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Iot-Based Recirculating Systems: Advancing Climate-Resilient Aquaculture

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Abstract
Aquaculture still proves to be a lucrative business engaging in the feeding and nutritional requirements of the expanding world populace. Prerequisites to food security and economic development are achieved through its value-chain relations. However, the industry encounters a couple of issues as a result of climate change as well as resource wastage. Using IoT, hydroponic filtration of the RAS, and random forest water quality prediction brings sustainability to the systems. IoT facilitates the control of vital parameters such as pH levels, oxygen levels, ammonia, and temperature of RAS installations. This makes it easier for the aquaculturists to take necessary corrective action at the earliest in case the defined conditions are not favorable hence enhancing the general wellbeing of the aquatic life and productivity of the farming process. Thus, including hydroponic filtration to RAS means that the water is purified to produce nutrients for plants as well as maintaining water recycling with minimal external inputs. In this context, this dual approach of water treatment also enhances the quality of water and renders aquaculture businesses economical and efficient. A machine learning algorithm called Random Forest is used to predict water quality given the history of water samples and the environment. These features make it possible for the aquaculture managers to give an estimate of the extent of control of the environment and reduce stress on the species of fish that are grown and thus increasing the efficiency of the aquaculture systems. Random Forest applied to an IoT-based RAS with hydroponic filtration and predictive capabilities is a step towards more reliable bio-culture systems. Such planning minimizes resource exploitation conserving the ecosystem as well as enhancing its flexibility over fluctuating temperature and weather. As the IoT and machine learning progresses in the future, increased improvement in sustainable aquaculture is greatly achieved to continuously secure food to feed the world's population in the present and future world.

Keywords: IoT, RAS, Abiotic stress, Random Forest, Hydroponics filtration

Introduction

Aquaculture, the farming of aquatic organisms, has become an essential component of global food production, playing a crucial role in meeting the dietary needs of a growing population (Food and Agriculture Organization of the United Nations(Profile, 2020) (Boyd et al., 2022). Moreover, aquaculture is increasingly recognized as a promising and innovative agricultural method for enhancing food security amidst a changing climate (Munguti et al., 2021)(Hewage et al., 2024). The Food and Agriculture Organization of the UN has noted the role of aquaculture as reliable sources of quality protein food for mankind and does admit that aquaculture has a role to play in food security and global economy (Su et al. , 2021). The global finfish aquaculture produced about 80 million tons in the year 2016 which test the fact that aquaculture has become one of the prominent food producing sectors (Dang et al. , 2021). This growth has been due to the role of aquaculture as the main source of fish protein and the integration into the food system as pointed out by Hubert et al. , (2021). Besides the tool for food production, increases in aquaculture assure improvement in nutrition, people's quality of life, and environmental management. However, the conventional aquaculture development approaches still have various complications including the deterioration of environment, wastage and misuse of resources, and sensitivity to climatic change (Berio & Salugsugan, 2022). To solve these problems, new strategies should be implemented to improve sustainability & profitability in aquaculture farms (Hou et al. , 2023).

The objectives and actions which have been formulated by UN'S SDG are fairly timely for the advancement and diversification of aquaculture. It lays down objectives that facilitate formulation, organization, and administration of policies in the sector. However, there are problems in aquaculture which are as follows:- scarcity of the land, water, energy and feed. These challenges are gradually intensifying and having no proper solutions, especially if they are accompanied by the consequences of climate change that negatively affect water bodies (Nguyen & Furlan, 2024). Consequently, there is a need to intensify early undertakings. Climate change, characterized by long-term changes in weather patterns and increased average global temperatures, poses a significant threat to aquaculture (Awotunde, 2024). The sector is already experiencing impacts such as drastic weather changes, reduced water levels, altered hydrological regimes, heavy windstorms, and increased flooding and drought incidents (Freire et al., 2021). Although small-scale fisheries and aquaculture have minimally contributed to climate change, they are among the first sectors to feel its effects (Sowman et al., 2021).

Freshwater aquaculture is particularly vulnerable to climate change due to the sensitivity of poikilothermic animals (organisms whose internal temperatures vary with the ambient environment) to biotic and abiotic stress factors (Nati et al., 2021). These stress factors directly affect fish growth, reproduction, physiology, and behavior (Marvin D. Mayormente, 2024). Key climate change elements impacting aquaculture production include rising sea levels and temperatures, changing monsoon patterns, extreme climatic events, and water stress (Galappaththi et al., 2020; Nazar et al., 2024; Reckermann et al., 2022) .

