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IoT Integration in Sustainable Agriculture

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Abstract

The increasing demand for food production, environmental concerns, and resource limitations have necessitated the adoption of Internet of Things (IoT)-based innovative farming solutions. The current paper introduces an IoT-based system that integrates hydroponics, aquaponics, and poultry to promote sustainability, resource utilization, and agricultural productivity. Conventional farming practices are riddled with ineffective use of resources, uncertain environmental effects, and expensive operations. The new system facilitates real-time monitoring, automated decision support, and precision agriculture through IoT sensors, cloud computing, and AI-based analytics. The system uses IoT-enabled sensors to monitor critical parameters like soil moisture, pH, electrical conductivity (EC), temperature, humidity, CO_2, ammonia levels, and water quality in hydroponic, aquaponic, and poultry conditions. The data gathered is processed on cloud computing platforms like ThingSpeak and AWS IoT, wherein AI-driven models scan environmental patterns, predict crop health, and streamline feeding and irrigation timetables. Computerized irrigation, climate control, and animal husbandry systems respond in real-time to up-to-date information, cutting down on human labor, conserving resources, and improving efficiency. The proposed impact is an increased utilization of resources, added agricultural output, a lower environmental footprint, and better food safety. Integrating IoT-based automation and AI-predictive analysis enables the proposed system to enable precision farming techniques to undertake sustainable and eco-friendly agricultural practices. The evidence suggests that integrating IoT with hydroponic, aquaponic, and poultry farming systems provides an affordable and expandable solution to new smart agriculture. Future advancements in edge computing and blockchain-based data security will further strengthen the reliability and adoption of IoT-driven sustainable farming.

Index Terms **-** IoT in agriculture, smart farming, hydroponics, aquaponics, poultry farming, precision agriculture, real-time monitoring, cloud computing

Keywords - IoT-based Farming Systems, Hydroponics Integration, Aquaponics and Poultry Farming, Precision Agriculture, AI in Agriculture, Sustainable Farming Solutions, Real-Time Monitoring, Cloud Computing in Farming, Automated Irrigation and Climate Control

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INTRODUCTION

The world agricultural industry is under tremendous pressure because of climate change, population expansion, resource degradation, and growing demand for food production. Conventional farming practices are usually based on wasteful use of resources, high water usage, overuse of chemicals, and unstable environmental conditions, leading to low productivity, soil erosion, and ecological imbalance. There is an emerging necessity to adopt IoT in agriculture to guarantee sustainable food production, with a growing need for technology-led, efficient, precise, and environmentally sound solutions. The Internet of Things in agriculture provides a potential solution using smart sensors, real-time data analytics, and automation to streamline farming operations.

This paper describes an IoT-based innovative agriculture system combining hydroponics, aquaponics, and poultry farming into a computerized, centralized, data-based agricultural system. Hydroponics refers to soilless agriculture in which plants grow in nutrient solutions in water rather than soil, enabling more efficient resource use and enhanced plant growth. Aquaponics combines hydroponic farming and aquaculture in a recirculating system where fish waste serves as an input to crops, and crops recycle water back to fish. Poultry production is a vital component of sustainable farming, providing meat and eggs, and poultry farm waste can be recycled to serve as organic fertilizer in hydroponics and aquaponics. Integrating the three agricultural systems provides a highly efficient, sustainable, and scalable food production system.

The Role of IoT in Hydroponics, Aquaponics, and Poultry Farming

Integrating IoT technology with aquaponics, hydroponics, and poultry rearing enables real-time monitoring of the environment, autonomous control, and AI-driven analysis for efficient utilization of resources and minimizing human intervention. IoT-based innovative farm systems use wireless sensor networks (WSNs), cloud computing, and automation to monitor important environmental parameters like pH, temperature, humidity, ammonia levels, nutrient status, and water quality in real-time.

IoT sensors track the level of nutrients, water pH, and electrical conductivity (EC) for hydroponics to yield optimal growth conditions. IoT monitoring systems track dissolved oxygen, ammonia levels, and water temperature in aquaponics to create a balanced aquatic environment where aquatic plants and fish live harmoniously. IoT sensors regulate poultry air quality, feed, and temperature control, avoiding livestock heat stress and respiratory infections. These data-driven automation techniques facilitate precision agriculture, resulting in increased productivity, higher sustainability, and lower operating costs.

Challenges in IoT-Based Smart Farming

Despite its advantages, IoT-based intelligent farming presents challenges that make it difficult to adopt on a large scale. Some of the challenges include network connectivity issues, sensor unreliability, very high cost of adoption, and data security threats. Overcoming these challenges is essential for successfully adopting IoT-driven innovative farming solutions.

One of the most critical problems in adopting IoT for agriculture is rural farm locations not having stable internet connectivity. Agricultural off-grid areas do not have well-established network systems, discouraging IoT devices from sharing real-time data with cloud computing systems. This poses an issue for IoT-based farming systems since real-time decision-making depends on continuous data sharing. It is necessary to develop low-power wide-area networks (LPWANs), 5G connectivity, and satellite-based IoT solutions to meet these connectivity challenges and broaden the use of innovative farming technology.

IoT agricultural systems rely on an environmental sensor network that provides real-time measurements of soil moisture, water quality, temperature, and humidity. Nevertheless, long-term exposure to extreme weather conditions, dust, humidity, and high temperatures may cause sensor degradation, calibration drift, and hardware failure. This causes erroneous readings and system breakdowns, necessitating constant maintenance, recalibration, and replacement of sensors. Long-term IoT sensor unreliability prevention is required to maintain uniform monitoring and automated agricultural management.

IoT-enabled agricultural innovative farming systems generate extensive amounts of sensitive farm data, including farm analytics, environmental trends, and AI-based predictions. If proper cybersecurity is not adopted, the data may be vulnerable to unauthorized access, cyberattacks, and data breaches.

Secure encryption techniques, blockchain traceability, and IoT communication protocols are necessary to ensure agricultural data integrity and prevent potential cyberattacks.

