Research Paper

Design of Internet of Things (IoT) Based Indoor Hydroponic System for Pagoda Mustard (*Brassica Rapa* Subsp. *Narinosa*)

Bagus Muhammad Akbar*, Arif Umami, Mukti Ahmad Nur Cahya,
Ahmad Shidiq Misbahudin, Devid Ilham Syahroni
Universitas Pembangunan Nasional Veteran Yogyakarta, Indonesia

Received : Oct 3, 2025	Revised : Oct 6, 2025	Accepted : Oct 7, 2025	Online : October 14, 2025

Abstract

Hydroponics offers a land-efficient alternative for vegetable production, yet indoor operation requires reliable monitoring and control of nutrient chemistry and microclimate. This work implements an IoT-based indoor hydroponic system for Brassica rapa subsp. Narinosa and addresses the gap between conceptual design and functional verification. This research is intended to realize the system and verify its essential functions prior to closed-loop agronomic trials. This Methodology used an engineering/design approach with snapshot-based checks (no full time-series). We performed two-point pH calibration (7–4), EC calibration at 1.413 mS/cm normalized to 25 °C, peristaltic-pump characterization (pulse duration → delivered volume), and checkpoints before dosing and after standardized mixing (T+10 min). With this methodology, the system was successfully realized; pH readings were accurate in the acidic range and showed a small neutral-range bias (~0.2 pH). Pump dosing was predictable with a +10% tendency at the 10 mL setting, and TDS increased consistently with nutrient addition. Spatial spread among sampling points after 10 min mixing indicated non-uniformity/stratification, explaining the larger post-dosing pH gap between the in-line sensor (~6.1–6.3) and the handheld meter (~7.0–7.1). We recommend improved mixing/recirculation, sensor placement downstream of the mixing zone, EC normalization to 25 °C, and short pulse-and-cooldown dosing with a per-channel correction table. These results confirm readiness for closed-loop pH–EC evaluation (MAE, %overshoot, settling time) and provide replication artifacts (wiring/BOM and calibration SOP) to support future agronomic testing.

Keywords: *Internet Of Things, Hydroponics Indoor System, Pagoda Mustard, Smart Indoor Hydroponic System.*

INTRODUCTION

Over the past few centuries, the human population has experienced a very significant increase. In 1800, the world population was around one billion, while currently it has exceeded eight billion. In Indonesia, the population in 2023 is estimated to reach ± 231 million people (Roser et al., 2013). Rapid population growth is putting pressure on the availability of open agricultural land. On the other hand, the vegetable requirement for adults according to WHO is around 400 grams per day (one portion is ± 80 grams), where insufficient fruit and vegetable intake increases the risk of death from gastrointestinal cancer (± 14%), coronary heart disease (± 11%), and stroke (± 9%) (WHO/FAO).

Pagoda mustard (*Brassica rapa subsp. narinosa*) is a leafy vegetable with high economic value and increasing market demand (Yati & Dewanti, 2022). However, production has not been able to keep up with consumption due to limited land and constraints of conventional cultivation such as pest and disease attacks, weather fluctuations, and declining land productivity (Shintia, 2022). Hydroponics is one approach to urban farming that is efficient in water and nutrients, and can be applied both outdoors and indoors. Hydroponics, soilless cultivation with water-based nutrient solutions, is highly dependent on the regulation of nutrient parameters and microclimate

Corresponding author's email: bagusmuhammadakbar@upnyk.ac.id

(Ramsari & Hidayat, 2022). In indoor practices, regular monitoring is required to maintain the quality of the results (Caniago & Masril, 2023). The concept of smart farming based on the Internet of Things (IoT) allows for real-time remote monitoring and control of growing conditions, and has the potential to reduce maintenance costs compared to conventional practices (Komaludin, 2018). In indoor environments, key factors include lighting and nutrient provision; lighting parameters include spectrum, duration (photoperiod), and intensity which are adjusted to the physiological needs of the commodity or mimic the spectral characteristics of sunlight (Musayannah et al., 2024). A reference study demonstrates the design of an IoT-based hydroponic control device with a clear architecture (NodeMCU/ESP, ADS for analog readings, pH–TDS–temperature/humidity sensors, and a peristaltic pump) and sensor placement at the inlet line so that readings represent nutrient input to the roots. However, this work is still in the design stage and therefore has not reported the performance of the closed pH–EC control (set-point stability, overshoot, settling time), calibration procedures & sensor drift mitigation, reliability/operational indicators, and LED lighting settings for a specific indoor scenario for pagoda mustard (Umami & Akbar, 2022).

