

AQUA GROW SMART INDOOR FARMING SYSTEM

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ABSTRACT

Growing fresh vegetables in cities is becoming harder because of limited land, irregular weather, rising water costs, and long supply chains that reduce freshness. Indoor farming using hydroponics allows plants to be grown without soil in a controlled environment, but it requires careful and continuous management of nutrient solution, water level, light, temperature, and humidity. This paper presents Aqua Grow, a Smart Indoor Farming System that uses Internet of Things technology to automate and monitor these conditions so that home users, schools, and small growers can maintain healthy crops with little manual effort.

The proposed system is based on an ESP32 microcontroller connected to sensors for nutrient solution pH, electrical conductivity, water temperature, water level, air temperature, humidity, and light intensity. Actuators include a submersible pump for circulating nutrient solution, peristaltic dosing pumps for pH and nutrient adjustment, full-spectrum LED grow lights, an exhaust fan, and a mist humidifier. The controller reads sensors at regular intervals and adjusts actuators according to target ranges that depend on the crop and its growth stage. All electronics run from a single low-voltage supply, and the mains-powered loads are isolated through relay modules for safety.

Aqua Grow uses closed-loop control to keep each parameter within its target range. When the pH of the nutrient solution drifts, small doses of pH-up or pH-down solution are added and the reading is checked again after mixing. When conductivity falls as plants absorb nutrients, concentrated nutrient solution is added in measured quantities. Lights follow a programmed photoperiod and their intensity is supplemented according to ambient light, while the fan and humidifier maintain suitable air conditions. A small camera captures images of the plants periodically for visual growth tracking.

All sensor data and actuator events are sent to a cloud platform using MQTT over Wi-Fi. A mobile application and web dashboard show live conditions, historical graphs, and plant images, and allow the user to select crop profiles, change targets, or switch devices manually. Notifications are sent when the reservoir level is low, when dosing solutions need refilling, or when any parameter stays outside its range. This gives the user remote visibility and control of the farm from anywhere.

A prototype with lettuce, spinach, and basil grown in a nutrient film setup showed stable pH and conductivity over several weeks with far less manual checking than a manually managed setup, and water use was significantly lower than soil-based cultivation. Aqua Grow shows that affordable IoT hardware can make indoor

hydroponic farming practical for urban households and small enterprises. Future work includes image-based detection of nutrient deficiency and disease, energy optimisation using solar power, and support for multiple racks managed from one application.

I. INTRODUCTION

Urban populations are increasing, and with them the demand for fresh, pesticide-free vegetables. Most leafy greens and herbs consumed in cities travel long distances from farms, losing freshness and nutritional value on the way. At the same time, agricultural land near cities is shrinking and water scarcity is becoming a serious concern in many regions. These factors have created interest in growing food closer to where it is consumed, including inside homes, apartments, rooftops, and small commercial spaces.

Hydroponics is a method of growing plants in a nutrient-rich water solution without soil. It uses much less water than conventional farming because the solution is recirculated, and it allows plants to grow faster when nutrients, light, and climate are kept at suitable levels. However, hydroponic systems are sensitive. If pH moves outside the preferred range, plants cannot absorb nutrients properly. If the pump stops or the water level falls, roots can dry out within hours. Beginners often lose crops because they cannot monitor these conditions frequently enough.

The Internet of Things provides a way to take over this constant monitoring and adjustment. Sensors can measure the key parameters continuously, a microcontroller can respond immediately when conditions change, and a cloud-connected application can keep the grower informed. Automation reduces the knowledge and time required to run a hydroponic system, which makes indoor farming more accessible to people without an agricultural background. It also allows a grower to check the farm from a phone while travelling, instead of relying on a neighbour to look after the plants.

This paper describes Aqua Grow, a Smart Indoor Farming System that combines hydroponic cultivation with IoT sensing, automated dosing, lighting and climate control, and cloud-based monitoring. The system maintains nutrient solution quality and growing conditions automatically according to crop profiles, records all data for later review, and alerts the user when attention is required. The aim is to provide a reliable, compact, and affordable platform for growing leafy vegetables and herbs indoors throughout the year. The system is sized for a single rack but is designed so that more racks can be added later.