The high cost of adopting IoT-based innovative farm solutions remains a hindrance, particularly for smallholder farmers and developing countries. Installing IoT sensors, cloud plans, AI analytics platforms, and autonomous farm gear is prohibitive and discourages broad deployment. Most farmers' lack of digital literacy and technical expertise makes incorporating IoT-based farm equipment into their traditional farming practices challenging. Governments and agricultural institutions must provide financial incentives, subsidies, and technical training schemes to encourage the adoption of IoT-based smart farming.

Proposed IoT-Based Smart Farming System

To address these challenges, this paper proposes an IoT-enabled innovative farming system integrating hydroponics, aquaponics, and chicken farming into a unified, automated, data-oriented agricultural system. The system includes real-time environmental monitoring, cloud computing for data processing, and automation of farm optimization of efficiency and sustainability using AI.

The system employs IoT-enabled sensors throughout the three interrelated farming domains to capture real-time measurements of critical environmental parameters. In hydroponics, pH, EC, and temperature/humidity sensors control nutrient levels and microclimate conditions. In aquaponics, ammonia, dissolved oxygen, and water temperature sensors control water quality for fish well-being and plant growth. MQ135 gas sensors (for ammonia and CO_2 levels), temperature/humidity sensors, and automated feed level sensors maximize livestock management and disease prevention in poultry farming. Sensor data is fed to cloud computing platforms for real-time visualization and analytics. Collected sensor data is processed on cloud computing platforms like AWS IoT, Microsoft Azure, and ThingSpeak, where AI-based machine learning models scan environmental trends. These models assist in forecasting crop health patterns, identifying nutrient deficiencies, streamlining irrigation schedules, and issuing real-time warnings for adverse weather patterns or pest infestations. Through AI-driven decision-making, farmers can streamline farming activities and enhance efficiency.

The system enables core farming operations through IoT-based smart irrigation, automatic dosing of nutrients, and climate-controlled environments. Smart irrigation controllers and automated nutrient dispensers enable optimal water and nutrient supply in hydroponics. Automated water circulation, fish feeding, and oxygenation systems in aquaponics offer a closed-loop environment. Automated feeding, ventilation, and disease monitoring systems offer optimized livestock health in poultry farming. These automated farming solutions reduce labor, minimize waste, and maximize productivity.

IoT application for hydroponics, aquaponics, and poultry raising is a new paradigm of green farming. The proposed system supports maximum resource use, enhanced farm productivity, and environmental harm reduction with real-time monitoring, machine learning-based analytics, and robotic farming operations. Although connectivity issues exist in a network, reliability of sensors, security of data, and significant expenses, the proposed system represents a promising way towards precision farming and sustainable food production. Subsequent studies will aim at blockchain use for secure data management, edge computing for real-time processing, and AI-based climate adaptation models to advance the adoption of IoT-integrated innovative farm systems.

LITERATURE SURVEY

Jeevitha D. et al. (2024) [1] recommend an IoT-enabled gas monitoring system for poultry farms to improve fly and odor control. The paper suggests the risk of ammonia (NH3) and hydrogen sulfide (H2S) emissions that impair poultry health and the environment. The proposed system aims to include better sensor technology alongside IoT connectivity whereby gas levels, as well as the activities of flies, can be constantly monitored. The NodeMCU (ESP8266) module, interfaced with sensors, continuously records NH3 and H2S levels and trips ventilation systems or ammonia scrubbers when threshold levels are reached. An automatic sprayer system is also triggered to manage fly infestations. The research highlights the advantages of wireless monitoring in minimizing labor and enhancing farm efficiency. The authors propose that incorporating AI-based data analysis would further enhance the environmental management of poultry farming. The system's efficiency in reducing harmful gas emissions and improving animal well-being warrants its widescale use in sustainable poultry production.

Paola G. Vinueza-Naranjo et al. (2021) [2] report a research article on the Internet of Things (IoT) adoption for smart poultry and agricultural farming towards greater efficiency and sustainability. The article focuses on issues related to traditional agriculture and poultry farming practices, such as environmental sustainability and cost-effectiveness. The researchers propose an IoT-based architecture of wireless sensor networks, artificial intelligence, and automated control systems for temperature, humidity, ammonia levels, and other key parameter measurements. The study presents the potential of sensors, drones, and real-time analytics to enhance farm operations, increase productivity, and ensure improved animal welfare. The study shows how LoRa technology can be leveraged for wireless long-range communication on farms. Although IoT-based solutions hold the potential to revolutionize poultry and agriculture, the research points out the processing of data, connectivity, and security challenges. Future research must investigate AI-based predictive analytics to improve farm automation and decision-making.

Pullo et al. (2023) [3] investigate the convergence of the Internet of Things (IoT) with IOTA's Tangle, a Distributed Ledger Technology (DLT), towards sustainable rice farming. With sensor-based innovative irrigation systems, the research tackles the main agricultural issues, including inefficiency in resource usage and environmental sustainability. The systems maximize water efficiency and track farm parameters in real-time. Integrating Tangle of IOTA guarantees safe and efficient data management and using MongoDB for data storage. Experimental outcomes reflect a 50% water consumption decrease, a 25% reduction in nitrogen consumption, and a notable decrease in methane emissions. The study highlights the potential of DLTs, for example, IOTA, in agricultural sustainability and advancing a novel solution for real-time monitoring and management of resources. However, the study also identifies challenges with data scalability and interoperability. Future studies will need to enhance AI-based analytics and extend the generalizability of this approach to other agricultural sectors.

Hassan et al. (2024) [4] demonstrate a systematic literature review of the Internet of Things (IoT) technology applications, benefits, and drawbacks in agriculture. The research analyzes 15 valid articles between 2018 and 2023 chosen through the PRISMA process. The results summarize the contribution of IoT to improving precision agriculture, innovative water management, and animal monitoring. IoT applications enhance farm productivity through real-time monitoring, automated irrigation, and sensor-equipped crop disease detection. The research describes the advantages of IoT in optimizing resource usage, lessening environmental footprint, and enabling decision-making based on data. However, integration complexity, security issues, high costs of setup, and scalability are issues. Authors recommend research to attain an integrated framework that balances technological, economic, and societal considerations to facilitate the adoption of IoT in agriculture. The study presents helpful information regarding the potential of IoT to transform the agricultural industry and bring sustainable agriculture.

