THE POTENTIAL APPLICATION OF SMART AQUACULTURE TECHNOLOGY ON MAXIMIZING SIGANIDS (RABBITFISH) PRODUCTION IN COASTAL MARINE ENVIRONMENT OF THE PHILIPPINES

Franklin M. Ganancias [1], Cheryl O. Tayo [1] and Nelyne Lourdes Y. Plaza[1]
North Eastern Mindanao State University – Cantilan Campus, Cantilan Surigao del Sur
Correspondence: *fmganancias@nemsu.edu.ph*

ABSTRACT: *This study explores the impact of environmental factors on the growth and survival of Siganus Canaliculatus and Siganus Fuscescens within smart fish cage aquaculture systems. Environmental parameters, including temperature, salinity, dissolved oxygen, and pH, were monitored over two farming cycles to evaluate their influence on growth and mortality rates. Descriptive statistics revealed that temperature and salinity exhibited notable fluctuations, with ascending trends during the second cycle correlating with improved growth rates. Siganus Canaliculatus demonstrated superior growth, achieving a mean size of 230mm or 23 cm compared to 200mm or 20cm for Siganus Fuscescens in the second cycle. Mortality rates improved, declining from 6% in the first cycle to 4% in the second, indicating enhanced management practices. Correlation analysis showed strong positive relationships between temperature and salinity with growth rates, highlighting their critical roles in fostering metabolic efficiency. Dissolved oxygen exhibited a significant negative correlation with mortality, emphasizing the need for consistent oxygen levels to minimize fish losses. While pH levels remained stable and within acceptable ranges, their influence on mortality was negligible due to acceptable water quality parameters.*

The findings underline the importance of precise environmental monitoring in optimizing aquaculture productivity. The study demonstrates the potential of Siganus Canaliculatus as a high-yield species and highlights the efficacy of smart fish cage technology in maintaining favorable conditions. This research provides valuable insights for sustainable aquaculture practices and offers a foundation for further innovations in marine farming systems.

Keywords: Fish Mortality, Siganids Farming, Rabbitfish, Mariculture, IoT

INTRODUCTION

The coastal marine ecosystems of the Philippines are vital for supporting the livelihoods of millions of people through fisheries and aquaculture. However, the increasing demand for marine resources has placed significant pressure on these ecosystems, necessitating the development of sustainable technologies to enhance productivity while minimizing environmental impact. Modern aquaculture systems require the control of a large number of parameters; industrialization was linked to the adoption of technology. Some of these processes necessitate sophisticated instruments and carefully constructed facilities that have resulted from years of research and development. Advances in technology have aided the modernization of aquaculture in general [4], some of these technologies were not designed expressly for use in farming systems but later found its applications in this field. Some technology breakthroughs are specifically designed for aquaculture operations. Semisubmersible cages, autonomous feeders, water recirculation monitoring systems, for example, necessitate specialized technological applications based on good scientific understanding [6, 19].

Dissolved oxygen (DO), salinity, water temperature, and hydrogen potential (pH) are the four most important water factors for marine aquaculture [2, 25, 26]. Depending on the type of aquaculture and the fish species being cultivated, the appropriate content for those criteria varies. The importance of those characteristics varies as well, with dissolved oxygen (DO) being the most important for aquaculture, as it controls the fish's growth [7, 25]. As the water temperature rises, the DO content decreases because it can no longer contain O2. However, too much dissolved oxygen (DO) can induce a gas bubble disease, which can kill fish. If the level is too low, microorganisms can readily infect the fish which eventually lead to death [13, 8]. The apparent benefits of technology have created a solid foundation for taking aquaculture systems to the next level, which involves the use of computer controls and the Internet of Things (IoT) to increase automation, administration, and decision-making [3,14, 15].

The deployment of IoT technology in fish farming has led to the development of an intelligent system that monitors crucial water parameters such as temperature, pH, and dissolved oxygen, utilizing the MSP430 family chip for efficient sensing [10][20]. This system employs a ZigBee wireless sensor network to facilitate communication while minimizing power consumption, and it integrates control devices like RGB lights and feeders to optimize the farming process [22]. Additionally, research into big data architecture for underwater monitoring has revealed that technologies like Hadoop MapReduce can significantly enhance data analytics efficiency compared to traditional systems [23, 24], while also addressing protocol challenges in IoT applications through studies on various communication protocols such as MQTT, which was deemed suitable for sensor networks [11, 16]. Furthermore, the IFTTT model has been adapted for home automation systems, showcasing the potential for customized triggers and actions that can be applied to aquaculture settings [12, 17].

