JURTEKSI (Jurnal Teknologi dan Sistem Informasi) ISSN 2407-1811 (Print)
Vol XII No 3, June 2026, hlm. 553 – 560 ISSN 2550-0201 (Online)
DOI: https://doi.org/10.33330/jurteksi.v12i3.4710
Available online at https://jurnal.stmikroyal.ac.id/index.php/jurteksi

DEVELOPMENT OF AN ARTIFICIAL INTELLIGENCE BASED VERTICAL HYDROPONIC CULTIVATION SYSTEM

Bachtiar Efendi[1*], Abdul Karim Syahputra[1], Lola Zeramenda Br Tarigan[2]
[1]Computer System, Universitas Royal
[2]Biolgy Education, Universitas Royal
email:*youngthady@gmail.com

Abstract: The advancement of smart agriculture has become a promising solution to increase food productivity and land use efficiency in urban environments. This research aims to develop an Artificial Intelligence (AI)-based vertical hydroponic farming system integrated with LED grow light technology and catfish aquaponics. The proposed system combines vertical hydroponics and aquaponics to optimize plant growth and water utilization. Internet of Things technology enables real-time environmental monitoring through an Arduino Uno microcontroller integrated with LDR, soil moisture, pH, and NPK sensors. The obtained sensor data is processed using the Mamdani Fuzzy Logic algorithm, which performs fuzzification, rule inference, aggregation, and defuzzification to generate adaptive control decisions for irrigation, nutrient circulation, and LED grow light intensity. This research uses the Research and Development (R&D) method through prototype development and performance evaluation for 30 days using spinach (Amaranthus spp.) and mustard greens (Brassica juncea) as test plants. Experimental results showed that the developed system successfully maintained stable environmental conditions, with soil moisture ranging between 69–72%, a pH value between 6.4 and 6.6, and optimal nutrient availability. Plant growth increased significantly. The integration of IoT, AI and aquaponics improves cultivation efficiency, enabling environmental control as a smart and sustainable solution for urban agriculture.

Keywords: artificial intelligence; aquaponic; hydroponic; LED grow light; vertical farming

Abstract: Kemajuan pertanian cerdas telah menjadi solusi yang menjanjikan untuk meningkatkan produktivitas pangan dan efisiensi penggunaan lahan di lingkungan perkotaan. Penelitian ini bertujuan untuk mengembangkan sistem pertanian hidroponik vertikal berbasis Kecerdasan Buatan (AI) yang terintegrasi dengan teknologi lampu tumbuh LED dan aquaponik ikan lele. Sistem yang diusulkan menggabungkan hidroponik vertikal dan aquaponik untuk mengoptimalkan pertumbuhan tanaman dan pemanfaatan air. Teknologi Internet of Things memungkinkan pemantauan lingkungan secara real-time melalui mikrokontroler arduino uno yang terintegrasi dengan sensor LDR, kelembaban tanah, pH, dan NPK. Data sensor yang diperoleh diproses menggunakan algoritma Logika Fuzzy Mamdani, yang melakukan fuzzifikasi, inferensi aturan, agregasi, dan defuzzifikasi untuk menghasilkan keputusan kontrol adaptif untuk irigasi, sirkulasi nutrisi, dan intensitas lampu tumbuh LED. Penelitian ini menggunakan metode Pengembangan (R&D) melalui pengembangan prototipe dan evaluasi kinerja selama 30 hari menggunakan bayam (Amaranthus spp.) dan sawi hijau (Brassica juncea) sebagai tanaman uji. Hasil eksperimen menunjukkan bahwa sistem yang dikembangkan berhasil mempertahankan kondisi lingkungan yang stabil, dengan kelembaban tanah berkisar antara 69–72%, nilai pH antara 6,4 dan 6,6, dan ketersediaan nutrisi yang optimal. Pertumbuhan tanaman meningkat secara signifikan. Integrasi IoT, AI dan aquaponik meningkatkan efisiensi budidaya, untuk pengendalian lingkungan sebagai solusi cerdas dan berkelanjutan untuk pertanian perkotaan.