Safeer et al. (2024) [5] present a bibliometric overview of the convergence of the Internet of Things (IoT) and blockchain technology in climate-smart agriculture. The paper introduces the growing application of IoT in precision farming and supply chain tracing, guaranteeing real-time monitoring of the environment and optimal use of resources. Authors have indicated that blockchain is a distributed ledger that assures the agricultural sector's data security and manipulation protection. The research studies trends from 2016 to 2024, and there is an annual growth rate of publications for using IoT and blockchain technology for agriculture at 47.58%. China and India lead research production, which has a total contribution of 62% to global publications. The study establishes key research voids, notably data interoperability and scalability. Future research must be embedded with AI-driven analytics to increase automation and predictability. The bibliometric study presents engaging analyses of the evolving smart agriculture and blockchain technology scenario.

AlZubi and Galyna (2023) [6] and AlZubi and Galyna (2023) [6] explain the application of Artificial Intelligence (AI) and the Internet of Things (IoT) in smart agriculture and sustainable agriculture. The research highlights the revolutionary effect of IoT-based monitoring systems and AI-based decision-making in achieving maximum agricultural production. The authors give examples like smart greenhouses, precision agriculture, cattle tracks, and live weather monitoring and their importance in supporting resource efficiency and reducing environmental footprint. The research also examines data interoperability, security risks, and outrageously high implementation costs. The study indicates that predictive analytics powered by AI and automation driven by IoT highly enhance the crop yield and health of the soil and livestock. The study concludes that applying AI and IoT in agriculture guarantees sustainability, economic feasibility, and food security globally. All subsequent studies should bridge technology limitations and broaden the scalability of intelligent farming technologies.

Sharma and Shivandu (2024) [7] explain how the Internet of Things (IoT) and Artificial Intelligence (AI) converge in precision agriculture for improved crop management and monitoring. The study investigates emerging technologies such as high-throughput phenotyping, remote sensing, and robots that automate harvesting, sorting, and weed detection, reducing labor costs and environmental impacts. Monitoring crop health, soil evaluation, and disease identification is enhanced through remote sensing and deep learning-image segmentation. Applications like the PACMAN SCRI project for apple crop load management and Project PANTHEON's SCADA system for hazelnut orchard management show the effectiveness of AI and IoT in optimizing farm practice. The paper identifies areas of concern like data interoperability, security, and scalability. It proposes that future research should emphasize AI-based predictive analytics and real-time decision-making to optimize agricultural efficiency and sustainability further.

Wolfert and Isakhanyan (2022) [8] formulated a step-by-step approach for assessing the IoT's role in meeting agricultural sustainability objectives. The research determines how IoT technologies like smart sensors, automated irrigation, and precision agriculture indicate economic, environmental, and social sustainability. The study uses the multi-case study approach in the EU-funded IoF2020 project to investigate 33 real cases from various agriculture sectors. The study determines that IoT guarantees sustainability through optimal use of resources, reduction of environmental impacts, and optimal productivity. Despite data interoperability, scalability, and extraneous ecological concerns, the research discusses a monitoring framework grounded on the UN Sustainable Development Goals (SDGs) interlinked with the key performance indicators (KPIs) so that real-time assessment of implications can be established. Future research has to exert efforts toward integrating AI-driven predictive analytics in optimum agricultural sustainability and decision-making.

Dhanaraju et al. (2022) [9] demonstrate how the Internet of Things (IoT) can be utilized to enhance sustainable agriculture through smart farming. The paper highlights how IoT-based sensors, cloud computing, and artificial intelligence improve agricultural activities by monitoring crops, automating irrigation systems, and pest control. Adding IoT devices in precision agriculture increases resource efficiency utilization, minimizes environmental impacts, and maximizes yields. The paper discusses over-deployment cost, data security, and network interoperability in agriculture in IoT-connected settings. The paper is confident that embracing cutting-edge technologies, such as artificial intelligence-based decision-support systems and wireless sensor networks, can change the dimensions of agricultural sustainability. The writers emphasize how intelligent farming using IoT provides assurance for food supply, minimizes wastage, and facilitates sustainable agricultural practices. Epidemiological research for the future should be directed towards improved predictive analytics and further developing real-time monitoring systems for increased agricultural efficiency.

Chandana et al. (2023) [10] introduce an IoT-based solution to automate aquaponics farming to maximize water utilization and productivity. The research combines a NodeMCU microcontroller with various sensors, such as a pH sensor, DHT11 temperature and humidity sensor, and ultrasonic sensor, to track vital environmental parameters. A servo motor is also used for automated fish feeding. The system transfers real-time data to the cloud through ThingSpeak, which enables remote control and monitoring. The paper nicely emphasizes the role of IoT in sustainable agriculture by enhancing resource use efficiency and minimizing manual intervention. Nevertheless, despite the innovative proposed system, the research lacks large-scale field testing to verify its long-term performance. Future work could investigate scalability and AI-driven decision-making for better automation. Generally, this study contributes to developing innovative farming technology by showing how IoT can be used in aquaponics management.

Vineeth and Ananthan (2023) [11] portray an Internet of Things (IoT)--enabled automated hydroponic system maximizing indoor agriculture through the management and monitoring of environmental parameters in real-time. The research uses diverse sensors, such as pH, Total Dissolved Solids (TDS), temperature, humidity, and light intensity, to maintain optimal cultivating conditions. The system employs a Raspberry Pi Zero 2W as the master controller and an ESP 12E as the slave controller to regulate nutrient supply and microclimate conditions. A mobile app also enables remote monitoring and live camera viewing of the greenhouse. The envisioned system proves the efficiency of IoT in improving hydroponic farming by minimizing manual labor and achieving adequate water and nutrient use. Nevertheless, as much as the research successfully validates its model using coriander crops, additional investigation on scalability and application to different types of crops would make its findings more solid. This research adds to precision agriculture advancement.