The potentials of improving the aquaculture industry in Cantilan, Surigao del Sur and the challenges of Siganids farmers was the motivation of the conduct this study. The annual availability of wild seedlings of Siganids provides a wide opportunity for coastal communities to gain benefits from it rather than just collecting it for fermentation [24]. The current Siganids farming process in Cantilan was manual and that opens various issues of concerns and challenges that lead to the issues on high crop mortality specially during summer season where temperature is higher. This concern is what the researcher is very interested upon because rabbitfish are very challenging to culture, a comparative study on survival rate was conducted on cage farming gaining 95.33% on fixed and 80% on floating [25]. These means that cage farming of rabbitfish on whatever species especially on the pacific region is very crucial as its temperature raises during summer season and that requires strategies to mitigate the issues that lead to high mortality rate [5, 18].

Materials and Methods

In this study, the researcher employed descriptive experimental research design to assess the potential of smart fish cage technology in marine application. Our primary objective was to investigate the effects of using smart technology on two consecutive farming of *"Siganus Canaliculatus"* and *"Siganus Fuscescens"* in floating cages and on a pre-defined stocking density. The descriptive experimental approach allows us to systematically collect data, providing a comprehensive understanding of how smart fish cage technology influences aquaculture outcomes over multiple cycles [21]. The researcher aimed to evaluate the impact of this technology on fish health, growth rates, and overall aquaculture productivity.

The study employed a multi-pronged strategy to acquire thorough data for our investigation. First, we continuously tracked two farming cycles' worth of important environmental variables, such as water temperature, salinity, and dissolved oxygen levels. The integration of technology on this farming operation conveys an impact on characteristics, which are crucial for the health and development of Siganids species. In order to determine any potential associations with the usage of this technology, we also recorded and examined the general death rates of the fish across these two farming cycles. In order to comprehend how technology affected the health of *"Siganus Canaliculatus"* and *"Siganus Fuscescens"* fish, growth rates were also carefully studied using conventional measurement methods.

A. Framework/Model

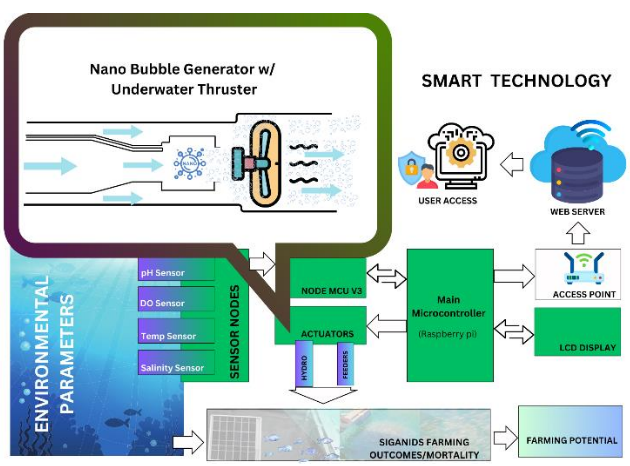

Figure 1: Conceptual Framework

The figure outlines the framework of the study revealing the farming potential of smart aquaculture technology in Cantilan, Surigao del Sur. We seek to shed light on the potential advantages and constraints of the technology in marine applications by investigating the use of smart fish cage technology over two farming cycles of *"Siganus Canaliculatus"* and *"Siganus Fuscescens"* while meticulously observing environmental variables, mortality rates, and fish growth rates. The results provide practical ramifications for fish farmers, aquaculture professionals, and policymakers, providing advice on the use of smart fish cage technology and its effect on sustainable and effective fish farming techniques in marine environments. In the end, this study supports aquaculture innovation and responsible technology utilization.