II. LITERATURE SURVEY

Research on controlled environment agriculture has shown that plant growth depends strongly on a small number of controllable factors, namely nutrient availability, root zone conditions, light, temperature, humidity, and carbon dioxide. Studies comparing hydroponic and soil-based cultivation of leafy greens report that hydroponics can produce higher yields in shorter cycles while using a fraction of the water, provided that the nutrient solution is managed correctly. Nutrient film technique, deep water culture, and ebb and flow systems have each been studied, with nutrient film

technique being favoured for lettuce and herbs because of its efficient use of solution and good root oxygenation. Researchers have consistently noted that the main risks in hydroponics are rapid failure when pumps stop and gradual yield loss when pH and nutrient concentration drift. These findings underline the need for continuous monitoring rather than occasional manual checks, especially in small setups where the volume of solution is low.

Early automation of hydroponic systems used timers to switch pumps and lights on fixed schedules. Timers reduced routine work but could not respond to changes in the solution or the environment. Later studies introduced microcontroller-based systems with pH and electrical conductivity sensors that displayed readings on an LCD and sounded an alarm when values moved out of range. Several authors extended this by adding dosing pumps that added pH-adjusting or nutrient solutions when thresholds were crossed. Reported results showed better stability of solution parameters, but some systems overcorrected because they added doses before the previous dose had mixed, causing pH to swing back and forth. Recommended solutions included waiting periods between doses, small fixed dose volumes, and proportional control that adjusts dose size according to the size of the error. Several authors also recommended logging every dose so that the consumption of nutrient and pH solutions could be tracked over the crop cycle.

The use of IoT platforms in smart agriculture has been widely documented. Studies have connected soil moisture, temperature, and humidity sensors to Wi-Fi enabled controllers and sent data to cloud services, where it is displayed on dashboards and used to trigger irrigation. In hydroponics, similar approaches have been used to monitor pH, conductivity, and water level remotely and to control pumps and lights from mobile applications. MQTT has been adopted in many of these systems because it uses little bandwidth and supports publish and subscribe messaging between devices and applications. Researchers have pointed out practical issues such as loss of Wi-Fi connectivity, the need for local control that continues when the cloud is unreachable, and the security of remote control commands. They recommend that critical control loops remain on the device while the cloud handles monitoring, configuration, and history. This division of responsibility has become a common pattern in IoT agriculture designs that must remain safe when connectivity is unreliable.

Lighting research for indoor farming has examined the effect of light spectrum, intensity, and photoperiod on plant growth and energy use. Studies have shown that red and blue wavelengths are most effective for photosynthesis in leafy greens, and that full-spectrum LEDs with suitable ratios provide good growth with lower heat output than traditional lamps. Photoperiods of around sixteen hours have been reported as effective for lettuce and basil. Energy consumption for lighting is the largest operating cost in indoor farms, so researchers have explored dimming LEDs when natural light is available and scheduling lighting during lower tariff periods. Climate control studies have similarly shown that maintaining air temperature and

humidity within moderate ranges reduces tip burn, fungal disease, and stress in indoor crops, and that simple fan and humidifier control can achieve this in small enclosures. More recent work has added computer vision and data analytics to indoor farming systems. Cameras placed above the plants capture images at regular intervals, and image processing is used to estimate leaf area, canopy cover, and colour, which relate to growth rate and nutrient status. Machine learning models have been trained to detect yellowing, tip burn, and common diseases from leaf images. Historical sensor data has been used to predict harvest time and to recommend changes in nutrient targets. Researchers note that these methods are most useful when combined with reliable environmental control, since image analysis can detect problems but cannot prevent them without the ability to act. Aqua Grow follows this combined approach, with automated closed-loop control of solution and climate on the device and cloud-based monitoring, image logging, and alerts. In this design, vision is treated as a monitoring aid that supports sensor-based control rather than replacing it.

