



# Low-Cost Anti-Cannibalistic IoT Prototyping for Sustainable Catfish Farming

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# ABSTRACT

Abstract: As the global demand for food rises, the aquaculture industry faces challenges in meeting this demand while minimizing environmental impact and ensuring sustainable practices. This paper explores the design, and implementation of a low-cost Internet of Things (IoT) solution tailored to enhance sustainability by minimizing cannibalism during catfish production. The proposed system integrates sensor technologies, data analytics, and automation to monitor and manage crucial parameters that influence cannibalism within catfish farming environments. Sensors are deployed to measure water quality, temperature, dissolved oxygen levels, light intensity, and feeding conditions, providing real-time data to a centralized control system. The implementation of a low-cost IoT system will optimize resource efficiency as well as improve the overall health and growth of the catfish, resulting in higher yields and economic viability for subsistence and commercial farmers. The findings suggest that the integration of IoT technologies in catfish farming can help reduce cannibalism which is a major contributor to financial losses among African catfish farmers. The insights from this study contribute to a broader discourse on leveraging IoT for sustainable agriculture practices and highlight the potential for similar systems in addressing challenges across diverse sectors of the aquaculture industry.

#### INTRODUCTION

With the advancement of monitoring and automation technology in recent years, aquaculture practices could be significantly improved thereby enhancing the quality of fish farming ponds, resulting in increased fish production at lower costs. Simply put, Aquaculture is the application of biological principles to the business of fish farming, aquatic plants growing, or other aquatic animals in controlled conditions, within artificial water environments or enclosures [18]. The cultivation of freshwater fish (also called pisciculture) is the commonest type of controlled fish farming in Nigeria. The African catfish (*Clarias* 

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gariepinus, Heterobranchus Iongifilis, Heterobranchus bidorsalis and hybrid of Clarias and Heterobranchus) is the most commonly cultured freshwater fish.

Aquaculture currently accounts for 53% of total fisheries production, excluding non-food uses such as fishmeal and fish oil [2]. Due to the expansion of aquaculture farms, the global fish supply was estimated to reach 16.2 million tons in 2014 [5]. Water pollution is the leading source of financial losses in aquaculture. The biggest mortality rates in aquaculture are linked to water quality, and monitoring water conditions can minimize deaths by 30% to 40% [8].

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Environmental monitoring and control is necessary to comply with international rules to ensure fish quality and agricultural conditions. The major markers of toxicity induced by fish feces and feed are ammonia, ammonium, and nitrite.

Cannibalism is an undesirable problem in aquaculture especially among species that exhibit this tendency. Catfishes are cannibalistic, which means they consume one another. Sibling cannibalism occurs in African catfish larvae and juveniles. *Clarias gariepinus* larval and juvenile sibling cohort cannibalism has resulted in significant losses (up to 65 percent). The African catfish exhibits behavioral issues such as reduced feed intake, aggression, and cannibalism when kept in confined spaces. Aggressive activities also expend a lot of energy that could otherwise be used for growth.

Stock losses reduced food conversion efficiency, and slower growth can all result from aggression. Cannibalism is a predatory feeding strategy and a biological marvel that involves the killing and devouring of members of the same species. It occurs in over 30 fish families [13]. Catfishes are predominantly cannibals [13]. Sibling cannibalism is common in the African catfish. This sibling cannibalism results to significant financial losses (up to 65 percent), a drastic fall in fish survival, and injuries. Water quality (such as electrical conductivity, dissolved oxygen, ammonia, pH, and temperature) affects the survival, growth, and health of every fish. An average subsistence fish farmer's daily practice includes monitoring the factors that influence fish development [16]. Slight changes in parameters can also have a significant impact on fish development and induce stress.

Some farmers use portable meters to measure each parameter, while others send a sample of their pond water to a laboratory for examination. This takes time, and the data may not be as precise as real-time measurements at the pond or tank site. Quality feed, quantity of feed, feeding regime (the number of times the fish is fed per day), good water conditions, and feed management are very important for the growth of catfish and for mitigating the cannibalism.

The cannibalistic behavior of African catfish is influenced by various factors including stress, lighting conditions, pollution [13, 30]). According to Sallehudin[28], increased light intensity and wavelength affect biting activity among the African catfish, while low intensity and certain wavelengths lead to reduced biting. Water pollution also cause functional impairment in the liver, heart, and kidney of the African catfish, as well as reduced protein synthesis and impaired growth [26]. Stocking density can also impact aggression and mortality rates, with medium density leading to the highest aggression and mortality [27]. Dark or dim conditions can reduce cannibalistic behavior and improve survival rates in African catfish larvae [29]. This study aims at prototyping a low-cost loT-based system to improve the survival rate of catfish and mitigate fish cannibalism.

#### **RELATED WORKS**

Agricultural IoT(AIoT) is an emerging field that currently attract a lot of studies [31, 32,33,34,35, 36, 37, 38]. In this paper we present some of the works in the AloT spectrum that are related to the application of IoT to sustainable catfish farming. Nocheski et al[21] employed an IoT system to monitor fishpond water quality metrics. The said IoT system comprises numerous sensors that monitor temperature, light intensity, and water level, as well as a small board computer that interprets the data and notifies the fish farming manager via audible and visual notifications. However, the studies did not cover the issue of cannibalism among catfishes. Dupont et al[5] assessed three European Commissionfunded initiatives to determine the value of IoT in aquaculture based on three parameters: highperformance and low-cost sensors, economical and easy-to-deploy systems, and intelligent systems.

