

Cloud internet of things-based cyber-physical system for microalgae integrated-aquaculture recirculating system in Sarawak

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ABSTRACT

The escalating demand for high-quality protein has driven commercial aquaculture's growth, and microalgal biomass shows potential to support this sector and contribute to global food security. Digitalizing integrated microalgal-aquaculture systems can significantly enhance sustainable protein production. Enabling technologies like the internet of things (IoT) and cyber-physical systems (CPS) are crucial for creating resilient aquaculture systems that ensure profitability, ecosystem health, and climate adaptability. However, applying cloud IoT and CPS solutions in the microalgae industry, especially the integrated microalgae and prawn farms remain underexplored. This work aims to develop a smart system for real-time monitoring and analysis of integrated microalgae and prawn farms in Sarawak, supported by an intelligent decision-support system. Utilizing a hybrid cloud-fog architecture, the system ensures efficient data acquisition, storage, and analysis and provides real-time monitoring through various user interfaces. Deployed in the plant site for over three months, the proposed system has proven effective in enhancing process efficiency and functionality, offering valuable reference in sustainable aquaculture for future enhancements such as multi-sensor and multi-site deployment in other farming systems to promote holistic environment sustainability and digital transformation.

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1. INTRODUCTION

Aquaculture has seen substantial growth globally and is drawing widespread participation. China particularly leads global aquaculture, followed by Indonesia, Vietnam, and Thailand as major competitors. Based on the UN's 2014 State of World Fisheries and Aquaculture report, aquaculture supports the livelihoods of 60 million people in Asia and Africa [1]. In Malaysia, the aquaculture sector contributes to national seafood production increased from 7% in 1992 to nearly 13% in 2003, with production increasing from under 80,000 metric tons in 1992 to over 427,000 metric tons, amounting to RM3 billion in 2017 [2]. This growth is primarily driven by population increases, generating employment, business, and investment opportunities, amounting to over 18,000 aquafarmers managing over 34,000 hectares as of 2017.

The escalating demand for high-quality protein has propelled commercial aquaculture for fish, crustaceans, mollusks, seaweeds, and other aquatic organisms. Identified as a priority sector, Malaysia ranked among the top 15 world producers in 2014 [3]. Sarawak had the second-highest number of aquaculture

culturists in 2018, *i.e.*, 6,686 aqua culturists [4]. There is significant growth potential through technological advancements, improved resource use, and integrating aquaculture with other farming activities. However, challenges persist, such as high feed costs, inefficient systems, deteriorating water quality, and limited advanced technology integration [5]–[7]. Recent growth in aquaculture feed and fishery sectors underscores the need for sustainable, nutrient-rich feed ingredients. Microalgal biomass shows promise for fish and prawn aquaculture, contributing to food security in the bio-economy. The biochemical composition and nutritional value of microalgae remain under-explored. Digitalizing integrated microalgal-aquaculture systems offers potential for sustainable protein sources. Industry 4.0 (IR 4.0) technologies, including internet of things (IoT), artificial intelligence (AI), and wireless sensor networks, can conserve freshwater and maximize crop yields [8]–[12]. However, the smart farming that integrates microalgae cultivation and prawn farms to cope with dynamic process parameters remains underexplored. Key parameters such as biomass concentration, pH, light intensity, temperature, and tank level need real-time and precise monitoring for optimal biomass productivity [13].

Sarawak's land banks and inland waterways present significant commercial aquaculture potential. Aquaculture growth can be fostered through technological advancements. Developing low-cost and efficient aquaculture technologies can help local farmers optimize production and contribute to regional economic development and food security. This project aims to develop a pilot-scale prototype for a cloud-based microalgae-integrated recirculating aquaculture system (MIRAS) in Sarawak, facilitating real-time monitoring, analysis, and control of the integrated system with a decision-support system (DSS). This system will enhance the circular economy and productivity in Sarawak by reusing nutrients and wastewater from prawn effluent tanks for microalgae cultivation, reducing feed costs and wastewater. Figure 1 depicts the proposed pilot-scale prototype of MIRAS.

