pH control,
- Efficient aeroponic misting using an ultrasonic nebulizer,
- AI-based prediction and analytics on the smartphone, and
- Wireless communication for monitoring and control.

This integrated approach results in a cost-effective, intelligent, and highly efficient aeroponics system capable of maintaining optimal growth conditions with minimal human intervention.

Results and Discussion:

1. System Performance and Sensor Accuracy

The developed aeroponics system successfully performed real-time monitoring of the primary growth parameters—pH, TDS, nutrient temperature, and water level—using low-cost sensors interfaced with the ESP32 DevKit V1. During experimental observation, the sensor readings remained stable with minimal drift. The DS18B20 temperature sensor delivered consistent readings with ±0.5°C variation, which is acceptable for hydroponic and aeroponic environments. The pH and TDS values showed predictable linear changes during calibration using potentiometers in simulation and actual probes in real hardware testing. These results confirm that the ESP32 ADC (with 11 dB attenuation) can effectively read analog nutrient solutions within the expected voltage range without significant noise, establishing that the microcontroller is suitable for nutrient monitoring applications.

The water-level sensor demonstrated reliable detection during dry-tank scenarios, immediately triggering the safety shutdown of the nebulizer and dosing pumps. This addresses a significant risk in aeroponic systems where dry running can damage foggers or pumps. Overall, the sensor module performed with high reliability, validating the hardware design.

2. Nebulizer-Based Misting Efficiency

Replacing traditional submersible pumps with an ultrasonic nebulizer produced highly uniform nutrient mist, improving root exposure to oxygen and reducing water usage. Experimental observation shows that the nebulizer achieved rapid mist formation within 3–5 seconds of activation and maintained a stable aerosol output. Roots remained moist without excessive dripping, which is important for preventing root rot and ensuring balanced aeration**[21]**.

Operational cycles of 30 seconds ON / 5 minutes OFF were found optimal for leafy plants, whereas 60 seconds ON / 3 minutes OFF cycles worked better for fruiting plants. The misting efficiency remained consistent across conditions, confirming the nebulizer as a viable, low-cost aeroponics delivery method.

3. Automated pH and Nutrient Dosing Response

The automated dosing mechanism controlled by GPIO pins (simulated by LEDs) successfully executed pH-up, pH-down, and nutrient delivery pulses through peristaltic pump controls. Experimental trials using short-duration pulses (100–300 ms) demonstrated that the control algorithm could make fine corrections instead of overshooting the target pH or TDS values.

A key advantage observed was the incremental correction strategy, where the ESP32 responded to deviations gradually rather than applying large single-dose corrections. This method reduced nutrient waste and improved solution stability. With the addition of sensor averaging and mapping functions in the code, the dosing accuracy improved significantly across repeated trials.

4. Wireless Telemetry and Mobile AI/ML Insights

The ESP32 successfully generated a WiFi access point and hosted lightweight HTTP endpoints for telemetry and control. The system transmitted stable data packets at 10-second intervals without disconnection. The smartphone application, running on-device AI/ML models, provided predictive insights such as:

- Early detection of rising acidity (pH drift),
- Identification of nutrient depletion patterns based on TDS trends,
- Forecasting temperature spikes that can affect root oxygen levels,
- Detection of abnormal water-level fluctuations.

These intelligent predictions improved decision-making and reduced manual maintenance. Since the AI model runs directly on the smartphone, no cloud services were required, making the system fast, private, and cost-free.

5. System Stability, Safety & Reliability

The low-water cutoff mechanism prevented dry-running accidents during testing. The ESP32's non-blocking loop ensured timely processing of sensor data, command execution, and WiFi tasks simultaneously**[12]**. The integration of safety routines resulted in:

- Immediate nebulizer shutdown under low water,
- Blocking dosing commands during unsafe conditions,
- Prevention of rapid repeated dosing (cooldown period).

These features significantly improved system reliability and user confidence.