Climate change has been shown to have negative impacts on fish production, such as the warming of water bodies, degradation of breeding sites, and receding water levels of freshwater bodies. Rising temperatures can reduce dissolved oxygen levels and increase fish metabolic rates, further stressing aquatic ecosystems and production systems (Cascarano et al., 2021; Jeppesen et al., 2010; Orság et al., 2023). These papers in totality give an insight into the complex changes and the ways through which climate change hampers the fish production systems through rise in water temperatures, changes in breeding environment, and falling water table. The study suggests that more knowledge on the effects of climate change that affects water bodies should be sought and means to counter it if fish production is to be sustainable despite the existing environmental hitches.

Summing up, climate change is a serious challenge that negatively affects the feasibility of aquaculture, and thus the need for prompt and efficient measures to enhance the sector's stability and further development as the important guarantor of food security and sound environmental management.

Environmental issues have gradually gained more attention in aquaculture during the last couple of years. This has led to the use of measures in a bid to reduce the vulnerability within the sector that is; Boyd et al. , 2020; Sun et al. , 2020. Climate change has emerged as a major threat to aquaculture; thus, the emphasis on identifying and applying CSA TIMPs targeting sustainable fish production (Munguti et al. , 2022). New technology becomes inevitable to intensify aquaculture that can meet the growing demand due to the scarcity of land and water from other sectors (Galappaththi et al. , 2020). The innovations are model farms, recirculating aquaculture systems (RAS), tanks, hydroponics, and aquaponics, high density, and high capacity intensively to use cages in lakes and reservoirs.

The IoT application is one of the prevalent technologies that has brought changes to different fields, and aquaculture is no exception. Recirculating aquaculture systems (RAS) with the usage of IoT is a revolutionary shift in the regular aquaculture industry that allows the usage of water efficiently, better controlling the environment as well as making an increases in the efficiency of production (Kumar & Sahu, 2020; Xu & Li, 2017). IoT applications in aquaculture provide chances to improve the dynamics of the operations, install automatic tracking solutions, and improve the usage of resources. Internet of Things (IoT) solutions that include sensors, data analytics, and connectivity tools will provide real-time information on the environment, stock, and production and hence a probable approach to enhance the results is to embrace IoT solutions in the practices of aquaculture (Prapti et al., 2022).

This paper on the recirculating system using IoT technology aims to describe how this IoT-based presents climate-smart aquaculture. It fulfills the advantage of integrating the use of IoT into centers, for instance, cutting expenses on natural resources, increasing environmentally sustainable consumption, and notably enhancing the adjustments in the climate

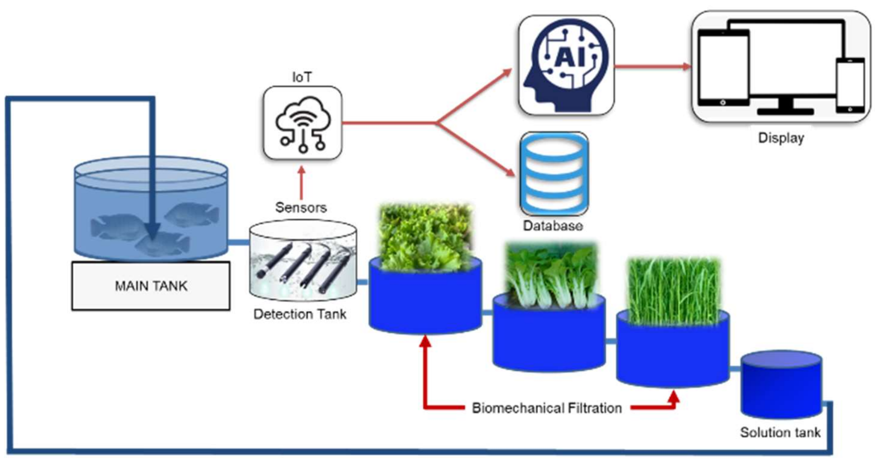
(Badiola et al., 2012). Additionally, it also analyses the IoT-based RAS and its capability to bring changes in the Aquaculture sector and make it sustainable, efficient, and capable of handling the new climate change issues in the future (Gentry et al., 2017). The potential of the IoT to revolutionize similar industries has been established with special emphasis on smart aquaculture, which is the future of the fish farming industry in terms of profitability, sustainability, and innovation. Moreover, the review helps researchers, practitioners, and policymakers, who are looking forward to using the Internet of Things optimization to enhance the development of the aquaculture sector, reveal the current situation in its development, and predict potential future patterns and trends for further research (Boyd & McNevin, 2015; Prapti et al., 2022).