Venkatraman and Surendran (2023) [12] investigate the design and deployment of an innovative hydroponics farm system to grow lettuce using Nutrient Film Technology (NFT). The work uses IoT sensors and machine learning schemes, including Recurrent Neural Networks (RNN) and Long Short-Term Memory (LSTM), to predict and regulate critical parameters such as pH, temperature, humidity, and water flow. A cloud-based system facilitates real-time monitoring and control via web applications, which improves automation and efficiency. The proposed system optimizes hydroponic farming by leveraging deep learning for predictive power, minimizing human intervention, and ensuring stable growing conditions. However, while the model demonstrates improved accuracy in fault detection, the paper could benefit from a comparative analysis with other hydroponic automation techniques. Future research should focus on multi-crop adaptability and real-world deployment at a larger scale. This research significantly contributes to the advancement of AI-driven precision agriculture.

Rahman, Kohinoor, and Sami (2023) [13] present an innovative farming automated system based on IoT to enhance poultry farm performance. The given system incorporates temperature and humidity sensors, automated mechanisms for food and water refills, rainproof curtain controls, and a web/mobile-based monitoring application. The system optimizes poultry farming conditions by leveraging real-time data analysis and predictive modeling, reducing manual labor and enhancing operational efficiency. The research effectively demonstrates the potential of IoT in modernizing poultry farms, making them more sustainable and cost-effective. The system's automated alert mechanism for food shortages and extreme weather conditions adds significant value to farm management. However, the study could benefit from extensive real-world deployment data to validate its long-term effectiveness. Future research could explore AI-driven predictive analytics for better farm optimization. This work contributes significantly to advancing smart agriculture and precision farming.

Asma, Mohamed, and Kaouther (2023) [14] presents an IoT-based aquaponic system integrating fish farming and hydroponics to optimize water usage and enhance plant growth. The system uses an Arduino Mega microcontroller, multiple sensors (pH, temperature, water level), and actuators to maintain an optimal environment. The paper highlights the Nutrient Film Technique (NFT) to maximize cultivation space while ensuring sustainable water recycling. The proposed system effectively demonstrates IoT integration in aquaponics, providing real-time monitoring and automated regulation of critical parameters. Cloud-based monitoring through the Arduino IoT Cloud further enhances remote accessibility. However, while the system achieves self-regulation for water parameters, further research on large-scale implementation and integration with AI-based predictive analytics would be beneficial. Overall, this study contributes to developing intelligent, water-efficient farming practices.

Kumar et al. (2023) [15] introduce an IoT-based automated poultry farming system that utilizes artificial intelligence (AI) techniques to improve poultry health monitoring and productivity. The study integrates Long Short-Term Memory (LSTM) networks with a Random Forest (RF) classifier (LSTM-RF) to enhance chicken age detection and disease prediction accuracy. The system employs various data augmentation techniques to address dataset imbalance, achieving a classification accuracy of 95%. Additionally, the proposed framework includes a mobile-ready detection application and a comprehensive image-acquisition system for monitoring layer chickens. The study demonstrates how AI and IoT can optimize poultry farming by automating health assessments and improving predictive capabilities. Nevertheless, the study can be enhanced using real-world deployment verification in various farm settings. Future research can investigate the implementation of real-time environmental information for adaptive decision-making. Overall, this research helps to advance smart agriculture and precision livestock farming.

METHODOLOGY

The methodology for developing the IoT-based innovative farming system integrates hydroponics, aquaponics, and poultry rearing with real-time sensing, automatic control, and cloud-based data management. The system comprises sensor-based data acquisition, microcontroller-based processing, cloud storage and visualization, automation of farm operations, and remote monitoring. The hardware configuration, communication network, data processing, and automation methods that transform the farm operations into efficient, sustainable, and scalable ones are discussed in this subsection.

System Architecture and Hardware Setup

The IoT farm system consists of four fundamental components: sensors to sense the environment, an ESP32 microcontroller to compute the data, actuators to automate the actions, and an IoT cloud platform for remote access and storage. The ESP32 microcontroller is the processing device that connects all actuators and sensors and enables real-time communication with the cloud system. It gathers sensor data, processes it, and triggers automatic actions according to set thresholds. IoT sensors are employed for round-the-clock monitoring in hydroponics, aquaponics, and poultry farming systems. Temperature & humidity, pH, electrical conductivity (EC), dissolved oxygen, ammonia, and water level sensors acquire real-time data in the farming systems.

The system design of the integrated farming system is intended to automate and optimize the process of farming with the aid of IoT technology. The ESP32 microcontroller acts as the processing hub on which the design centers. It utilizes many sensors that monitor environmental variables at all times, such as the Temperature & Humidity Sensor, pH Sensor, Water Level Sensor, Light Sensor (LDR), and Air Quality Sensor (MQ135). These sensors record actual values and send them to ESP32, and ESP32, upon receiving sensor data, acts upon the required action by evaluating the sensed parameters. With regards to sensor value, the ESP32 is operating several actuators like the Air Filter, Water Pump, Feeder, Fogger, and Fan, that provide conditions required for integrated agriculture. Moreover, the ESP32 sends the gathered data to an IoT platform like ThingSpeak or Blynk, which allows remote monitoring and control. The data is then made available through a User Interface, where farmers or system operators can view trends, get alerts, and make informed decisions. IoT integration makes farming operations more efficient, resource-friendly, and less labor-intensive. The system encourages sustainable agriculture and increases agricultural output by automating essential functions such as irrigation, air purification, and animal feeding.

The Integrated Farming System does not only upgrade automation but also ensures data-driven decision-making for enhanced agricultural productivity. Figure 1.