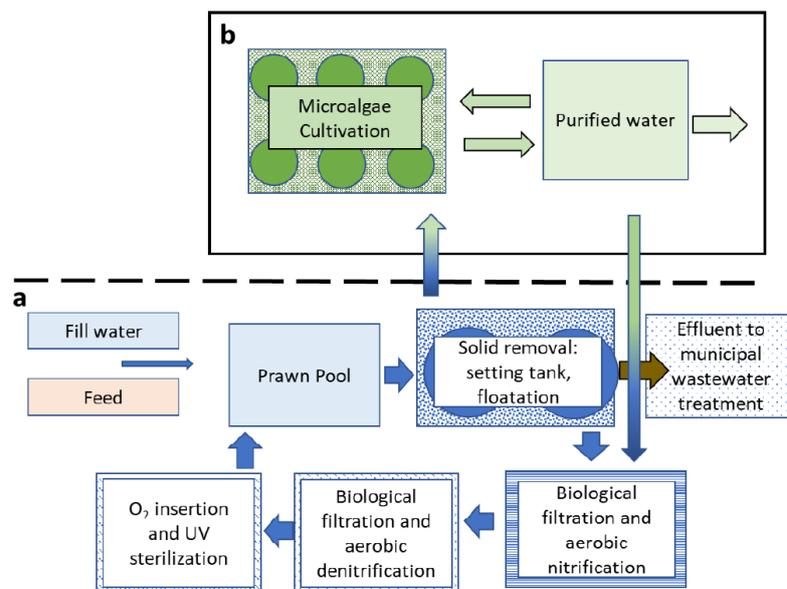


Figure 1. Proposed pilot-scale prototype of MIRAS

2. MIRAS FRAMEWORK

Implementing Industry 4.0 (IR 4.0) solutions aims to enhance collaboration within manufacturing by ensuring real-time access to accurate information for informed decision-making, boosting efficiency and productivity. A cornerstone of IR 4.0 is the cyber-physical system (CPS), which enables seamless integration of physical and computational components [14], by leveraging the IoT to connect to the cloud, enabling real-time monitoring and control of physical components [15]. Networks of physical sensors collect extensive data [16] that must be stored, processed, and analyzed on cloud platforms using advanced digital tools [17], [18]. While IoT-based CPS systems are widely used in sectors like manufacturing, biotechnology, and agriculture, their application in the microalgae industry especially within integrated microalgae and aquaculture farms, is relatively new and under-explored. The high cost of fish feed and the need for timely monitoring of farming wastewater highlight the necessity for an IoT layer-based CPS system to provide real-time monitoring, analysis and controlling of MIRAS supported by a DSS [19].

The proposed design of the MIRAS model is based on a hybrid cloud-fog architecture. Featured with both cloud computing and fog computing, MIRAS model consists of smart IoT data acquisition (i-DAQ), smart gateway (fog computing) and cloud platform (cloud computing) [20], [21]. Figure 2 shows the overall design of MIRAS model which Figure 2(a) illustrates the framework layout, and the data communication flow is depicted in Figure 2(b).