B. Hardware Design

The hardware design for this smart aquaculture system integrates an intelligent and energy-efficient architecture, focusing on real-time monitoring, automated feeding, and cloud-based data management to optimize aquaculture operations in marine environments. The central processing unit, a Raspberry Pi, coordinates system functions such as data collection, decision-making, and communication with other subsystems. It interfaces with an ESP8266 V3 module, which manages various water quality sensors (e.g., oxygen, temperature, pH, salinity) and wirelessly transmits data, thereby decentralizing processing and enhancing scalability. Actuators in the system automate tasks like precise feeding and activation of the nano bubble generator, which regulates dissolved oxygen levels for the fish. An LCD display provides real-time, on-site monitoring of sensor data and system status, serving as a local backup in case of connectivity failures. The system also incorporates an access point module for secure data transmission to cloud platforms, enabling remote access and centralized data analytics. To ensure continuous, sustainable operation, especially in remote marine locations, the system is powered by a solar power setup comprising a solar panel, charge controller, battery, and voltage regulator. Time synchronization is maintained via Network Time Protocol (NTP), ensuring accurate operation of time-dependent functions such as feeding schedules. Additionally, temperature, pH, dissolved oxygen, and conductivity sensors monitor key water quality parameters, triggering automatic responses when thresholds are exceeded, ensuring

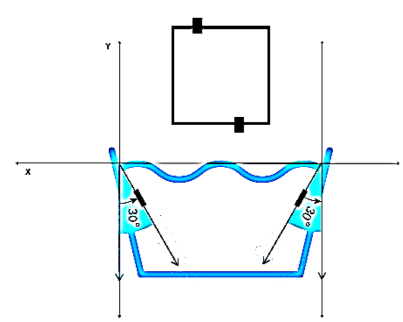

Figure 2: Nano Bubble Angle and Positioning

optimal conditions for rabbitfish health and growth. Overall, this hardware design offers a robust, scalable, and sustainable solution for modern aquaculture management.

C. Angle and Positioning

In the illustrated design, the nano bubble generators are strategically positioned at a 30° downward angle from opposite sides of the marine fish cage. This angled deployment facilitates a deeper and more targeted dispersion of the water-bubble mixture, allowing nano bubbles to reach lower depths where oxygen stratification commonly occurs. By delivering oxygen more efficiently to the bottom layers, this setup helps maintain uniform dissolved oxygen levels throughout the water column, enhancing fish health and metabolic activity.

Notably, the devices are installed opposite each other but not in a perfectly perpendicular arrangement, as indicated by the offset positioning within the black rectangular schematic. This asymmetry avoids direct bubble collision paths and instead promotes cross-flow circulation, improving water movement, reducing dead zones, and ensuring wider spatial oxygenation coverage within the fish cage environment. This positioning is ideal for optimizing the performance of nano bubble technology in open marine aquaculture systems.

D. Software Design

The software design of the smart aquaculture system follows a modular, event-driven architecture that supports real-time sensor monitoring, data transmission, and actuator control. The flowchart illustrates a streamlined operational process beginning with the establishment of communication between sensor nodes (ESP8266 and Raspberry Pi). If the connection is unsuccessful, the system loops until the link is re-established. Once the connection is successful, the system proceeds to simultaneously read data from all integrated sensors (temperature, pH, dissolved oxygen, and salinity). The data is then evaluated against predefined threshold values. If none of the readings breach the thresholds, the system continues monitoring. However, if a value exceeds or falls below acceptable limits, the software triggers corresponding actuator operations—such as the feeding mechanism or the nano bubble generator.

Regardless of actuator activation, all collected data is transmitted to a cloud repository for remote access, analytics, and historical tracking. This supports long-term optimization and data-driven management decisions. The software design thus emphasizes continuous feedback loops, autonomous response, and cloud-based monitoring, ensuring efficient and intelligent aquaculture operations.

RESULTS AND DISCUSSION

The oceans and their ecosystems are a vital component of our planet, providing food, energy, and other resources to millions of people worldwide.