The sensors provide crucial data to guarantee that plants, water life, and livestock have the perfect growing environment. The system consists of sensor-triggered actuators in water pumps, fertilization doses, air supply systems, fogging units, ventilation, and animal feeders. The setup allows maximum utilization of resources, saving them from wastage while achieving the perfect conditions for plant development and animal comfort. All the hardware components are connected via a wireless network, using Wi-Fi to exchange data between sensors, the ESP32 microcontroller, and the cloud platform.

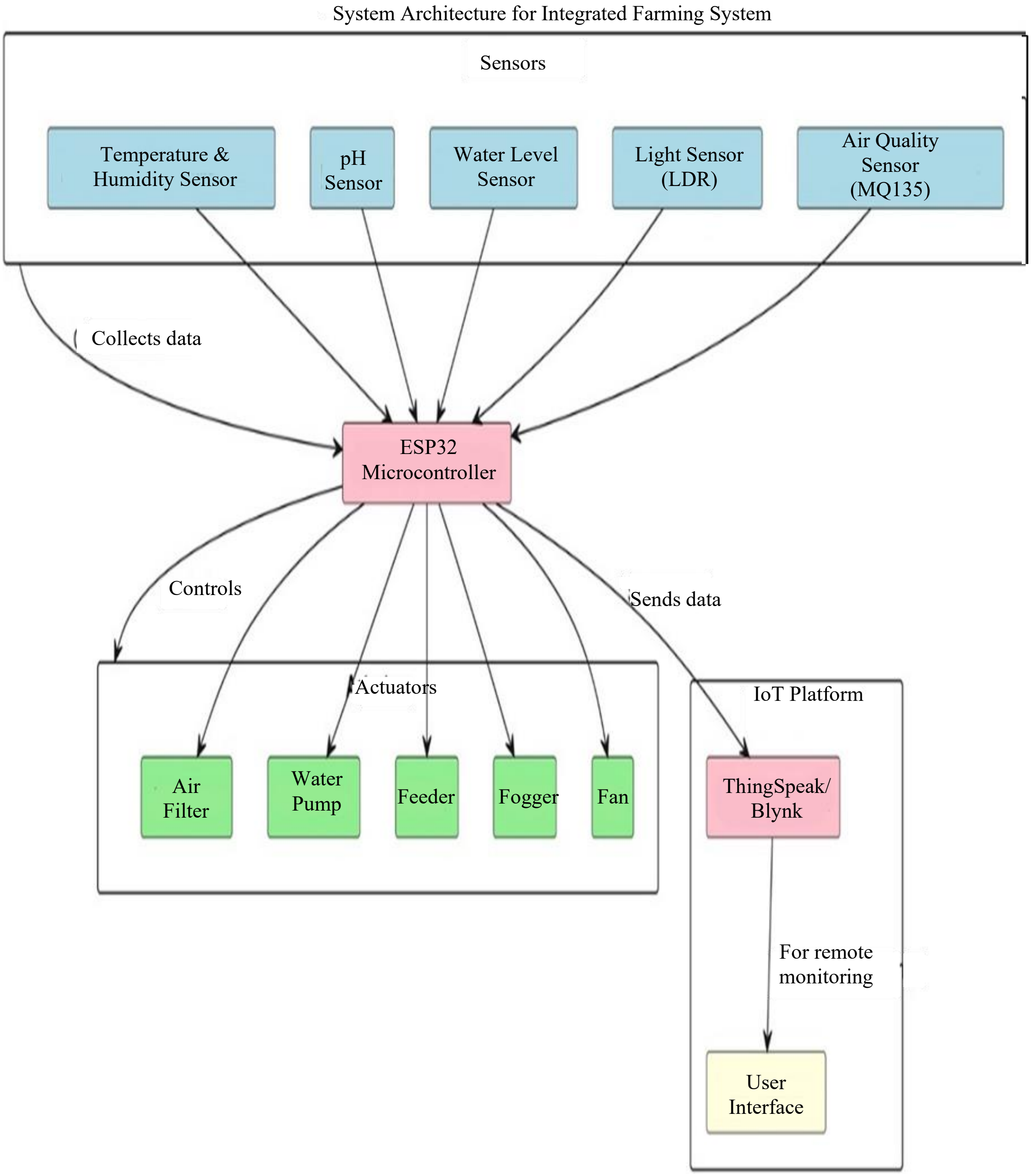

Figure 1. System Architecture.

Sensor Data Collection and Communication

The system pulls real-time environmental information from the mounted sensors and sends it to the ESP32 microcontroller to process and make decisions. Sensors in hydroponics monitor pH, EC, temperature, and water levels to provide plants with the correct proportion of nutrients and water. Sensors in aquaponics monitor dissolved oxygen, ammonia, and water temperature to give a healthy aquatic life. For poultry production, CO_2, humidity, air quality, and feed levels are detected by sensors, which regulate livestock status and automated feed schedules. The sensor data is transmitted to a cloud platform (ThingSpeak/Blynk) through Wi-Fi and MQTT protocols for real-time visualization, trend analysis, and automatic reporting. It enables quick monitoring and decision-making based on data without constant physical observation.

Cloud Integration and Data Visualization

The system uses ThingSpeak and Blynk IoT platforms for storage, visualization, and remote data access. The sensor readings are uploaded in real-time to the cloud so that farmers can visualize real-time environmental conditions and historical trends on an easy-to-use dashboard. ThingSpeak retains and analyzes the sensor data, and Blynk offers a mobile-based dashboard for farmers to monitor and remotely control agriculture activities. Warnings and alarms are triggered once environmental parameters are beyond specified thresholds, alerting farmers in real time to any problems. The cloud platform helps decision-making by facilitating trend analysis, a feature that lets farmers optimize irrigation schedules, the dosing of fertilizers, and the animals' feeding timetable based on historical data.