To address this gap, this research implements the design into an IoT-based indoor hydroponic system specifically for pagoda mustard greens, focusing on: (i) designing and functionally verifying a pH–EC control loop based on sensor readings at the inlet line and peristaltic pump actuation (reporting MAE, overshoot, and settling time); (ii) developing a calibration SOP and monitoring pH/EC sensor drift; and (iii) evaluating initial operational reliability (uptime, manual intervention, power consumption). Agronomic evaluation (growth/biomass) and LED lighting optimization are planned as follow-up work after this initial functional verification.

LITERATURE REVIEW

The primary reference reports the design of an IoT-based hydroponic control device for indoor/greenhouse settings, using NodeMCU/ESP8266, an ADS1115 16-bit ADC, and pH–TDS–temperature/humidity sensors with data streamed to a ThingsBoard dashboard, an architecture this study adopts as its hardware–software foundation (Umami & Akbar, 2022). More recent NFT implementations demonstrate automated pH–EC control via IoT monitoring pH, EC, and water level, and performing automatic dosing of acid/alkali, nutrients, and make-up water, thereby reducing manual intervention and enabling remote operation (Jain & Kaur, 2024).

Theoretically, the system operates as a closed loop: sensors read pH/EC, the controller computes error to a set-point, and peristaltic pumps dose until the process variable restabilizes. Concurrent pH–EC control can also be approached by real-time manipulation of the ammonium:nitrate ratio in the nutrient solution, underscoring the need to report loop metrics such as set-point stability, overshoot, and settling time when a design is realized (Bosman et al., 2024). For leafy vegetables, practical guidance places the hydroponic operating pH roughly around 5.5–6.0 (with a broader workable range of 5.0–7.0), making accurate set-point selection and dosing strategy critical (Penn State Extension, 2023).

From an instrumentation standpoint, EC readings should be normalized to 25 °C because conductivity is temperature-dependent; metrology notes recommend a compensation coefficient of about 2%/°C for fresh-salt solutions so that measurements are comparable across conditions (Mettler Toledo, 1996/1997). This study, therefore applies two-point pH calibration (7 and 4), EC calibration at 1.413 mS/cm with 25°C normalization, and peristaltic-pump characterization ($Q=\Delta V/\Delta t$) to map pulse duration to delivered volume, then verifies performance with snapshot criteria (±0.10 pH; ±0.10 mS/cm) before/after dosing and after a fixed mixing time. For future indoor-lighting experiments, a reference DLI ≈ 11.5 mol m^{-2} day^{-1} under a 16-h photoperiod at constant PPFD has been reported for lettuce, offering a useful starting point for light-parameter planning (Gavhane et al., 2023). Finally, this research focuses on designing the Internet of Things for a smart hydroponic indoor system, especially for pagoda mustard.

RESEARCH METHOD

This study follows an engineering/design approach to realize an IoT-based indoor hydroponic system and verify its basic functions using a test vessel. Data were collected as manual checkpoints rather than continuous logging: sensor and reference readings were recorded before dosing (T0) and after mixing at fixed intervals (e.g., T+5 min and T+10 min), alongside calibration records (two-point pH at 7 and 4; EC at 1.413 mS/cm @25 °C) and pump dispensing tests (measured volume for preset pulse durations). Quantitative analysis reports absolute error/bias and percent deviation of pH and EC versus the reference instrument at each checkpoint, as well as dispense accuracy and repeatability (mean ± SD, CV%) for the pumps. A simple pass/fail criterion is used for control verification: after dosing and mixing, the solution should enter and remain within the tolerance band (±0.10 pH; ±0.10 mS/cm) by T+10 min. Qualitative notes from brief expert/usability checks on the dashboard and procedures are summarized to inform the Discussion. System wiring is shown in Figure 1.