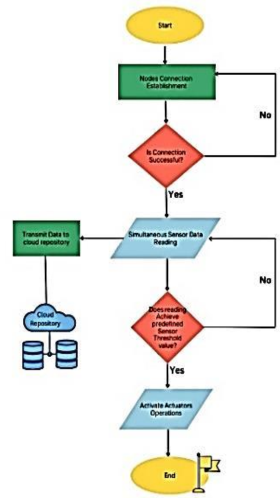

Figure 3: System Flowchart

E. Prototype Design

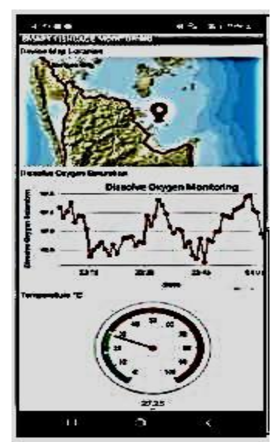

Figure 4: Mobile Application

As human populations continue to grow, there is a pressing need to develop sustainable technologies that can support and enhance the productivity of marine ecosystems. Marine culture technology research plays a critical role in identifying and developing these technologies, enabling us to harness the potential of the oceans while minimizing their impact on the environment. Selecting the most promising areas of marine culture technology research were therefore essential to ensuring that our use of ocean resources is both economically viable and ecologically sustainable in the long term [1]. This study identifies the area of implementation by considering numerous factors such as the annual weather data and environmental condition. The identified location is located in a semi cove area in General Island Cantilan Surigao del Sur, Philippines (see Figure 4).

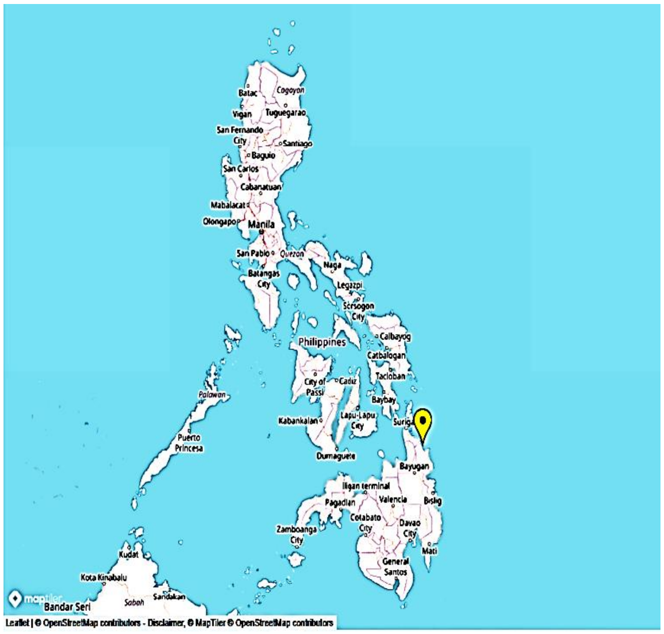

Figure 4: Project implementation Location

The area is identified due to its ideal location having a small islet as cover for strong wind and waves in case of a bad weather condition. Siganids, also known as rabbitfish, are a popular and economically important marine fish species in the Philippines, particularly in coastal regions. Managing small-scale fisheries in the Philippines was challenging due to high pressures from expanding fishing population, poverty, and lack of alternative options.