III. SYSTEM ANALYSIS

Aqua Grow is analysed as a controlled growing unit with sensing, actuation, local control, and cloud monitoring. The growing unit consists of a nutrient reservoir, channels for nutrient film technique cultivation, a grow light panel, and an enclosure with ventilation. Sensors include an analog pH probe, an EC probe, a waterproof DS18B20 temperature sensor in the reservoir, an ultrasonic or float sensor for water level, a DHT22 for air temperature and humidity, and a BH1750 light sensor. An ESP32 reads these sensors and drives a relay board and MOSFET drivers for the circulation pump, three peristaltic dosing pumps, LED lights, exhaust fan, and humidifier. The controller holds crop profiles with target ranges and runs control loops with waiting times between doses. An ESP32-CAM captures plant images at fixed times. Data and events are published through MQTT to a cloud broker, and a mobile application and dashboard provide monitoring, history, manual control, profile selection, and alerts.

Existing System

Most people who try hydroponics at home or in small setups rely on manual methods. They measure pH and conductivity with handheld meters once a day or less, mix nutrients by estimation, and adjust pH by adding drops of acid or base until the reading looks correct. Pumps and lights are usually controlled by simple mechanical timers. Air temperature and humidity are rarely monitored in small indoor setups. If the grower travels or forgets to check the system, pH can drift, the reservoir can run low, or a pump can fail without anyone noticing, and the crop can be damaged within a day. Commercial smart gardens exist but are often expensive, support only a few plants, lock users into proprietary nutrient pods, and offer limited control over parameters. Larger commercial vertical farms use industrial automation that is far beyond the budget and technical skills of households, schools, and small entrepreneurs.

Disadvantages of Existing System

- pH and nutrient levels are checked manually and only occasionally.
- Manual dosing is based on estimation and often overshoots the target.
- Mechanical timers cannot respond to changes in solution or climate.
- Pump failure or low water level can go unnoticed until plants wilt.
- Air temperature and humidity are rarely monitored in small setups.
- The grower must be physically present to check and adjust the system.
- No record of conditions is kept to understand why a crop performed poorly.
- Commercial smart gardens are costly and limited to a few plants.
- Proprietary nutrient pods restrict the choice of crops and increase cost.
- Beginners lose crops because hydroponic management needs experience.

Proposed System

Aqua Grow is an IoT-based smart indoor farming system that automates hydroponic cultivation and provides remote monitoring through a mobile application. An ESP32 controller reads nutrient solution pH, conductivity, temperature, and level together with air temperature, humidity, and light intensity. For each crop, the user selects a profile that defines target ranges for every growth stage. The controller runs closed-loop control in which pH and nutrients are adjusted by peristaltic pumps using small doses followed by a mixing period and a fresh reading, preventing overcorrection. The circulation pump runs on a cycle that keeps roots moist and oxygenated, and the controller checks level readings to detect pump or leak problems. LED grow lights follow a photoperiod and are dimmed when natural light is sufficient, while the fan and humidifier keep air conditions in range. An ESP32-CAM records daily plant images. All data is published over MQTT to the cloud, where the dashboard shows live values, history, images, and alerts.

Advantages of Proposed System

- Keeps nutrient solution pH and conductivity within target ranges automatically.
- Prevents overcorrection by dosing in small steps with mixing time.
- Detects low water level and pump problems before roots dry out.
- Controls lights, fan, and humidifier according to crop requirements.
- Allows crop profiles to be selected for different plants and growth stages.
- Provides remote monitoring and manual control through a mobile application.
- Records sensor history and plant images for review and learning.
- Uses much less water than soil-based cultivation through recirculation.
- Continues local control even when the internet connection is lost.
- Built from affordable components suitable for homes and schools.