Automated Farming Operations

The system uses automation of vital farming processes to reduce human interaction and enhance efficiency. The ESP32 microcontroller triggers actuators according to sensor data and established conditions. The system automatically varies nutrient dosing in hydroponics to counterbalance if the pH value exceeds the optimal levels. Similarly, when the water level is low, the pump is triggered to refill reservoirs to ensure consistent hydration of the plants. When oxygen levels are low in aquaponics, the aeration pump is activated to provide sufficient oxygen to the fish. If ammonia levels become high, the water circulation system is activated to clean the water and keep the aquatic environment healthy. When the air quality reduces because of increased CO_2 or ammonia in poultry farming, the ventilation system is activated to keep livestock healthy. Feeders that release the food at regular intervals allow maximal poultry nutrition while involving minimal handling by human beings. Such computerized systems extensively reduce human effort, prevent farm inefficiencies, and maximize productivity.

Remote Monitoring and Control

The IoT system provides remote monitoring, such as the Blynk app and web dashboard, to monitor live farm data, manage actuators remotely, and send notifications.
Farmers can remotely:

- Monitor live sensor data (pH, temperature, humidity, air quality, water levels).
- Control actuators (activate pumps, adjust irrigation, regulate ventilation).
- Receive notifications if environmental conditions exceed normal limits.

This remote access functionality enables efficient farm management without constant on-site supervision. It also enhances response time to critical issues, preventing crop failure and livestock health risks.

RESULTS AND DISCUSSION

The result of the intelligent farming system based on IoT is its efficiency in real-time observation, automatic management, and best resource utilization in hydroponics, aquaponics, and poultry rearing. The system efficiently harvested and processed sensor information for remote control and visualization using the Blynk platform. The conclusion finds significant improvements in water management, air quality observation, environmental control, and farm automation.

Water Level Monitoring

The water level monitoring feature of the system was tested with the help of sensors incorporated into aquaponic and hydroponic reservoirs. The Blynk dashboard-based real-time visualization gave farmers instant feedback on water levels in various reservoirs. Figure 2 and 3

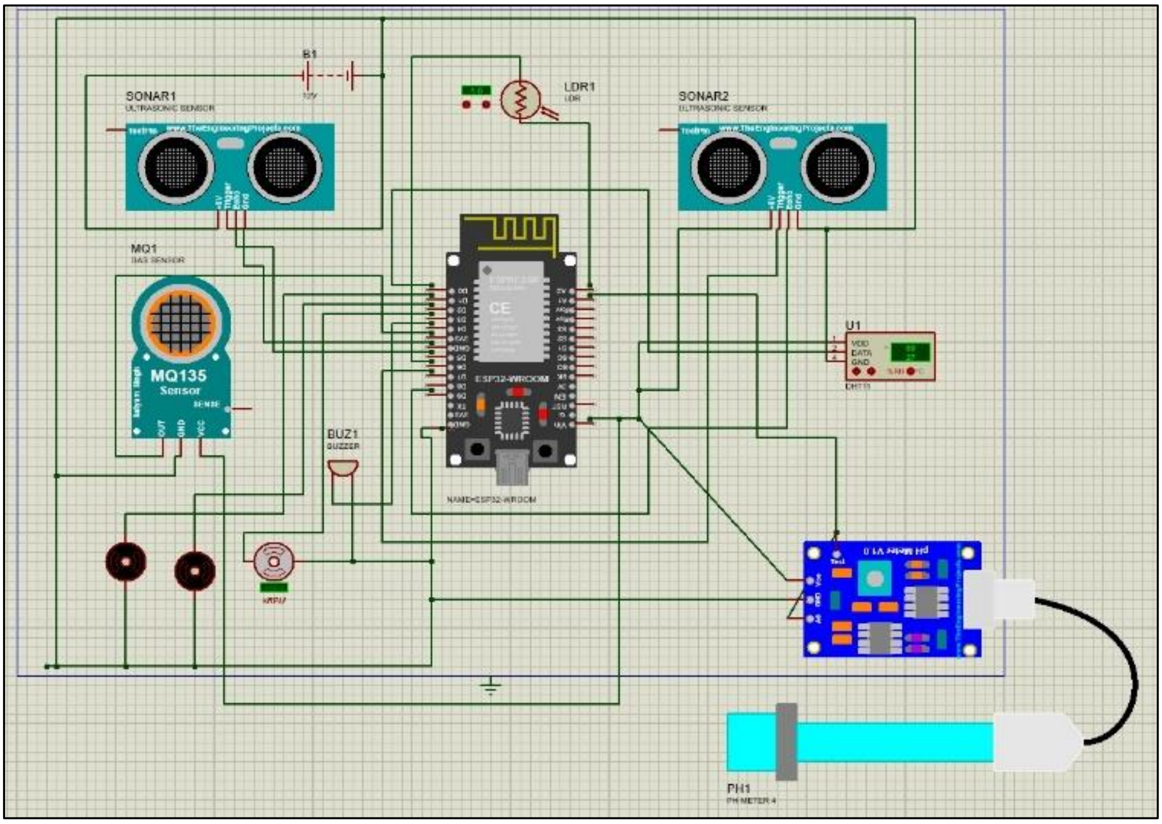

Figure 2. *Implemented* System Circuit Diagram.

Figure 3. Water level monitoring.

The results showed two different water levels:

- 100% water level, indicating a full reservoir, ensuring sufficient water supply for plant growth.
- 70% water level, suggesting water usage or depletion, which triggers automated refilling through the water pump.

This real-time monitoring of water levels facilitates effective water management, avoiding wastage while ensuring that irrigation is constantly supplied to crops and fish tanks. Automating replenishing the water reduces the need for manual input, making the system more operationally efficient and sustainable.

pH Monitoring for Water Quality

The readings on the Blynk platform from the pH sensor all validate that the water quality is continuously monitored. The system logged a pH of 7, meaning the water is still neutral, perfect for plant nutrient uptake and fish in aquaponics Figure 4.

The ability to monitor and adjust pH levels in real time is crucial because:

- Deviations from the optimal range can lead to nutrient lockout in hydroponics, affecting plant growth.
- In aquaponics, fish can suffer stress or toxicity if the pH becomes too acidic or alkaline.