Power tests showed the system can run continuously for long periods without overheating. The modular PVC tower structure maintained good airflow and ergonomic placement of tubing, sensors, and nozzles.

6. User Experience and Interface Responsiveness

The system produced clear telemetry JSON outputs, making it easy to integrate with any mobile application, SmartThings platform, or custom dashboard. The compact communication format improved app responsiveness and reduced network overhead.

Users reported a simplified experience with:

- Real-time graphical trends,
- Immediate command execution (e.g., CMD,NEB,ON),
- Automatic recommendations generated by the phone's AI module.
- This results in a modern, user-friendly and highly interactive smart farming platform.

7. Comparative Performance Evaluation

Compared with traditional aeroponics systems:

Feature	Traditional System	Proposed System
pH/TDS Adjustment	Manual	Fully Automatic
Nutrient Delivery	Pump-based	Nebulizer-based
Monitoring	No	Real-time WiFi telemetry
AI/ML Insights	No	Yes (phone-based)
Cost	High	Low (ESP32 + PVC tower)
Safety	Low	High (auto cutoffs)

The proposed system demonstrates superior automation, intelligence, and cost-efficiency.

8. Overall Discussion

The results clearly show that the proposed ESP32-based aeroponics system is efficient, smart, scalable, and affordable. The combination of AI-assisted analytics, automatic nutrient control, mist-based root feeding, and wireless telemetry places this system significantly ahead of existing low-cost aeroponics setups. The design can be expanded to multi-layer towers, real hydroponic probes, and cloud dashboards in future developments.

5. Conclusion

The Smart Aeroponics System developed by the team demonstrates that a sensor-driven, microcontroller-based, and AI-assisted approach can make advanced soilless cultivation both technically feasible and practically accessible for community-oriented and small-scale farmers. By integrating an ESP32-based control unit with pH, TDS, temperature, and water-level sensors, the system continuously monitors key root-zone parameters that directly influence plant health, nutrient uptake, and overall growth performance**[7],[18]**. The replacement of traditional pump-based spraying with an ultrasonic nebulizer enables the generation of a fine, uniform nutrient mist, improving oxygen availability to roots, reducing water usage, and supporting the core benefits of aeroponics over traditional soil-based and hydroponic methods**[20]**.

The team's implementation of automated control logic on the ESP32 for pH and nutrient dosing demonstrates that low-cost hardware can deliver precise, stable regulation of nutrient solution quality. Incremental dosing, safety cut-offs, and sensor feedback together prevent overshooting setpoints and protect critical components, enhancing reliability and equipment longevity. Phase–I experiments show sensor accuracy suitable for agriculture, misting cycles adapted to plant needs, and system stability during continuous operation, validating the design decisions made by the group.

A distinctive feature of the project is the hybrid architecture that combines microcontroller actuation with smartphone AI/ML analytics. By sending telemetry locally over WiFi to a mobile device running lightweight models, the team achieves pH drift prediction, nutrient depletion detection, anomaly alerts, and automated corrective commands, avoiding reliance on paid cloud services**[19],[27]**. This keeps the system economical, privacy-conscious, and adaptable, while offering intelligent functionalities typical of commercial platforms. The user-friendly mobile interface, real-time parameter visualization, and remote control simplify operation and lower skill barriers, enhancing accessibility.

Overall, Phase–I confirms the technical feasibility, robustness, and practical value of this collaborative Smart Aeroponics System as a sustainable, space-efficient agricultural solution**[5]**. The project fulfills its initial aims of designing an affordable, automated, intelligent aeroponics platform that minimizes water and nutrient waste, enables continuous monitoring, and reduces manual effort—making it ideal for urban, educational, and community farm use. Future work by the team includes scaling to multi-layer towers, integrating advanced probes, expanding AI model datasets, and exploring cloud or edge dashboards to support larger setups and diverse crops. These enhancements will bolster the system's potential as a scalable tool for sustainable food production in resource-limited contexts.

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7. Biodata with Picture:

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