IV. METHODOLOGY

The methodology starts with the design of a nutrient film technique unit sized for about twenty plants, with a reservoir, channels, and a lighting frame. Sensors are selected, wired to the ESP32, and calibrated, with the pH probe calibrated against buffer solutions and the EC probe against a standard solution. Crop profiles for lettuce, spinach, and basil are prepared from horticultural guidance, specifying pH, EC, water

temperature, air conditions, and photoperiod for seedling and growth stages. The firmware is written as a set of tasks that sample sensors, run control loops, handle MQTT communication, and log events. For pH and EC, the controller calculates the error, dispenses a small dose, waits for mixing, and reads again until the value is within range or a dose limit is reached. The ESP32-CAM captures images at fixed times and uploads them to cloud storage. The mobile application is developed to subscribe to data topics and publish commands. The system is evaluated over a full crop cycle by recording parameter stability, water use, growth, and manual interventions.

SYSTEM ARCHITECTURE

The architecture of Aqua Grow is organised in layers that connect the plants to the user. The Sensing Layer includes pH, EC, water temperature, water level, air temperature, humidity, and light sensors placed in the reservoir and grow chamber. The Imaging Layer uses an ESP32-CAM above the plants for periodic photographs. The Control Layer on the ESP32 reads sensors, applies calibration, compares values with crop profile targets, and runs the dosing, pump, light, and climate control loops. The Actuation Layer consists of the circulation pump, peristaltic dosing pumps, LED grow lights, exhaust fan, and humidifier switched through relays and MOSFET drivers. The Connectivity Layer uses Wi-Fi and MQTT to exchange data and commands with the cloud. The Cloud Layer stores sensor data, images, and events, hosts crop profiles, and applies notification rules. The Application Layer provides a mobile application and web dashboard for live monitoring, history, images, profile selection, manual control, and alerts.

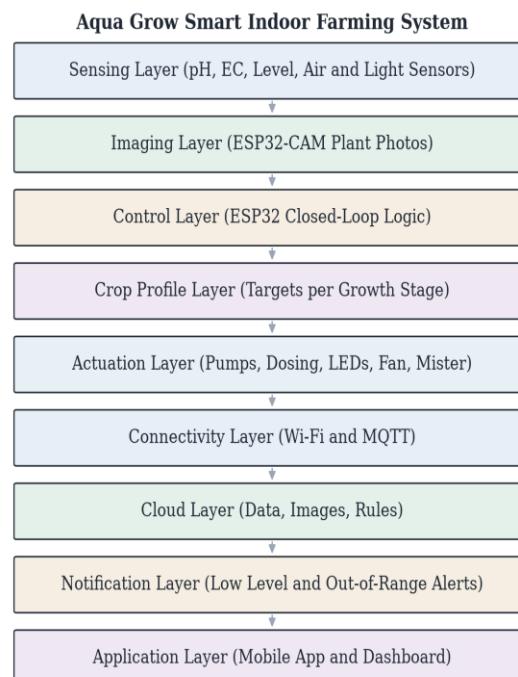


Fig. 1 System Architecture

V. RESULT AND OUTPUT



VI. CONCLUSION

This paper presented Aqua Grow, a Smart Indoor Farming System that uses IoT technology to automate hydroponic cultivation. The system monitors nutrient solution pH, conductivity, temperature, and level together with air temperature, humidity, and light, and it controls pumps, dosing, lighting, and climate devices to keep conditions within crop-specific targets. The design allows households, schools, and small growers to grow fresh vegetables indoors without constant manual attention. The complete unit fits on a single rack and can be assembled from widely available parts.

The closed-loop dosing approach, with small doses followed by mixing time and verification, kept pH and conductivity stable during testing and avoided the overcorrection that is common with manual adjustment. Automatic detection of low water level and pump problems addressed the most common cause of sudden crop loss in small hydroponic setups. Local control on the ESP32 ensured that the system continued to function when the internet connection was unavailable.

The cloud platform and mobile application give growers a clear view of their farm from any location. Historical graphs, event logs, and daily plant images help users understand how conditions affect growth, which is valuable for learning and for improving future crop cycles. The prototype grew lettuce, spinach, and basil successfully with far less water than soil cultivation and with only occasional refilling of the reservoir and dosing bottles. Because the crop profiles are stored as editable settings, the same hardware can be adapted to other leafy greens and herbs without changes to the firmware.