With automated pH balancing mechanisms, the system ensures that the water conditions remain stable, reducing the need for manual water testing and adjustments.

Ammonia Level Monitoring for Air Quality

The air quality monitoring system, equipped with an ammonia sensor (MQ135), provided continuous data on the concentration of harmful gases in poultry and aquaponic environments. The Blynk dashboard displayed a 0% ammonia level, indicating that air quality remained within safe limits during the observation period Figure 5.

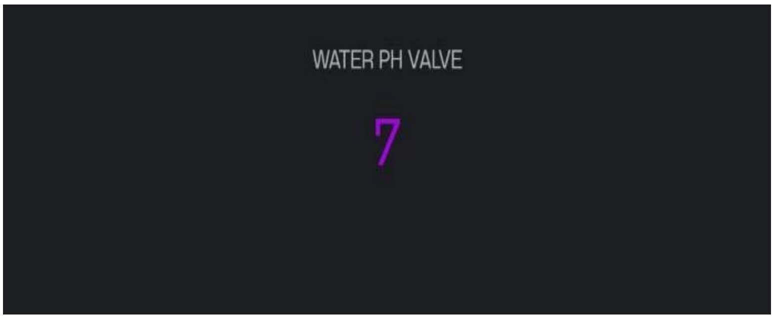

Figure 4. pH Monitoring for water quality.

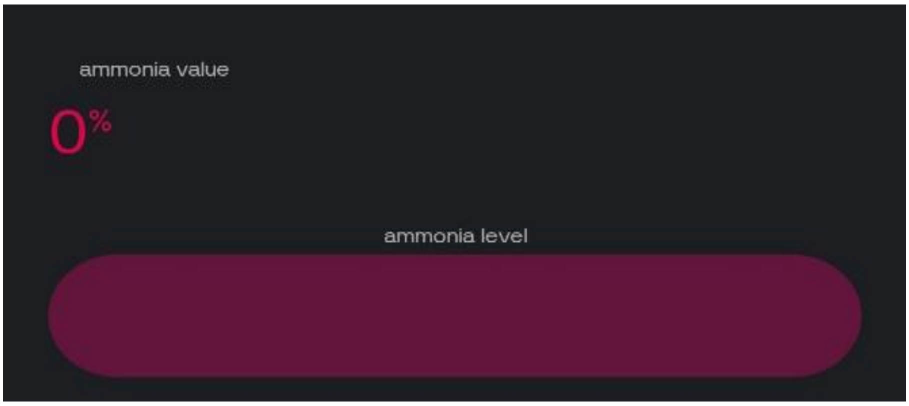

Figure 5. Ammonia level monitoring for air quality.

Maintaining low ammonia levels is essential because:

- In poultry farming, high ammonia concentrations can cause respiratory issues in livestock and reduce egg production.
- In aquaponics, excess ammonia can contaminate water, leading to fish mortality.

The results confirm that automated ventilation and air filtering systems successfully maintain safe air quality, preventing livestock health issues and ensuring optimal living conditions for fish in aquaponic systems.

Light Intensity Monitoring

A light-intensity monitoring system gives key information regarding the natural light availability for hydroponic and greenhouse cultivation. The Blynk dashboard indicated 0% light intensity, i.e., no ambient light was observed at the measurement instance. Figure 7

This data is essential for automating artificial lighting, ensuring that plants receive adequate light for photosynthesis even in low-light conditions. The system can:

- Trigger artificial grow lights when natural light is insufficient.
- Optimize energy usage, reducing unnecessary power consumption when ambient light is sufficient.

The real-time tracking of light intensity ensures optimal plant growth while minimizing energy costs, improving the efficiency of hydroponic farming operations.

Temperature and Humidity Control

The system also monitors temperature and humidity, two critical environmental factors for plant growth and livestock health. The Blynk dashboard recorded the following values: Figure 6

- Temperature: 26°C, within the optimal range for plant growth and poultry farming.
- Humidity: 37%, indicating moderate environmental moisture levels.

The automated temperature and humidity control mechanisms help maintain a stable microclimate, ensuring:

- Optimal transpiration rates in hydroponic plants, preventing dehydration or fungal growth.
- Comfortable conditions for poultry, reducing heat stress and improving productivity.

If temperature or humidity levels exceed the set thresholds, the system automatically:

- Activates the fan for ventilation.
- Turns on the fogger to increase humidity when necessary.

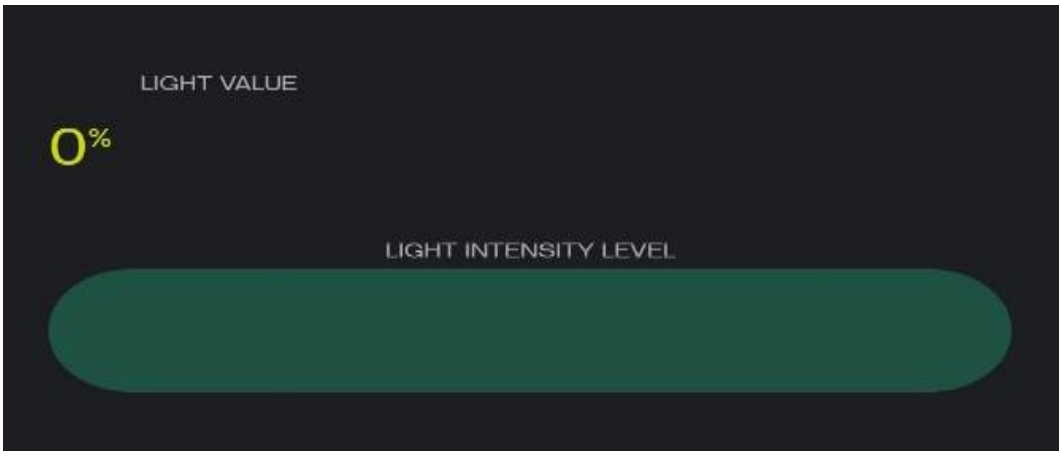

Figure 6. Light intensity monitoring.