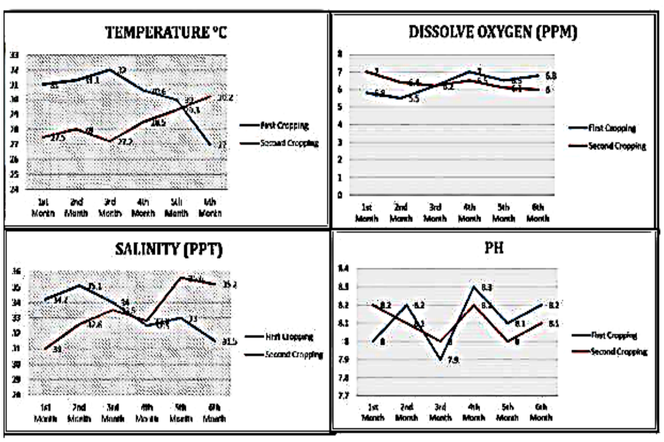

Figure 5: Sensor Characteristics

The descriptive statistics provide a detailed overview of the environmental conditions and aquaculture outcomes observed during the two farming cycles of *Siganus Canaliculatus* and *Siganus Fuscescens*. The mean temperature was recorded at 28.93°C with a standard deviation of 1.88°C, reflecting a range from 27°C to 31°C. These variations highlight the influence of seasonal or external environmental changes on the farming environment. While temperatures remained within the species' tolerance range, the ascending trend in the second cycle likely contributed to enhanced growth rates due to the increased metabolic activity in warmer waters. The salinity levels averaged 33.00 ppt with a standard deviation of 1.98 ppt, ranging between 31 ppt and 35.2 ppt. This relatively broad range indicates fluctuations that could result from varying water exchange dynamics or environmental inputs, such as rainfall and nearby water streams. This was further support based on the annual geographical weather data in Cantilan, Surigao del Sur which shows a weather season pattern [9]. Despite these variations, the mean salinity fell within an optimal range for signed growth, as evidenced by the strong growth rates observed, particularly during the second farming cycle.

Table 1: Data Analysis

Variable	Mean	Std. Deviation	Minimum	Maximum
Temperature (°C)	28.93	1.88	27.00	31.00
Salinity (ppt)	33.00	1.98	31.00	35.20
Dissolved Oxygen (ppm)	6.40	0.52	5.80	7.00
pH Levels	8.13	0.10	8.00	8.20
Growth Rate (mm)	211.25	15.94	195.00	230.00
Mortality Rate (%)	5.00	1.15	4.00	6.00

Dissolved oxygen levels averaged 6.40 ppm with a standard deviation of 0.52 ppm, ranging from 5.8 ppm to 7 ppm. The observed changes, particularly the decline during the second cycle, emphasize the critical need for maintaining oxygen levels within optimal ranges. Since the area of implementation is in an open water cove area, the possibility of having stagnant water with no current flow is only during low tide with 1-2 hours window. These findings suggest the importance of adequate aeration or water movement systems to ensure consistent oxygen availability.

The pH levels displayed remarkable stability, with a mean of 8.13 and a narrow standard deviation of 0.10, ranging from 8.0 to 8.2. This consistency indicates effective water management practices within the smart fish cages, ensuring that the pH remained within the acceptable range for signed health. The minimal variation also underscores that pH was not a limiting factor in the farming cycles.

Growth rates for the signed species averaged 211.25mm with a standard deviation of 15.94 mm, ranging from 195mm to 230mm across both farming cycles. These figures highlight the overall productivity of the smart fish cage system, with *Siganus Canaliculatus* consistently achieving higher growth than *Siganus Fuscescens*, possibly due to inherent species characteristics or adaptability. The mortality rate averaged is 5%, with a standard deviation of 1.15%, reflecting a range of 4% to 6%. The decline in mortality rates from the first to the second cycle demonstrates improvements in aquaculture practices.

CONCLUSION

This study demonstrated the successful development and implementation of a smart aquaculture system for monitoring and managing environmental parameters critical to rabbitfish production in a coastal marine setting. By integrating IoT-based sensor technology with automated systems for aeration and feeding, the smart system prototype provided a real-time, responsive platform for monitoring and managing water parameters including temperature, salinity, dissolved oxygen, and pH. The system architecture, anchored on the Raspberry Pi and ESP8266 microcontrollers, enabled efficient data acquisition and decision-making, supported by solar-powered energy solutions suited to the remote nature of marine farming environments. Empirical results across two farming cycles showed a good farming results having a very low mortality rate.

The modular and scalable nature of the system, including features such as cloud synchronization, nano bubble oxygenation, and automated feeding, reflects a robust technological approach adaptable to varying environmental conditions. The observed improvements in growth and survival outcomes were a possible result of the systems implementation. The downward-angled deployment of nano bubble generators and their strategic positioning enhanced water column oxygenation, demonstrating design consideration for spatial dynamics within the aquaculture cage. The effectiveness of the design supports its applicability in other similar tropical marine environments facing the same environmental volatility as Cantilan, Surigao del Sur.