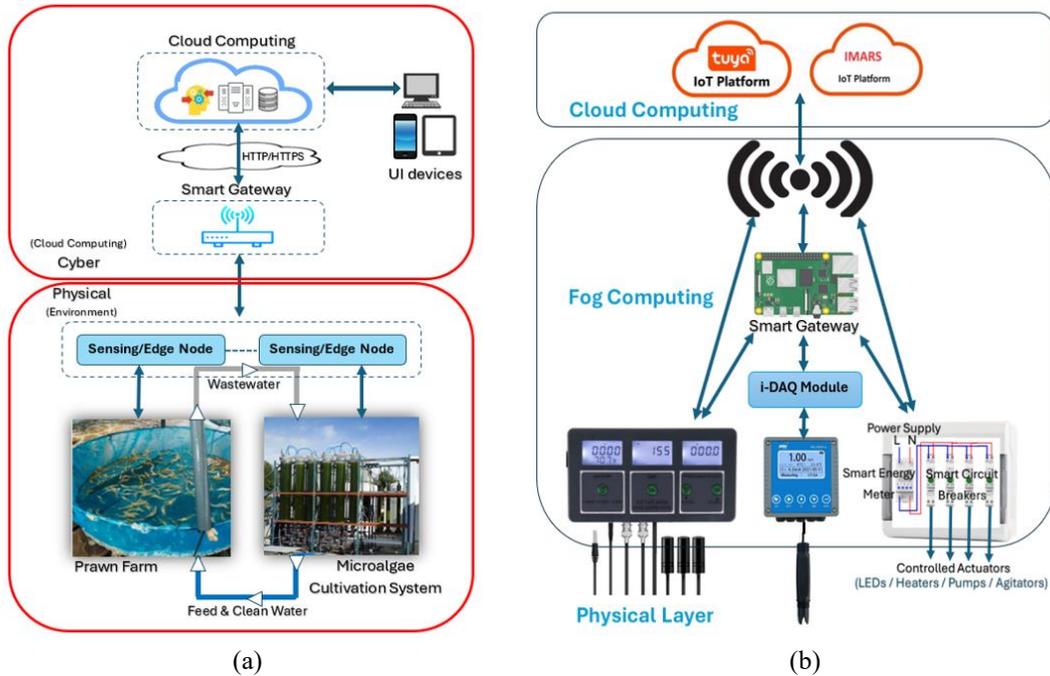


Figure 2. The proposed design of IoT-based CPS system for MIRAS (a) the framework layout and (b) the data communication flow

3. METHOD

The proposed MIRAS system facilitates remote monitoring of water quality parameters from the physical environment of the pilot farm of MIRAS with real-time data visualization. It integrates cloud computing to enable informed decision-making to dynamically adapt and optimize the cultivation system's operational environment. Ultimately, IoT, CPS and cloud computing technologies are integrated within MIRAS to create sustainable and resilient aquaculture systems that ensure profitability, maintain healthy aquatic ecosystems, and enhance the capacity to adapt to climate change [17]. The hardware prototype of MIRAS system is illustrated in Figure 3.



Figure 3. The hardware prototype of IoT-based CPS system for MIRAS

3.1. MIRAS sensing and controlling nodes

The sensors and actuators are connected to the MIRAS sensing and controlling nodes, facilitating the monitoring and control of the MIRAS system. These include the YIERYI 8-in-1 smart water monitor [22], BOQU pXG-2085Pro online ion meter for ammonia nitrogen sensor [23], and TXCB2-VAP smart circuit breakers [24]. The YIERYI water monitor is an intelligent IoT-based water sensor utilized to measure precise water quality measurement of scientific parameters such as pH, EC, TDS, ORP, SG, CF, RH, and temperature. This multifunctional water sensor ensures accurate and real-time data transmission over Wi-Fi, with measurements uploaded and stored in the Tuya IoT Cloud Platform. The measurement accuracy of the YIERYI water monitor is tabulated in Table 1.

BOQU's pXG-2085Pro is deployed for online process monitoring and control across various water applications, including environmental, industrial water, agriculture, and farming. Featured with RS485 Modbus communication capability, the pXG-2085Pro can seamlessly interface with any computers or microcontrollers via the standard Modbus RTU communication protocol [23]. On the other hand, a group of TXCB2-VAP smart circuit breakers facilitates remote monitoring and control of electrical load demands, temperature settings and other critical system information in the MIRAS system. The controlled actuators include LEDs, heaters, pumps and agitators, as depicted in Figure 4.

Table 1. Measurement parameters (YIERYI 8-in-1 water tester) [22]

Parameter	Range	Accuracy	Resolution
pH	0.00-14.00 pH	±0.03 pH	0.01 pH
ORP	-2000 to 2000 mv	±5 mv	1 mV
EC	0-19000 us/cm	±2% F.S	1 us/cm
CF	0-1999.0 CF	±2% F.S	-
TDS	0-19990 ppm	±2% F.S	1 ppm
SALT	0-199.9 ppt	±2% F.S	1 ppm
S.G	0.990-1.400	±0.001	0.001
Temperature	0-50 °C	±1.0 °C	0.1 °C



Figure 4. Controlling node consists of several smart circuit breakers for the controlled actuators

3.2. Intelligent data acquisition (i-DAQ) module

The i-DAQ module interfaces with the MIRAS sensing node to acquire data from various sensor through the Modbus RTU communication protocol. Figure 5 illustrates the design of i-DAQ module. It comprises an ESP8266 microcontroller (MCU) [25], a Modbus converter and a voltage logic shifter, as depicted in Figure 5(a), and the interfacing module for Modbus communication is illustrated in Figure 5(b). The ESP8266 features a built-in voltage regulator providing a constant 3.3 V power supply, a USB interface for programming and powering the device, and a built-in Wi-Fi shield that enables seamless connectivity and wireless communication with other devices via the internet. Additionally, it offers 11 general-purpose input/output (GPIOs) pins and a built-in analog-to-digital converter (ADC) converter.