The objective of this research paper is to analyze and illustrate how IoT can improve RAS to be more effective against the consequences of climate change. The study aims to apply IoT advancements in the enhancement of RAS concerning resource allocation, climate control, and general performance. Thus, the study intends to contribute to the enhancement of aquaculture practices that would be resilient to climate variability and change impacts.

Materials and Method

This paper is focused on the use of the internet of things with hydroponic filtration in addition to Random Forest water quality prediction to enhance the sustainability of Recirculating aquaculture systems (RAS). This shows that IoT allows for remote monitoring of other parameters including; pH, oxygen levels, ammonia, and temperature in the RAS facilities. The incorporation of Hydroponics filtration into RAS and water purification will be improved hence promoting nutrient recycling and decreased dependence on outside resources.

1. System Design and planning



RAS ARCHITECHTURAL DIAGRAM

Water physical parameters (Temperature,pH, Total dissolved solid, Dissolved Oxygen (DO)) were measured *insitu* using different sensors built in an arduino UNO. Amnonia of the water was programmtically computed using. The data collection was done from everyday in the detection tank from from 6am to 9pm .

$$NH3 = \frac{1}{(10(pKa-pH)+1}$$

2. Experiment protocols

The experiment was in a backyard or indoor fish farming setting, and multiparameter water quality parameters were measured and monitored directly from the detection tank. Water from deep-well was used as a source. Aside from the mechanical and biological filtration, the RAS was combined with hydroponics as an additional filtration mechanism.

Multi-parameter sensors for water quality were directly measured from the detection tank. The developed system used NodeMcu Lua ESP8266 served as the Internet of Things (IoT) device to transmit recorded readings to the database. Recorded readings were then analyzed using Random forest algorithm to predict water quality status.

The experiment used a grow-out tilapia (50 to 72 grams) cultivated in the fish tank. The feeding process followed the BFAR recommended rate. Seedlings of Kangkong, Onion Leaks, and lettuce were plants used in the hydroponics. The cultivation period was taken within 2 months.

Results and Discussion

New and efficient methods in fish farming have yet been introduced through the invention of an IoT-based Recirculated Aquaculture System (RAS) that can design a backyard or even an indoor fish farming system for continuous fish production all year round. Besides, IoT has been incorporated into the RAS to predict water quality by applying Random Forest algorithms to improve the stability of the developed system.

The water for this system is sourced from a deep well while hydroponics acts as the filtration system. Besides, it has the effect of preserving a lot of water as well as the fish and plant are mutually benefiting in the way that both the fish and the plants grow healthy. The aquaculture fish waste is used as nutrients for the plants in the hydroponic component with the water being recirculated back to the fish tanks after the plants have helped in filtering the water.

These IoT sensors are vital to this configuration since they assure lasting measurement of significant water quality parameters that include pH, dissolved oxygen, ammonia levels, and water temperature governing aquaculture and hydroponic operations. By implementing the Random Forest machine learning technique, this research has successfully obtained 95% prediction accuracy in the context of water quality parameters for fish farmers to manage water quality.

Supervisory control and, in some cases, statistical forewarning help the operators to foresee and possibly offset effects that may affect water quality. This demonstrates to have a positive impact and reduces stress to organisms in water during changes in the temperatures, availability of water and other climate conditions hence improving the reliability of production and reducing the impacts of climate variation to the economy. Lastly, it leads to enhanced crop productivity together with the health of the fish in the closed-loops food chain.

Conclusion:

Incorporation of IoT into RAS integrated with hydroponic systems and Random Forest-based water quality modelling is one of the significant developments in sustainable aqua farming. This new way enhances the productivity of systems and provides perishable support against problems such as fluctuations in temperature and water quality.

By the help of IoT, various important parameter including the pH, DO, TDS, and ammonia can be monitored across the various components of aquaculture in real-time fashion. According to anticipated results from the knowledge of machine learning algorithms such as Random Forest, operators can estimate the fluctuations in water quality, and therefore assist fish farmers to alter the RAS environmental conditions in advance. This proactive management helps to create the maximum of the favourable factors for the state of fish and different crops and the minimum of the negative effects which can occur because of the fish and crops' production affecting the environment, using the minimum amount of the resources and treating the wastewater.

Hydroponics integrated with RAS increase nutrient recycling and decrease nutrient loading and pollution of natural water by reusing aquaculture effluents to feed plants. This closed loop cycle benefits the ecosystems and sustains them and hence the aquaculture is practices in a way that is environmentally friendly.

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