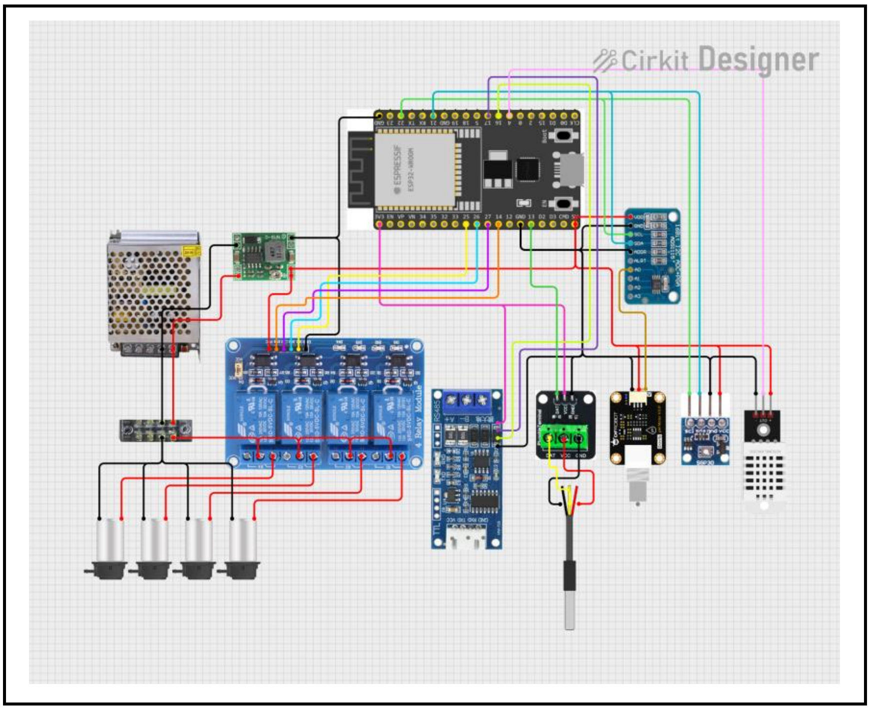

Figure 1. Wiring diagram

The pump characterization showed good accuracy in this research with AB channel and pH channel in the pump characterization delivered in Figure 2.

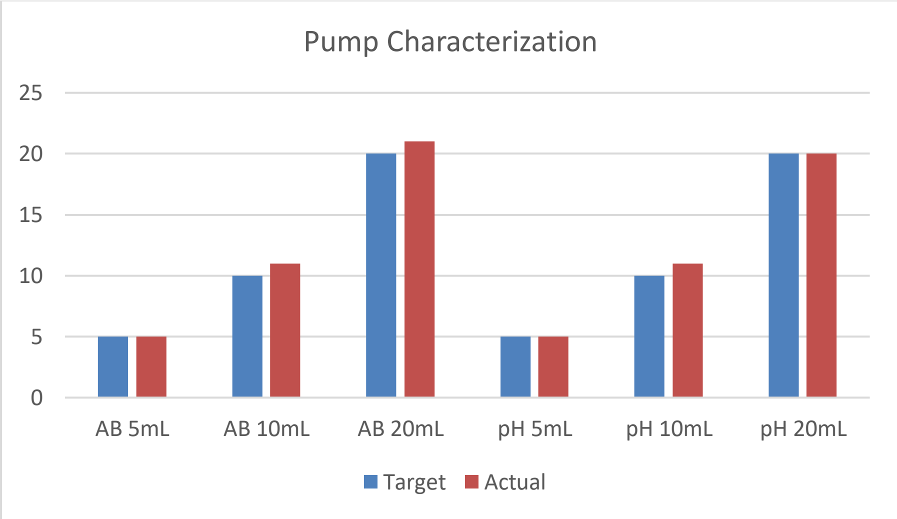

Figure 2. Pump characterization

FINDINGS AND DISCUSSION

Based on the test, the system was successfully implemented and all components were functional. In the pH test, the sensor read 4.1 (buffer 4.1) and 6.8 (buffer 7.0), and 7.3 in the raw water, compared to the pH meter's reading of 7.5, indicating a negative bias of ~0.2 pH in the neutral range (pH 7.0).

Table 1. pH Checkpoints

Checkpoint	Sensor_pH	Reference_pH	Δ pH (Sensor - Ref)
Buffer pH 4.0	4.10	4.10	0.00
Buffer pH 7.0	6.80	7.00	-0.20
Raw water	7.30	7.50	-0.20
After 5 mL dosing (10 min mix)	6.30	7.10	-0.80
After 10 mL dosing (10 min mix)	6.20	7.10	-0.90
After 20 mL dosing (10 min mix)	6.10	7.00	-0.90

The TDS test showed an initial reading of 139 vs. a TDS meter reading of 132 (≈+5.3%). After gradual addition of A+B concentrates, the sensor TDS increased from 139→194→255→367, while the TDS meter at different points showed a range of 213–229 (5 ml), 239–276 (10 ml), and 342–376 (20 ml) 10 minutes after mixing; this indicates a reduced inter-point mixture non-uniformity at higher doses.