In this work, the i-DAQ module also interfaces with BOQU's pXG-2085Pro online ion meter, acquiring and uploading sensor data to the cloud platform via the smart gateway. The Modbus communication setup comprises two primary components: i) an RS485-to-TTL UART Modbus converter, and ii) a TTL logic level shifter. The RS485-to-TTL Modbus converter is essential for converting serial communication data between the Modbus RS485 and RS-232 standards. The TTL logic level shifter converts the 5 V TTL output signal from the RS485 Modbus converter to a 3.3 V signal voltage level, compatible with the ESP8266 MCU.

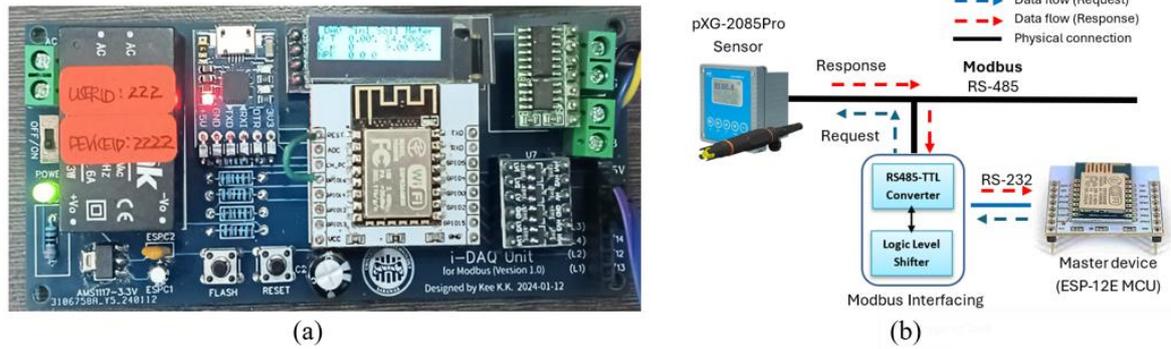


Figure 5. Design of i-DAQ module: (a) prototype of i-DAQ module and (b) interfacing module for Modbus communication

3.3. Smart gateway

The smart gateway (SG) module is a critical component of the MIRAS system based on the Raspberry Pi (RPi) processing unit. It performs several fog computations such as signal pre-processing and transforming for better insights used for data analysis. In addition, SG also serves as a communication gateway, streamlining and transferring data from various sensing and controlling nodes with different communication protocols to the cloud platform for storage and computation. In this work, SG provides Internet connectivity to the cloud platform via the standard HTTP/HTTPS protocol.

Smart devices like YIERYI smart water monitor and TXCB2-VAP smart circuit breakers are registered and activated in the Tuya IoT Platform, enabling remote monitoring and control via the Tuya mobile App. In this work, the smart devices are accessed in real-time through a local Wi-Fi network using Python scripts and the TinyTuya API library module executed by RPi [26]. The data points from these smart devices are retrieved by calling TinyTuya APIs to read or write device status, as illustrated in Figure 6.