Despite these advancements, the study also identified limitations that offer direction for future work. Sensor precision and stability, particularly during prolonged exposure to dynamic marine conditions, remain a key concern. There is a need for the incorporation of higher-quality or industrial-grade sensors to reduce potential inaccuracies caused by environmental stressors. Future iterations should also consider expanding the monitored parameters to include turbidity, ammonia, and feeding behavior analysis through video or AI-based pattern recognition. Enhancing data analytics using AI and predictive modeling, integrated with historical weather and farm data, could further advance proactive management strategies. Ultimately, this study lays the groundwork for more intelligent and sustainable marine aquaculture practices and emphasizes the necessity of continued innovation in sensor technology, energy efficiency, and automated system integration.

REFERENCES

[1] Rowan, N. J. (2023). The role of digital technologies in supporting and improving fishery and aquaculture across the supply chain – Quo Vadis? *Aquaculture and Fisheries*, *8*(4), 365-374 https://doi.org/10.1016/j.aaf.2022.06.003

[2] Mariu, A., Chatha, A., Naz, S., Khan, M. F., Safdar, W., & Ashraf, I. (2023). Effect of Temperature, pH, Salinity and Dissolved Oxygen on Fishes. *Journal of Zoology and Systematics*, *1*(2), 1-12. https://doi.org/10.56946/jzs.v1i2.198

[3] Lavorato, D., & Piedepalumbo, P. (2023). How Smart Technologies Affect the Decision-Making and Control System of Food and Beverage Companies—A Case Study. *Sustainability*, *15*(5), 4292. https://doi.org/10.3390/su15054292

[4] Zhang, H., & Gui, F. (2023). The Application and Research of New Digital Technology in Marine Aquaculture. *J. Mar. Sci. Eng.*, *11*(2), 401. https://doi.org/10.3390/jmse11020401

[5] Muniesa, A., Furones, D., Rodgers, C., & Basurco, B. (2022). An assessment of disease occurrence and mortality in marine fish farming in Spain. *Aquaculture Reports*, *25*, 101257. https://doi.org/10.1016/j.aqrep.2022.101257

[6] Tolentino, L. K., Pedro, C. P., Icamina, J. D., Navarro, J. B., Salvacion, L. J., Sobrevilla, G. C., . . . Madrigal, G. A. (2020). Development of an IoT-based intensive aquaculture monitoring system with automatic water correction. *International Journal of Computing and Digital Systems*, *10*, 1355-1365.

[7] Dewiyanti, Aminah, S., Helmahera, A., Nurfadillah, N., & Defira, C. N. (2020). Growth patterns and condition factor of fish live in Kuala Gigieng waters of Aceh Besar as the basic for sustainable fisheries development. *IOP Conference Series: Earth and Environmental Science*, 493. https://doi.org/10.1088/1755-1315/493/1/012020

[8] Dzulqornain, M. I., Rasyid, M. U., & Sukaridhoto, S. (2018). Design and Development of Smart Aquaculture System Based on IFTTT Model and Cloud Integration. *MATEC Web Conf.*, *164*, 11 https://doi.org/10.1051/matecconf/201816401030

[9] Akasaka, I., Kubota, H., Matsumoto, J., Cayanan, E. O., Guzman, R. G., & Hilario, F. D. (2018). Seasonal march patterns of the summer rainy season in the Philippines and their long-term variability since the late twentieth century. *Prog Earth Planet Sci*, *5*, 20. https://doi.org/10.1186/s40645-018-0178-5

[10] Chen, J.-H., Sung, W.-T., & Lin, G.-Y. (2015). Automated Monitoring System for the Fish Farm Aquaculture Environment. *IEEE International Conference on Systems, Man, and Cybernetics,*1161-1166. https://doi.org/10.1109/SMC.2015.208

[11] Singh, M., Rajan, M. A., Shivraj, V. L., & Balamuralidhar, P. (2015). Secure MQTT for Internet of Things (IoT),. *International Conference on Communication Systems and Network Technologies*, 746-751. https://doi.org/doi: 10.1109/CSNT.2015.16

[12] Vorapojpisut, S. (2015). A Lightweight Framework of Home Automation Systems. *Journal of Software*, *10*(12), 1343-1350. doi:https://doi.org/10.17706/jsw.10.12.1343-1350