Keywords: aquaponik; kecerdasan buatan; hidroponik; lampu tumbuh LED; pertanian vertikal

JURTEKSI (Jurnal Teknologi dan Sistem Informasi) ISSN 2407-1811 (Print)
Vol XII No 3, June 2026, hlm. 553 – 560 ISSN 2550-0201 (Online)
DOI: https://doi.org/10.33330/jurteksi.v12i3.4710
Available online at https://jurnal.stmikroyal.ac.id/index.php/jurteksi

INTRODUCTION

The continuous growth of the global population has significantly increased the demand for food production each year. At the same time, the limited availability of agricultural land, particularly in urban areas, has become a major challenge in ensuring sustainable food security. These challenges have accelerated the development of modern agricultural technologies capable of improving land-use efficiency, optimizing water and energy consumption, and enhancing agricultural productivity in a sustainable manner [1], [2].

One of the most promising innovations is the vertical hydroponic farming system, which enables crops to be cultivated in vertically stacked layers, thereby maximizing land utilization compared with conventional farming methods. In addition to improving space efficiency, vertical hydroponics provides a more controlled growing environment through precise regulation of nutrient delivery, irrigation, and environmental conditions, leading to enhanced crop productivity and cultivation efficiency [3].

In addition to hydroponics, aquaponics has emerged as a promising technology in modern agriculture. Aquaponics integrates hydroponic crop cultivation with aquaculture in a closed-loop recirculating system, where organic waste produced by fish is biologically converted into nutrients for plants, while the plants simultaneously filter and improve water quality before it is recirculated back to the fish culture system [4]. This symbiotic approach is considered environmentally sustainable because it significantly reduces water consumption and minimizes the use of chemical fertilizers.

Beyond the implementation of the Internet of Things (IoT), Artificial Intelligence (AI) has become a key enabling technology for enhancing the intelligence and autonomy of smart agricultural systems. Unlike conventional threshold-based or if–else control strategies that generate fixed responses, AI is capable of simultaneously analyzing multiple environmental parameters to produce adaptive and data-driven control decisions. Among various AI techniques, the Mamdani Fuzzy Logic algorithm has been widely adopted in intelligent control systems because of its capability to model uncertainty and nonlinear relationships among environmental variables under dynamic cultivation conditions.

In this research, the Mamdani Fuzzy Logic algorithm is employed to process data collected from LDR, soil moisture, pH, and NPK sensors through four computational stages: fuzzification, rule inference, aggregation, and defuzzification. The resulting output is used to generate adaptive control actions for regulating irrigation pumps, nutrient circulation pumps, and LED grow light intensity automatically according to real-time environmental conditions. Consequently, the integration of IoT-based sensing and AI-driven decision-making enables the proposed system to perform autonomous environmental monitoring and intelligent control, thereby improving cultivation efficiency and maintaining optimal plant growth conditions.

Another essential component of the proposed smart farming system is the LED grow light, which provides the light spectrum required for photosynthesis when natural sunlight is insufficient. The use of LED grow lights ensures continuous plant growth under varying environmental conditions while offering higher energy efficiency than conventional lighting technologies [6].

Several previous studies have explored the application of the Internet of Things (IoT) and Artificial Intelligence (AI) in smart agriculture. Baraskar et al. (2025) developed an AI-based automated hydroponic system; however, their work did not integrate vertical hydroponics with aquaponics. Herrera-Arroyo et al. (2025) proposed an IoT-enabled hydroponic system for real-time environmental monitoring, yet it lacked an AI-based decision-making mechanism for adaptive control. Meanwhile, Mozumder and Sharifuzzaman (2021) implemented a Decision Regression Tree algorithm for an IoT-based biofloc water management system, although their approach was not applied to vertical hydroponic cultivation. Based on these studies, the novelty of the present research lies in the integration of IoT, Mamdani Fuzzy Logic, vertical hydroponics, catfish aquaponics, and LED grow light technology into a unified intelligent farming system capable of simultaneously performing real-time monitoring and adaptive environmental control [2], [4].

Motivated by these research gaps, this research aims to develop an Artificial Intelligence-based vertical hydroponic farming system integrated with LED grow light technology and catfish aquaponics. The proposed system is expected to enhance the efficiency of integrated plant and fish cultivation, maintain optimal environmental conditions through intelligent decision-making, and contribute to the advancement of sustainable urban agriculture by improving resource utilization and cultivation productivity.

METHOD

This research employed the Research and Development (R&D) method, which consisted of four main stages: system design, hardware implementation, software development, and system performance evaluation [9].