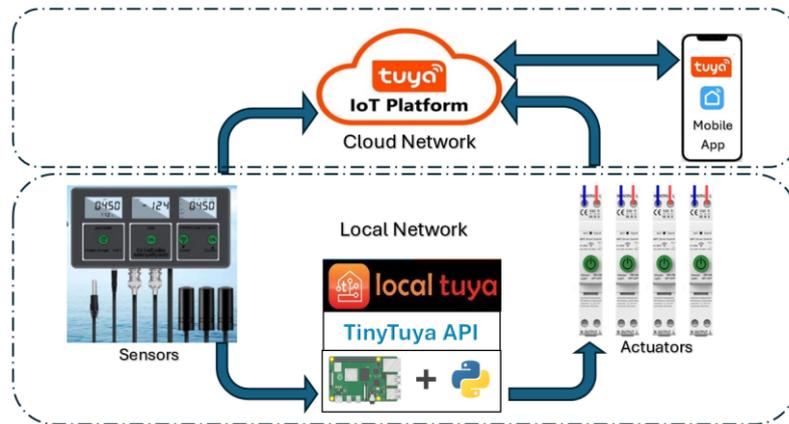


Figure 6. The data points (DPS) access from Tuya smart devices using TinyTuya API module

3.4. Cloud platform

Cloud platform comprises a group of cloud computing resources or servers for data storage, monitoring and analysis. It facilitates a DSS by incorporating machine learning (ML) algorithms such as anomaly detection, optimization, alerting and notification. These resources include a web-based MIRAS Portal, MySQL database server, and third-party cloud servers such as Microsoft Azure, Tuya IoT Cloud Platform and OpenWeather API.

The web-based MIRAS portal is essential to the overall functionality of the MIRAS system. It provides a comprehensive suite of tools and a holistic view for data storage, information retrieval, remote control of actuators, data trending, weather forecasting, and data visualization. Based on hypertext preprocessor (PHP) scripts and a MySQL database, the MIRAS portal incorporates numerous APIs

facilitating communication between MIRAS and the backend or third-party cloud servers. Upon accessing the web-based MIRAS portal, authorized users log in through the main menu, which serves as an informative gateway. It offers an overview of the system's functionality, including user and site information administration, holistic viewing of current site data, data analysis, weather forecasting, geolocation, and the remote control and automation of MIRAS operations, as depicted in Figure 7. The users can access these resources via HTTP protocol through graphical user interfaces such as web browsers (e.g., Google Chrome, MS Edge) or mobile apps (Android or iOS).

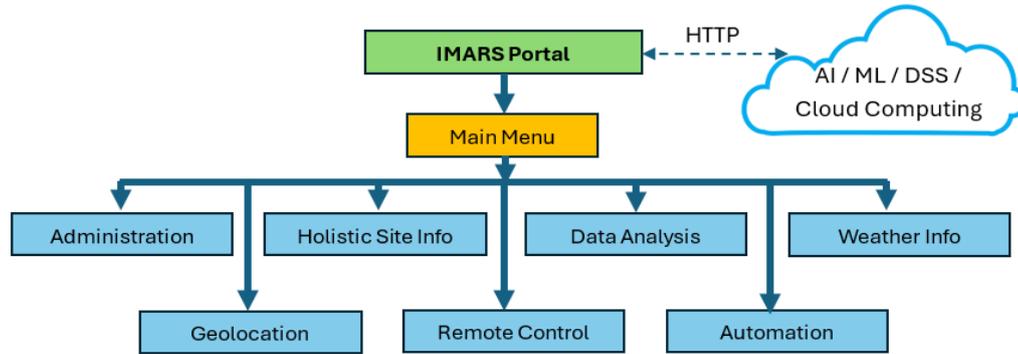


Figure 7. Web-based MIRAS portal structure

4. RESULTS AND DISCUSSION

In this section, the outcomes achieved in the study are explained. The section encompasses data acquisition and controlling of smart devices, web-based MIRAS Portal, and validation of MIRAS deployment. The system acquires and updates the monitored data at 5-minute intervals. Users can access the portal using any web browser or mobile app.

4.1. Data retrieving and control of smart devices

Upon the registration and activation of smart devices using the Tuya mobile app, the information on the connected devices can be accessed via the Tuya IoT cloud platform. To control and monitor these devices through the Tuya local network using the TinyTuya API module, information such as local network address, unique identified device ID, protocol version and local key is needed. A JSON list of the devices connected through the Tuya local network can be revealed using a Python script.