Table 2. TDS Snapshots

Dose_mL	Sensor_TDS	Reservoir_TDS	Middle_TDS	Mixing_min
0	139	132		
5	194	213	229.0	10.0
10	255	276	239.0	10.0
20	367	342	376.0	10.0

The pump characterization showed good accuracy: AB channel delivered 5 ml → 5 ml, 10 ml → 11 ml (+10%), 20 ml → 21 ml (+5%); pH channel 5 ml → 5 ml, 10 ml → 11 ml (+10%), 20 ml → 20 ml (0%).

Table 3. Pump characterization

Channel	Target_mL	Actual_mL	Error_mL	Error_%
AB	5	5	0	0.0
AB	10	11	1	10.0
AB	20	21	1	5.0
pH	5	5	0	0.0
pH	10	11	1	10.0
pH	20	20	0	0.0

Functionally, the device meets the design objectives: the sensor and actuator work, the flow rate is characterized, and the TDS response follows the nutrient addition trend. A small pH bias (~0.2) in the buffer indicates a near-correct calibration; however, the large gap (~0.8–0.9) during operation is likely influenced by the sensor location (inlet), mixing time/effectiveness (10 min), and differences in measurement conditions (in-line sensor vs. pH meter at another point). Suggested improvements: (i) place the pH/EC sensor in a homogeneously mixed zone (e.g., after circulation), add agitation/recirculation, or increase the mixing duration to even out the concentration; (ii) apply EC temperature compensation to 25 °C and recheck the two-point pH calibration after operation; (iii) for dosing, use short, repeated pulses (e.g., 1–2 s) with a cooldown and a correction table (as 10 ml tends to be +10%) to achieve the set-point without overshoot, while reducing pump wear. Overall, these results confirm the system's readiness for closed-loop pH–EC testing with time-series data logging (MAE, %overshoot, settling) in the following cycles: agronomic testing and lighting optimization can be placed as further work after control stability is verified.

CONCLUSIONS AND FURTHER RESEARCH

This study demonstrated that the designed IoT-based indoor hydroponic system is feasible and performs as intended. In snapshot tests without time-series, the pH sensor was accurate in the acidic range but exhibited a small bias of ~0.2 pH in the neutral range (sensor pH 7.3 vs meter pH 7.5), while peristaltic pump characterization showed predictable dosing with a +10% trend at the 10 mL setting and close to target at 5 mL and 20 mL. The TDS trend increased with nutrient addition, but the spread between measurement points after 10 minutes of mixing (e.g., 213/229/226 at 5 mL) indicated that solution homogeneity had not yet been fully achieved. The finding of lower post-mixing pH for the in-line sensor (≈6.1–6.3) compared to the handheld meter (≈7.0–7.1) is consistent with stratification and differences in measurement locations (in-line vs hand sample). These findings confirm that the system is at a sufficient level of readiness to proceed to closed-loop pH–EC control evaluation.

Technically, the small pH difference in the buffer and the larger one after dispersion can be understood as a combination of calibration that requires slope/offset refinement and non-uniform mixing throughout the volume. This has clear design implications: (i) increase recirculation or add a static mixer to ensure a truly homogeneous mixing zone; (ii) review the sensor position so that the in-line readings represent the nutrients received by the roots in line with the considerations of sensor placement in the inlet line in the reference design; and (iii) normalize the EC to 25 °C for each reading to eliminate temperature effects. With these three steps, the difference in readings between points is expected to narrow and the pH–EC control becomes more stable. From an operational perspective, dispensing characterization demonstrated the need for a pulse-and-cooldown strategy with a per-channel dose correction table to ensure setpoint is achieved without overshoot and reduced pump mechanical load (e.g., a small correction to the 10 mL target trending towards +10%). Recommended maintenance practices include post-run two-point pH recalibration, checking for a standard EC deviation of 1.413 mS/cm and correcting if necessary, and snapshot-based mixing validation (T+5 and T+10 min) before concluding that the target band (±0.10 pH; ±0.10 mS/cm) has been achieved.