[13] Yuan, Y., Wang, C., Feng, J., Wang, Z., Li, R., Wang, Y., & Li, K. (2022). Mortality risk evaluation methods for total dissolved gas supersaturation to fish based on a mitigation measure of utilizing activated carbon. *Water Research*, *225*, 119157. https://doi.org/10.1016/j.watres.2022.119157

[14] Brous, P., Janssen, M., & Herder, P. (2020). The dual effects of the Internet of Things (IoT): A systematic review of the benefits and risks of IoT adoption by organizations. *International Journal of Information*

Management, 51, 101952. https://doi.org/10.1016/j.ijinfomgt.2019.05.008

[15] Nižetić, S., Šolić, P., López-de-Ipiña, D., González-de-Artaza, & Patrono, L. (2020). Internet of Things (IoT): Opportunities, issues and challenges towards a smart and sustainable future. *Journal of Cleaner Production, 274*, 122877. https://doi.org/10.1016/j.jclepro.2020.122877

[16] Rani, D., & Gill, N. (2019). Review of Various IoT Standards and Communication Protocols. *International Journal of Engineering Research and Technology, 12*, 647-657

Retrieved from https://www.researchgate.net/publication/369771563_Review_of_Various_IoT_Standards_and_Communicatio n_Protocols

[17] Ubina, N. A., Lan, H.-Y., Cheng, S.-C., Chang, C.-C., Lin, S.-S., Zhang, K.-X., . . . Hsieh, Y.-Z. (2023). Digital twin-based intelligent fish farming with Artificial Intelligence Internet of Things (AIoT). *Smart Agricultural Technology, 5*, 100285. https://doi.org/10.1016/j.atech.2023.100285

[18] Aunsmo, A., Persson, D., Stormoen, M., Romstad, S., Jamtøy, O., & Midtlyng, P. J. (2023). Real-time monitoring of cause-specific mortality- and losses in industrial salmon farming.

Aquaculture, 563(2), 738969. https://doi.org/10.1016/j.aquaculture.2022.738969

[19] Chua, Y., Wang, C., Park, J., & Lader, P. (2020). Review of cage and containment tank designs for offshore fish farming. *Aquaculture, 519*, 734928. https://doi.org/10.1016/j.aquaculture.2020.734928

[20] Rastegari, H., Nadi, F., Lam, S. S., Ikhwanuddin, M., Kasan, N. A., Rahmat, R. F., & Mahari, W. A. (2023). Internet of Things in aquaculture: A review of the challenges and potential solutions based on current and future trends. *Smart Agricultural Technology, 4*, 100187. https://doi.org/10.1016/j.atech.2023.100187

[21] Atmowardoyo, H. (2018). Research Methods in TEFL Studies: Descriptive Research, Case Study, Error Analysis, and R & D. *Journal of Language Teaching and Research, 9*(1), 197-204. http://dx.doi.org/10.17507/jltr.0901.25

[22] Wang, J., Wang, H., He, J., Li, L., Shen, M., Tan, X., . . . Zheng, L. (2015). Wireless sensor network for real-time perishable food supply chain management. *Computers and Electronics in Agriculture, 110*, 196-207. https://doi.org/10.1016/j.compag.2014.11.009

[23] Ma, C., Zhao, M., & Zhao, Y. (2023). An overview of Hadoop applications in transportation big data. *Journal of Traffic and Transportation Engineering (English Edition), 10*(5), 900-917. https://doi.org/10.1016/j.jtte.2023.05.003

[24] Huang, T.-C., Huang, G.-H., & Tsai, M.-F. (2022). Improving the Performance of MapReduce for Small-Scale Cloud Processes Using a Dynamic Task Adjustment Mechanism. *Mathematics, 10*, 1736. https://doi.org/10.3390/math10101736

[25] Mulema, S., & García, A. C. (2019). Monitoring of an aquatic environment in aquaculture using a MEWMA chart. *Aquaculture, 504*, 275-280. https://doi.org/10.1016/j.aquaculture.2019.01.019

[26] Sánchez, I., & González, I. (2021). Monitoring shrimp growth with control charts in aquaculture. *Aquacultural Engineering, 95*, 102180. https://doi.org/10.1016/j.aquaeng.2021.102180