Future work will include image-based detection of nutrient deficiency and plant disease using machine learning, integration of carbon dioxide monitoring, and energy

optimisation through solar power and tariff-aware lighting schedules. Support for multiple racks and a shared dashboard would allow small commercial growers to manage larger installations. Long-term trials with a wider range of crops will help refine crop profiles and control parameters for different varieties. Guidance material for schools could also turn the unit into a practical teaching aid for plant science and electronics.

REFERENCES

- [1] Kumar, R. D., Prudhviraaj, G., Vijay, K., Kumar, P. S., & Plugmann, P. (2024). Exploring COVID-19 through intensive investigation with supervised machine learning algorithm. In *Handbook of Artificial Intelligence and Wearables* (pp. 145-158). CRC Press.
- [2] Swathi, B., Vijay, K., Sushanth Babu, M., & Dinesh Kumar, R. (2024, November). Machine Learning Techniques in Cloud Based Intrusion Detection. In *The International Conference on Artificial Intelligence and Smart Environment* (pp. 557-564). Cham: Springer Nature Switzerland.
- [3] Sv satyakrishna, shirisha rang, bhargavi nalacheruve. (2024) Prospective investigation on colorectal cancer with SMOTE on machine learning Algorithm
- [4] Dr.G.Vishnu Murthy, BhargaviNalacheruve 1Professor, Department of computer Science & engineering, Anurag University, TS, India. 2Student, Department of computer Science & engineering, Anurag University, TS, India.
- [5] V. N. S. Manaswini, K. K, C. Nigam, S. S. Ali, R. Niranjana, and Suman, "Real-Time Object Detection in Drone Surveillance Using YOLOv5," in *Proc. 2025 3rd Int. Conf. IoT, Communication and Automation Technology (ICICAT)*, Gorakhpur, India, 2025, pp. 1–6, doi: 10.1109/ICICAT68430.2025.11414670.
- [6] B. Soundarya, V. N. S. Manaswini, M. Ayyakrishnan, R. D. Kumar, "Contextual Analysis of Big Data Analytics in Intelligent Transportation Frameworks," in *Intersection of Artificial Intelligence, Data Science, and Cutting-Edge Technologies: From Concepts to Applications in Smart Environment*, Lecture Notes in Networks and Systems, vol. 1353, Cham: Springer, 2025, doi: 10.1007/978-3-031-88304-0_79.
- [7] R. D. Kumar, V. N. S. Manaswini, "Applications of blockchain in smart cities: detecting fake documents from land records using blockchain technology," in *Blockchain for Smart Cities*, Elsevier, 2021, pp. 105–117, doi: 10.1016/B978-0-12-824446-3.00017-X.
- [8] Tejavath Veeramma, Badarla Anil, Guguloth Ravinder, "An advanced movie recommender using collaborative filtering and sentiment analysis," *International Research Journal of Modernization in Engineering Technology and Science*, vol. 7, no. 7, July 2025, doi: 10.56726/IRJMETS81618.
- [9] Ravi Kumar Banoth, Ramana Murthy B V, "Automatic crop recommendation system using LightGBM and decision tree machine learning models," *Journal of Machine and Computing*, vol. 5, no. 1, pp. 343, Jan. 2025, doi: 10.53759/7669/jmc202505026.

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- [10] Ravi Kumar Banoth, Dr. B.V. Ramana Murthy, "Smart agriculture through IoT and machine learning for analyzing carbon footprints," in Proc. Int. Conf. Computer Science and Communication Engineering (ICCSCE), Apr. 2025.
- [11] Ravi Kumar Banoth, B. V. Ramana Murthy, "Soil image classification using transfer learning approach: MobileNetV2 with CNN," SN Computer Science, vol. 5, art. no. 199, 2024, doi: 10.1007/s42979-023-02500-x.