In this work, using the TinyTuya library module provides a way to poll device status and issue commands to these devices, enabling efficient and flexible management of smart devices within a local network. RPi executes the Python script to acquire and update their Tuya device DPS. Figure 8 shows the sample code used to access the smart devices. The DPS data of YIERYI Water Tester is retrieved with JSON response output as depicted in Figure 8(a). For the control of the TXCB2-VAP smart circuit breaker switching operation, the sample code is depicted in Figure 8(b).

```

import tinytuya
# *****
# "SmartWaterMon-8-in-1" or "WiFi smart online 8 in 1 tester"
# *****
DEVICE_ID = 'XXXXXXXXXXXXXXXXXXXX'
IP_ADDRESS = '192.168.0.196'
LOCAL_KEY = "XXXXXXXXXXXX"

d = tinytuya.OutletDevice(DEVICE_ID, IP_ADDRESS, LOCAL_KEY)
d.set_version(3.3)
data = d.status()
print('Device status: %r' % data)

```

Device status: {'dps': [{'8': 229, '102': 0, '103': 0, '106': 676, '107': 0, '108': 0, '111': 222, '112': 0, '113': 0, '116': 444, '117': 0, '118': 0, '121': 259, '122': 0, '123': 0, '126': 998, '131': 174, '132': 0, '133': 0, '136': 444, '137': 0, '141': 0, '142': 0, '143': 0}]}

```

import tinytuya
# *****
# "Smart CB"
# *****
DEVICE_ID = 'XXXXXXXXXXXXXXXXXXXX'
IP_ADDRESS = '192.168.0.195' # Current LAN IP address
LOCAL_KEY = "XXXXXXXXXXXX"

d = tinytuya.OutletDevice(DEVICE_ID, IP_ADDRESS, LOCAL_KEY)
d.set_version(3.3)
d.set_socketPersistent(True)

d.turn_on()
d.turn_off()

```

(a) (b)

Figure 8. The sample Python code to (a) retrieve DPS data from YIERYI water tester with its JSON response output and (b) issue commands of TXCB2-VAP smart circuit breaker

4.2. Web-based MIRAS portal

The portal allows for the real-time monitoring of various important water quality parameters from the MIRAS system and for making informed decisions by remotely and automatically regulating the connected actuators. It provides a holistic view for data storage, information retrieval, remote control of actuators, data trending, weather forecasting, and data visualization, as depicted in Figure 9. This encompasses the real-time presentation of water quality conditions, time-series data trending, and alerting users for any anomalies in the monitored parameters.

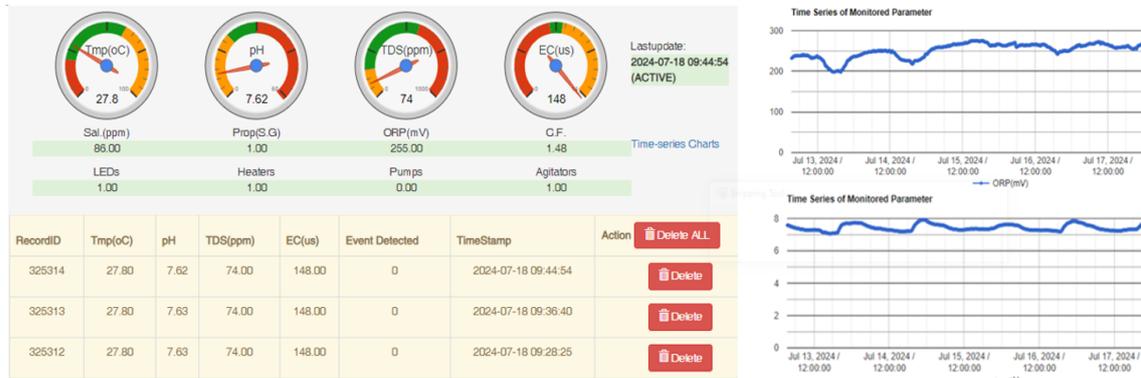


Figure 9. The holistic view of MIRAS data on the portal

4.3. Validation results for system deployment

The proposed MIRAS system has been deployed at Curtin Aquaculture Centre Research Laboratory Centre, Miri, Malaysia, for a period of three months. The system comprises a prawn culture tank, a microalgae-mediated bioreactor, and a biofiltration system. Its primary function is to absorb nitrogen and phosphorus from the prawn tank and recycle these nutrients for microalgae growth. Wastewater from the prawn tank is pumped into the biofiltration system for metabolic conversion, where ammonia is converted to nitrite by nitrifying bacteria, and nitrite is further transformed into nitrate before entering the microalgae reactor for nitrate absorption. The implementation of the proposed CPS-based MIRAS system has streamlined the monitoring of nitrate and other pollutant levels, ensuring optimal water quality for healthy prawn growth. The deployment of the MIRAS system has validated its functionality and efficiency in aquaculture operations. Figure 10 depicts the deployment site and its setup.