The proposed system was developed using an Arduino Uno microcontroller as the central control unit [10], [11]. The hardware architecture incorporated several environmental sensors, including an LDR sensor for measuring light intensity, a soil moisture sensor for monitoring the moisture content of the planting medium, a pH sensor for measuring water acidity, and a Soil NPK sensor for detecting nutrient concentrations.

The Internet of Things (IoT) architecture enables real-time environmental monitoring by integrating the Arduino Uno with the LDR, soil moisture, pH, and NPK sensors. Sensor data are continuously acquired and transmitted to the processing unit, where they are analyzed to determine the current environmental conditions. These data serve as input for the Artificial Intelligence (AI) module, which automatically controls the irrigation pump, nutrient circulation pump, and LED grow light according to the requirements of the cultivation environment [9], [10].

The Artificial Intelligence (AI) component is implemented using the Mamdani Fuzzy Logic algorithm. The acquired sensor data are processed through four computational stages: fuzzification, rule inference, aggregation, and defuzzification. Unlike conventional if–else logic, which produces fixed control responses based on predefined thresholds, Mamdani Fuzzy Logic

JURTEKSI (Jurnal Teknologi dan Sistem Informasi) ISSN 2407-1811 (Print)
Vol XII No 3, June 2026, hlm. 553 – 560 ISSN 2550-0201 (Online)
DOI: https://doi.org/10.33330/jurteksi.v12i3.4710
Available online at https://jurnal.stmikroyal.ac.id/index.php/jurteksi

generates adaptive decisions by simultaneously considering multiple environmental variables, including soil moisture, pH, light intensity, and nutrient concentration. The resulting control actions optimize irrigation, nutrient delivery, and LED grow light intensity, thereby improving the precision, adaptability, and operational efficiency of the intelligent hydroponic farming system [14], [15].

$$V\ sensor = \frac{ADC \times 5}{1023} \quad (1)$$

The system was evaluated over a 30-day experimental period using spinach (*Amaranthus spp.*) and mustard greens (*Brassica juncea*) cultivated in a multi-tier vertical hydroponic system. The evaluation focused on several performance indicators, including plant height, soil moisture, pH level, light intensity, and NPK nutrient concentration, to assess the effectiveness of the proposed IoT- and Artificial Intelligence-based cultivation system.

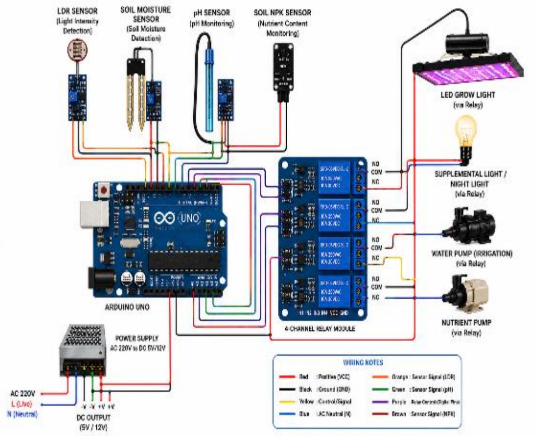

Image 1. System Configuration

From the system configuration image as shown in Figure 1, then the configuration results and tools information is obtained as in Table 1.

Table 1. Sensor and Actuator Configuration

Component	Function	Arduino Pin
LDR Sensor	Detects light intensity	A0
Soil Moisture Sensor	Monitors soil moisture	A1
pH Sensor	Monitors water pH	A2
Soil NPK Sensor	Monitors nutrient concentration	A3
LED Grow Light Relay	Controls LED grow light operation	D2
Irrigation Pump Relay	Controls irrigation system	D3
Nutrient Pump Relay	Controls nutrient solution delivery	D4

RESULTS AND DISCUSSION

The experimental results demonstrate that the proposed Artificial Intelligence (AI)-based vertical hydroponic farming system operated automatically and maintained stable performance throughout the evaluation period.

The LDR sensor successfully controlled the LED grow light automatically whenever the ambient light intensity decreased. The implementation of the LED grow light provided an adequate light spectrum to support photosynthesis, thereby maintaining optimal plant growth during nighttime and under low-light environmental conditions [12].

JURTEKSI (Jurnal Teknologi dan Sistem Informasi) ISSN 2407-1811 (Print)
Vol XII No 3, June 2026, hlm. 553 – 560 ISSN 2550-0201 (Online)
DOI: https://doi.org/10.33330/jurteksi.v12i3.4710
Available online at https://jurnal.stmikroyal.ac.id/index.php/jurteksi

The soil moisture sensor effectively activated the irrigation pump whenever the growing medium reached a low moisture level. This automatic irrigation mechanism maintained the soil moisture within the optimal range of 69–72%, ensuring favorable conditions for plant growth.