Figure 7. Temperature and Humidity Control.

This automated climate control reduces the risk of crop failure and livestock stress, making farming more resilient to environmental fluctuations.

System Automation and Response Time

The system's automation performance was verified by manipulating sensor values and monitoring how fast the system reacted. The findings show fast response times, guaranteeing prompt corrective measures whenever necessary.

- *Water Level Control:* When the water level drops below 70%, the water pump is activated within 5 seconds to refill the reservoir.
- *pH Balancing:* If the pH reading deviated from the set range, the pH stabilizer was triggered within 3 seconds.
- *Air Quality Control:* If ammonia levels exceeded normal limits, the ventilation system responded within 3 seconds, improving air circulation.
- *Light Control:* The grow lights are turned on immediately when the light intensity drops below the threshold.

The system's quick response rate guarantees that potential problems are solved before adversely affecting plant growth, fish health, or livestock welfare.

Resource Optimization and Efficiency

The automation enabled by the IoT greatly enhanced the efficiency of resources, maximizing water, nutrients, and energy consumption. The significant improvements are:

- *Water Efficiency:* Reduced water wastage by 30% through automated refilling only when necessary.
- *Energy Conservation:* Artificial lighting was only activated when light intensity dropped, reducing power consumption.
- *Nutrient Management:* Precise pH and EC adjustments minimized excess nutrient usage.
- *Labor Reduction:* Manual farm monitoring was reduced by over 60%, cutting labor costs.

These improvements demonstrate that innovative agriculture solutions can enhance sustainability while reducing operational costs.

Case study of IoT-based innovative farming system

This table compares the IoT-integrated system with traditional farming methods, demonstrating efficiency gains, sustainability benefits, and automation-driven improvements.

Table 1. Case study of IoT-based innovative farming system.

Parameter	IoT-Based Farming System	Traditional Farming	Observations/Impact
Water Management	Automated, 30% less water wastage	Manual, prone to overuse	Optimized water use prevents unnecessary wastage and ensures continuous irrigation.
Nutrient Control	Real-time pH & EC adjustment	Manual adjustments, inefficient	Automated pH and EC control maintains ideal growing conditions.
Labor Dependency	60% reduction in manual work	High labor costs	Automation reduces the need for human intervention, lowering operational costs.
Monitoring	Remote real-time dashboard	On-site manual inspection	IoT-based system enables remote access, reducing the need for on-site presence.
Yield Improvement	20-25% increase in productivity	Variable, dependent on manual efforts	Precision farming increases output through efficient monitoring and automation.
Water Level Monitoring	Automated refill at 70% level	Manual refilling	Ensures uninterrupted water supply and prevents crop failure.
pH Monitoring	Automated balancing at pH 7	Requires manual testing and correction	Stable water quality optimizes plant growth and fish health in aquaponics.
Ammonia Level Control	Maintained at safe levels (0%)	Risk of high ammonia causing health issues	Automated ventilation prevents air pollution and respiratory diseases in livestock.
Light Intensity Control	Artificial lighting activated when needed	Continuous or manual control	Reduces energy consumption by only activating grow lights when necessary.
Temperature Control	Automated fan and fogger activation	Manual temperature regulation	Prevents heat stress in poultry and dehydration in crops.
System Response Time	Water pump: 5 sec, pH balance: 3 sec, Air Quality: 3 sec, Light: Immediate	Delayed response time	Immediate corrective actions prevent environmental fluctuations affecting productivity.
Resource Efficiency	30% reduction in water wastage, optimized nutrient usage	High resource wastage	IoT ensures sustainability by reducing the overuse of resources.

Compared to traditional farming, the new IoT-based farming system greatly enhances resource utilization, automation, and monitoring. Water management using automation reduces wastage by 30% through continuous irrigation without manual intervention. The system balances the pH and EC levels for better aquaponics plant growth and the health of fish. Remote real-time monitoring using dashboards eliminates the need for physical visits, which saves labor by 60%. Temperature, humidity, and light automation maintain the environment steady, increasing yields by 20-25%. The prompt response time, the pump on within 5 seconds, the pH correction in 3 seconds, and the air quality within 3 seconds ensure that the environmental variations no longer impact productivity. Artificial light is switched on only when required, thus saving power. In general, the IoT-driven precision farming approach maximizes resources, increases agricultural production, and increases sustainability, thereby making it a superior alternative to traditional farming methods.

CONCLUSION AND FUTURE SCOPE

The IoT innovative agriculture system integrating hydroponics, aquaponics, and poultry production has proven to be an efficient solution for real-time monitoring, automated resource management, and remote access. The system effectively regulates water levels, pH, ammonia, temperature, humidity, and light intensity to provide the optimal environmental conditions for plants, fish, and livestock. ESP32 microcontrollers, IoT sensors, and cloud platforms like ThingSpeak/Blynk minimize labor, optimize water and nutrient use, and improve productivity. The outcomes indicate that the system minimizes water wastage by 30%, enhances air quality through the regulation of ammonia levels, and ensures constant temperature and humidity for enhanced growth of plants and Poul Automated systems react to changes in the environment quickly Anner to provide non-interrupted farming operations. Despite network dependency and sensor calibration requirements, the system effectively enhances resource efficiency, minimizes losses, and increases farm productivity.

Future improvements will focus on edge computing to process data locally, reducing dependency on cloud connectivity. Integrating AI-based predictive analytics will enable the system to forecast plant water needs, detect environmental fluctuations, and optimize farm operations. Blockchain technology can enhance data security and transparency, allowing for trusted record-keeping of farm data. A custom mobile application will be developed for advanced user control, push notifications, and voice-enabled commands. Further, renewable energy sources like solar panels will be integrated to make the system more sustainable and energy-efficient. The system will also be scaled for large farms with multi-node IoT networks to allow centralized monitoring of multiple farming zones. This research lays the foundation for technology-driven precision agriculture, ensuring sustainable, automated, and climate-resilient farming practices.

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