Figure 10. Deployed site location of MIRAS for validation

5. CONCLUSION

This study has successfully developed and implemented an IoT-based CPS for the MIRAS, leveraging cloud computing resources to dynamically adapt and optimize the operational environment. The system has been deployed in a pilot-scale aquaculture plant in Miri, Malaysia, where it demonstrated operational efficiency, feasibility and adaptability in supporting sustainable aquaculture practices. MIRAS

exemplifies how digital technologies can be harnessed to improve food security through scalable and intelligent aquaculture solutions. Further work includes the integration of ML models to support proactive decision-making, optimization of resource utilization, and anomaly detection. The system's scalability will also be explored through multi-sensor and multi-site deployments in other farming systems such as hydroponics, aquaponic and wastewater treatment, to promote holistic environment sustainability and digital transformation.

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CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

REFERENCES

- [1] Food and Agriculture Organization of the United Nations, "The State of World Fisheries and Aquaculture 2014 (SOFIA)." GLOBEFISH, 2014, Accessed: Jun. 04, 2024. [Online]. Available: <https://www.fao.org/in-action/globefish/publications/details-publication/en/c/338355/>.
- [2] A. Jumlati and M. S. Ismail, "Promotion of sustainable aquaculture in Malaysia." in *Proceedings of the International Workshop on the Promotion of Sustainable Aquaculture, Aquatic Animal Health, and Resource Enhancement in Southeast Asia*. Tigbauan, Iloilo, Philippines, pp. 31–40, 2021.
- [3] Food and Agriculture Organization of the United Nations, *The State of World Fisheries and Aquaculture 2016: Contributing to Food Security and Nutrition for All*. Rome, Italy: FAO, 2016.
- [4] Department of Fisheries Malaysia, "Annual Statistics - Department of Fisheries Malaysia Official Portal," Department of Fisheries Malaysia. [Online]. Available: <https://www.dof.gov.my/en/resources/i-extension-en/annual-statistics/>.
- [5] C. E. Boyd and Others, "Achieving sustainable aquaculture: Historical and current perspectives and future needs and challenges," *Journal of the World Aquaculture Society*, vol. 51, no. 3, pp. 578–633, 2020, doi: 10.1111/JWAS.12714.
- [6] V. P. Kour and S. Arora, "Recent developments of the internet of things in agriculture: a survey," *IEEE Access*, vol. 8, pp. 129924–129957, 2020, doi: 10.1109/ACCESS.2020.3009298.
- [7] A. Chehri, H. Chaibi, R. Saadane, N. Hakem, and M. Wahbi, "A framework of optimizing the deployment of IoT for precision agriculture industry," *Procedia Computer Science*, vol. 176, pp. 2414–2422, 2020, doi: 10.1016/j.procs.2020.09.312.
- [8] R. Akhter and S. A. Sofi, "Precision agriculture using IoT data analytics and machine learning," *Journal of King Saud University - Computer and Information Sciences*, vol. 34, no. 8, pp. 5602–5618, Sep. 2022, doi: 10.1016/j.jksuci.2021.05.013.
- [9] H. R. Lim, K. S. Khoo, W. Y. Chia, K. W. Chew, S. H. Ho, and P. L. Show, "Smart microalgae farming with internet-of-things for sustainable agriculture," *Biotechnology Advances*, vol. 57, p. 107931, 2022, doi: 10.1016/J.BIOTECHADV.2022.107931.
- [10] K. K. Kee, R. Rashidi, O. K. H. Kee, A. B. Han, I. Z. Patrick, and L. M. Bawen, "Context-aware self-powered intelligent soil monitoring system for precise agriculture," *International Journal of Electrical and Computer Engineering*, vol. 15, no. 1, pp. 1123–1131, 2025, doi: 10.11591/ijece.v15i1.pp1123-1131.
- [11] S. Kim, M. Lee, and C. Shin, "IoT-based strawberry disease prediction system for smart farming," *Sensors (Switzerland)*, vol. 18, no. 11, p. 4051, 2018, doi: 10.3390/s18114051.
- [12] A. Wietzke *et al.*, "Insect pollination as a key factor for strawberry physiology and marketable fruit quality," *Agriculture, Ecosystems and Environment*, vol. 258, pp. 197–204, 2018, doi: 10.1016/j.agee.2018.01.036.
- [13] H. R. Lim *et al.*, "Evaluation of real-time monitoring on the growth of spirulina microalgae: internet of things and microalgae technologies," *IEEE Internet of Things Journal*, vol. 11, no. 2, pp. 3274–3281, 2024, doi: 10.1109/JIOT.2023.3296525.
- [14] E. R. Griffor, C. Greer, D. A. Wollman, and M. J. Burns, "Framework for cyber-physical systems: Volume 1, overview," NIST, 2017, doi: 10.6028/NIST.SP.1500-201.
- [15] Z. Jakovljevic, V. Majstorovic, S. Stojadinovic, S. Zivkovic, N. Gligorijevic, and M. Pajic, "Cyber-physical manufacturing systems (CPMS)," in *Lecture Notes in Mechanical Engineering*, 2017, pp. 199–214.
- [16] A. Bagula, O. Ajayi, and H. Maluleke, "Cyber physical systems dependability using CPS-IoT monitoring," *Sensors*, vol. 21, no. 8, 2021, doi: 10.3390/s21082761.
- [17] A. Goknil *et al.*, "A systematic review of data quality in CPS and IoT for industry 4.0," *ACM Computing Surveys*, vol. 55, no. 14, 2023, doi: 10.1145/3593043.
- [18] S. Smetana, K. Aganovic, and V. Heinz, "Food supply chains as cyber-physical systems: a path for more sustainable personalized nutrition," *Food Engineering Reviews*, vol. 13, no. 1, pp. 92–103, 2021, doi: 10.1007/s12393-020-09243-y.
- [19] V. Kayvanfar, A. Elomri, L. Kerbache, H. R. Vandchali, and A. El Omri, "A review of decision support systems in the internet of things and supply chain and logistics using web content mining," *Supply Chain Analytics*, vol. 6, p. 100063, 2024, doi: 10.1016/j.sca.2024.100063.