The system's decision-making process was implemented using the Mamdani Fuzzy Logic algorithm. Sensor data collected from the LDR, soil moisture, pH, and NPK sensors were processed through four computational stages: fuzzification, rule inference, aggregation, and defuzzification, enabling the system to generate adaptive control decisions in response to dynamic environmental conditions [14],[15].

Compared with conventional if–else-based control, the proposed AI approach simultaneously considers multiple environmental variables to determine the optimal irrigation duration, nutrient solution delivery, and LED grow light intensity. Consequently, the intelligent control strategy improves decision-making accuracy, enhances resource utilization efficiency, and provides more stable environmental conditions for hydroponic cultivation.

Image 2. Aplication system

The experimental results showed that spinach growth increased from an initial height of 2 cm to 28 cm over a 30-day cultivation period. Similarly, mustard greens exhibited significant growth, with plant height increasing from 2 cm to 27 cm during the same experimental period.

Table 2. Plant Growth Evaluation Results

Plant	Initial Height (cm)	Final Height (cm)	Growth Perfor-mance
Spinach (Amaranthus spp.)	2	28	Excellent
Mustard Greens (Brassica juncea)	2	27	Good

Integrating an aquaponic system with catfish farming contributes positively to the efficiency of water and nutrient use. Pond water containing organic fish waste is reused as a natural nutrient source for plants, thereby reducing the need for chemical fertilizers [9], [13].

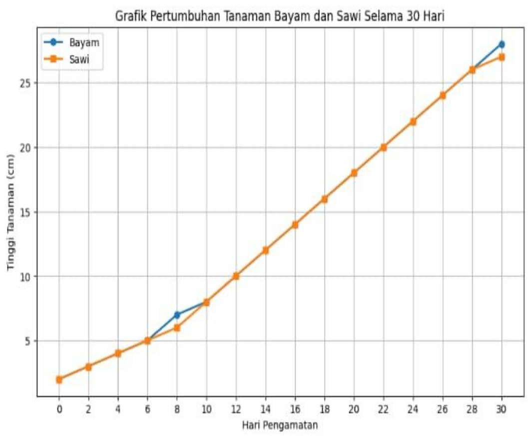

Image 3. Growth graph of spinach and mustard greens.

JURTEKSI (Jurnal Teknologi dan Sistem Informasi) ISSN 2407-1811 (Print)
Vol XII No 3, June 2026, hlm. 553 – 560 ISSN 2550-0201 (Online)
DOI: https://doi.org/10.33330/jurteksi.v12i3.4710
Available online at https://jurnal.stmikroyal.ac.id/index.php/jurteksi

The implementation of Artificial Intelligence (AI) through sensor-based automation significantly improved the operational efficiency of the proposed farming system compared with conventional manual methods. The system was capable of operating in real time while minimizing human intervention during environmental monitoring and control processes [16].

The findings of this research are consistent with previous research demonstrating that the integration of Internet of Things (IoT) technology and automated sensing systems can substantially enhance the productivity, efficiency, and sustainability of modern agricultural practices [6], [7], [17].

This research successfully developed an Internet of Things (IoT)- and Artificial Intelligence (AI)-based vertical hydroponic farming system employing the Mamdani Fuzzy Logic algorithm. The IoT architecture enables real-time acquisition of environmental data through LDR, soil moisture, pH, and NPK sensors. Subsequently, the AI module processes these data through the stages of fuzzification, rule inference, aggregation, and defuzzification to generate adaptive control decisions for regulating the irrigation pump, nutrient circulation pump, and LED grow light.

Image 4. Spinach Harvest Result

Experimental results demonstrated that the proposed system effectively maintained stable environmental conditions, improved the efficiency of water, nutrient, and energy utilization, and promoted optimal growth of spinach (Amaranthus spp.) and mustard greens (Brassica juncea). The integration of IoT and AI resulted in a more precise, responsive, and autonomous smart farming system with considerable potential for sustainable urban agriculture applications.