This sequence of procedures makes the system more reliable as a closed-loop platform in subsequent cycles. As an added benefit, we include a wiring summary/BOM and calibration SOP for easy system replication.

This research is still limited to designing an Internet of Things system for plants with a short lifespan and no fruit in indoor hydroponic systems. Future research is needed to design an Internet of Things model for indoor hydroponics for fruit plants and those with a longer harvest life.

REFERENCES

Bosman, R. C., Van Rooyen, I. L., Brancken, J., Brink, H. G., & Nicol, W. (2024). Simultaneous pH and EC control in hydroponics through real-time manipulation of the ammonium-to-nitrate ratio in the nutrient solution. *Scientia Horticulturae, 332*, 113185. https://doi.org/10.1016/j.scienta.2024.113185

Caniago, D. P., & Masril, M. A. (2023). Smart indoor hydroponic garden using Internet of Things. *Jurnal SIMETRIS, 14*(2). http://dx.doi.org/10.24176/simet.v14i2.9756

Gavhane, K. P., Hasan, M., Singh, D. K., Kumar, S. N., Sahoo, R. N., & Alam, W. (2023). Determination of optimal daily light integral (DLI) for indoor cultivation of iceberg lettuce in an indigenous vertical hydroponic system. *Scientific Reports, 13*, 10923. https://doi.org/10.1038/s41598-023-36997-2

Jain, S., & Kaur, M. (2024). Design and implementation of an IoT-based automated EC and pH control system in an NFT-based hydroponic farm. *Engineering, Technology & Applied Science Research, 14*(1), 13078–13081. https://doi.org/10.48084/etasr.6393

Komaludin, D. (2018). Penerapan teknologi *Internet of Things (IoT)* pada bisnis budidaya tanaman hidroponik sebagai langkah efisiensi biaya perawatan. *Prosiding FRIMA (Festival Riset Ilmiah Manajemen dan Akuntansi), 1*, 682–690. https://doi.org/10.55916/frima.v0i1.255

Mettler Toledo (Gray, D. M.). (1996). *Temperature compensation for conductivity in natural waters* (Tech. note). Mettler-Toledo Process Analytics. https://www.mt.com/my/en/home/library/know-how/process-analytics/Paper-THOR-Temp-Comp-Cond-Re-Bev-Gray-11-96.html

Musayannah, H., Adrianto, Y. R., & Budiarjo, H. (2024). Sistem HIPOI 1.0: *Hidroponik indoor* berbasis *Internet of Things* untuk tanaman selada dengan teknik NFT. *Electron: Jurnal Ilmiah Teknik*

Elektro, 5(1), 1–10. http://dx.doi.org/10.33019/electron.v5i1.113

Penn State Extension. (2023). *Hydroponics systems and principles of plant nutrition: Essential nutrients, function, deficiency, and excess.* https://extension.psu.edu/hydroponics-systems-and-principles-of-plant-nutrition-essential-nutrients-function-deficiency-and-excess/

Ramsari, N., & Hidayat, T. (2022). Monitoring system and hydroponic plant automation using microcontroller *Internet of Things* based (IoT). *Compiler, 11*(2), 59–74. https://doi.org/10.28989/compiler.v11i2.1365

Roser, M., Ritchie, H., & Ortiz-Ospina, E. (2013). *World population growth.* Our World in Data. Retrieved September 13, 2025, from https://ourworldindata.org/world-population-growth

Shintia, A. (2022). *Respons pertumbuhan sawi pagoda (Brassica narinosa L.) terhadap kombinasi konsentrasi nutrisi AB mix dan pupuk organik cair hidroponik dengan sistem sumbu* [Undergraduate thesis, Universitas ITERA]. https://repo.itera.ac.id/depan/submission/SB2206150068

Umami, A., & Akbar, B. M. (2022). Design of *Internet of Things (IoT)* based hydroponic controlling device in pyramid greenhouse. *Journal Techno, 8*(2), 159–166. https://doi.org/10.31315/journal%20techno.v8i2.8474

Yati, M., & Dewanti, P. (2022). Pengaruh pemberian limbah padat ikan lele terhadap pertumbuhan tanaman sawi pagoda (*Brassica narinosa*). *Berkala Ilmiah Pertanian, 5*(3), 163. http://dx.doi.org/10.19184/bip.v5i3.15913