- [20] G. Mokhtari, A. Anvari-Moghaddam, and Q. Zhang, "A new layered architecture for future big data-driven smart homes," *IEEE Access*, vol. 7, pp. 19002–19012, 2019, doi: 10.1109/ACCESS.2019.2896403.
- [21] K.-K. Kee, S. Lau Boung Yew, Y. S. Lim, Y. P. Ting, and R. Rashidi, "Universal cyber physical system, a prototype for predictive maintenance," *Bulletin of Electrical Engineering and Informatics*, vol. 11, no. 1, pp. 42–49, Feb. 2022, doi: 10.11591/eei.v11i1.3216.
- [22] "YIERYI smart water meter," *shop.yieryimeters.com*. <https://shop.yieryimeters.com/products/yieryi-wifi-ph-meter-temp-tdsppm-ec-orp-water-tester-tuya-app-smart-monitor-digital-analyzer-for-aquariums-hydroponics-swimming-pool> (accessed Aug. 26, 2024).
- [23] "BoQu PXG-2085PRO Ion Meter," *boquinstrument.com*. <https://www.boquinstrument.com/pxg-2085pro-online-ammonium-ion-meter> (accessed Aug. 26, 2024).
- [24] "TAXNELE smart circuit breakers," *taxnele.com*. <https://www.taxnele.com/product/product-98-899.html> (accessed Aug. 26, 2024).
- [25] "Espressif systems technical references," *espressif.com*. <https://www.espressif.com/en/support/documents/technical-documents> (accessed May 14, 2024).
- [26] "TinyTuya Python Library," *pypi.org*. <https://pypi.org/project/tinytuya/> (accessed Jun. 04, 2024).

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