CONCLUSION

This research successfully developed an Artificial Intelligence (AI)-based vertical hydroponic farming system integrated with LED grow light technology and catfish aquaponics. The proposed system automatically controlled lighting, irrigation, and nutrient distribution using an integrated network of LDR, soil moisture, pH, and Soil NPK sensors. Real-time environmental data collected through the Internet of Things (IoT) architecture were processed using the Mamdani Fuzzy Logic algorithm to generate adaptive control decisions, thereby improving the precision and efficiency of the cultivation process.

The experimental results demonstrated that the proposed system effectively maintained stable environmental conditions, resulting in optimal growth of spinach (Amaranthus spp.) and mustard greens (Brassica juncea). Furthermore, the integration of the aquaponics system enhanced water and nutrient utilization efficiency, while the LED grow light provided an optimal light spectrum to support photosynthesis under varying environmental conditions.

Overall, the developed intelligent farming system demonstrates significant potential for application in modern urban agriculture by improving land-use efficiency, reducing water and energy consumption, and supporting sustainable food production through the integration of IoT, Artificial Intelligence, and precision agriculture technologies.

BIBLIOGRAPHY

[1] G. Rajaseger, "Hydroponics: Current Trends in Sustainable Crop Production," Journal of Agriculture and Food Research, vol. 15, pp. 1–12, 2023.
[2] T. Baraskar, V. Khatri, P. Kolhe, and M. Katyarmal, "AI-Powered Automated Hydroponic System for Smart Agriculture," MethodsX, vol. 13, pp. 1–15, 2025.
[3] P. A. C. Setiawan, "Smart Vertical Farming: The Role of IoT in Achieving Sustainable Agriculture," Journal of Information Technology, vol. 8, no. 2, pp. 55–67, 2025.
[4] R. Herrera-Arroyo et al., "Smart Hydroponic Cultivation System for Lettuce Using IoT Technology," Smart Cities, vol. 8, no. 4, pp. 110–125, 2025.
[5] T. D. Akpenpuun, "Advancements in Vertical Farming: A Review of Potentials and Challenges," Korean Journal of Agricultural Science, vol. 52, no. 1, pp. 77–90, 2025.
[6] M. S. Dennison, "The Role of Automation and Robotics in Transforming Hydroponic and Aquaponic Farming," Discover Agriculture, vol. 3, no. 2, pp. 1–18, 2025.
[7] S. Wright and V. Hughes, "IoT and AI for Smart Aquaponics and Hydroponics Systems," International Journal of Smart Agriculture, vol. 6, no. 1, pp. 20–35, 2025.
[8] F. Assimakopoulos et al., "AI and Related Technologies in the Fields of Smart Agriculture," Information Journal, vol. 16, no. 100, pp. 1–40, 2025.
[9] M. Dutta et al., "Internet of Things-Based Smart Precision Farming in Soilless Agriculture," International Journal of Agricultural Engineering, vol. 11, no. 3, pp. 145–160, 2025.
[10] X. Cao et al., "IGrow: A Smart Agriculture Solution to Autonomous Greenhouse Control," IEEE Access, vol. 9, pp. 113421–113438, 2021.
[11] S. A. Mozumder and A. S. M. Sharifuzzaman, "Smart IoT-Biofloc Water Management System Using Decision Regression Tree," International Conference on Smart Agriculture, pp. 55–62, 2021.
[12] D. Rakocy, "Recent Advances in Aquaponic Systems: A Critical Review," Reviews in Aquaculture, vol. 17, no. 2, pp. 1–22, 2025.
[13] J. Resh, Hydroponic Food Production, 8th ed. Boca Raton, FL, USA: CRC Press, 2021.
[14] S. Agustian, I., Prayoga, B. I., Santosa, H., Daratha, N., & Faurina, R. (2022). NFT Hydroponic Control Using Mamdani Fuzzy Inference System. Journal of Robotics and Control.
[15] Escalante-Mamani, J. C., et al. (2025). Design and Validation of an IoT-Integrated Fuzzy Logic Controller for pH and Electrical Conductivity Regulation in NFT

Hydroponic Systems. Electronics (MDPI).
[16] S. Kurniawan and A. Pratama, “Implementation of Arduino-Based Smart Farming Systems Using Environmental Sensors,” Journal of Agricultural Informatics, vol. 9, no. 1, pp. 66–75, 2024.
[17] R. Pratama and A. Wijaya, “Efficiency Analysis of LED Grow Light on Hydroponic Vegetable Growth,” Journal of Smart Farming Technology, vol. 5, no. 3, pp. 88–97, 2023.