Ramya and Ravi[1] described an IoTbased smart monitoring system for fish farming. The present technology's objective is to provide a safe and secure environment that assists fishpond owners and aquatic plant growers in producing high-quality fish by keeping regular water levels in the fish tank. [4] collaborated on an IoT platform

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for seafood farmers and consumers. The paper discussed a case study of an enterprise-level IoT platform for seafood producers that satisfies consumers' end-to-end traceability requirements while also extracting data from downstream actors' information requests. The study utilized an IoT platform that integrated EPCIS (Electronic Product Code Information Services), ERP (Enterprise Resource Planning), CRM (Customer Relationship Management), and Blockchain technology.

[10] described an energy-efficient optimization scheme for water pump control in a smart fish farm. The researchers created a conceptual design for an Internet of Thingsenabled Fish Farm system. This design considers a closed environment of interest, namely a fish farm tank that requires automated control via the IoT to maintain a healthy environment for fish growth while maximizing resource use. The entire procedure is divided into four distinct stages. To begin, the tank environment is monitored by sensors that collect various data (e.g., temperature, oxygen level, water level, and pH). Sensor data provide information about the current state of the tank. Second, utilizing previous data, a prediction algorithm is used to forecast future situations. This assists in adjusting/controlling various settings before the circumstances inside the tank deteriorating for the resident fish. Thirdly, optimization techniques are necessary to determine ideal circumstances while considering the optimal settings for fish growth and system restrictions, such as power. Finally, actuator levels are adjusted to maintain optimal tank water quality for fish development. This contributes to providing the optimal conditions for fish growth while maximizing resource utilization.

[25] conducted study on the real-time monitoring and automation of fishponds using Arduino. Utilizing Arduino, this project measures water, temperature, pH, and DO levels and integrates them with aerating and water supply pumps. As long as the user has access to the internet, they can receive information at predetermined intervals on their selected communication or display device.

[15] conducted findings on the design and development of IoT based smart aquaculture system in a cloud environment. This study provided a framework for constructing an extremely beneficial aquaculture framework, capable of preparing the employments of observation, intelligent control of the Internet of things (IoT), irregularity awareness, and carbon outflow reduction, as well as energy protection. Additionally, it contained a check of the water's guality, environmental monitoring, electricity monitoring, and a web-based surveillance platform. The proposed system has the potential to improve aquaculture technology, reduce carbon emissions, increase energy efficiency, and relieve the problem of freshwater aquifers being depleted. [22] did a study on an IoT-based Automated Aquaculture Monitoring System for Fish Farms. This work develops and executes an innovative aquaculture monitoring system utilizing the Internet of Things. For convenience, this system combines Wi-Fi and Internet access. It was proposed and implemented in this work with the monitoring of aquaculture water quality using a Raspberry Pi, Arduino, different sensors, a smartphone camera, and an Android application. Temperature, pH, electrical conductivity, and colour are all employed as water quality criteria in this work. Arduino is utilized to acquire sensor data, while the Raspberry Pi serves as both a data processing device and a server. Raspberry Pi also acquires photos using an Android smartphone camera to determine the color of the water. A user can monitor the water quality using an Android app over Wi-Fi within the range of the app or via the Internet from anywhere in the world.

[24] researched on an online water quality monitoring system for intensive fish farming in China, which integrated web-serverembedded technology with mobile communications technology. It is intended to forecast water quality using artificial neural networks (ANNs) based on past data and adjust water quality in real time to prevent catastrophic losses. Experimental data have been used to validate the forecasting model for dissolved oxygen half an hour in the future. The findings that utilizing this well-established reveal

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monitoring technology, multi-parametric, longdistance, and online monitoring for water quality information may be accurately gathered and anticipated.

[9] investigated an intelligent fish farming and tracking control system based on the IoT. The system contains a forecasting method that enables autonomous water quality management and facilitates tracking the breeding and selling of freshwater fish. This system can assist fish farmers in intelligently controlling and managing water-guality treatment equipment in fishponds, as well as consumers in tracking and viewing historical farming process data via the QR code tag on an aquatic product, thereby increasing revenue for fish farmers and ensuring consumer food safety. Additionally, they offer a set of forecasting algorithms for water-quality indicators for a fishpond intelligent management module that begin by detecting and removing outliers using the local outlier factor (LOF) algorithm and then comparing to DBSCAN.

Then, using the model tree method, critical fishpond data are analyzed, modelled, and predicted, allowing water-quality indicators to be addressed in advance and maintained within a safe range that meets regulations. The experiments demonstrated that the mean values of the predicted data generated by the M5 model tree algorithm were closer to those of the training data than those generated by the Cubist, RF, or GBM algorithms, and that strong correlations between the predicted and verification data were discovered. Additionally, their technique's mean absolute errors are minor in comparison to the data means, showing that the suggested method can anticipate water-quality indicators efficiently and precisely.

[6] designed and deployed low-cost short-range wireless sensor network modules based on the ZigBee standard and virtual instruments technology for real-time monitoring and management of aquaculture systems. The system consists of a coordinator/gateway node, smart sensor nodes, and a personal computer (PC). The smart sensor nodes use appropriate sensors to monitor environmental parameters such as dissolved oxygen, water temperature, pH,

and water level. They transfer this data to the coordinator/gateway node over the ZigBee network and receive control signals for actuator control. The coordinator/gateway node receives acquired data and transmits commands to the PC, thereby establishing a human-computer interface. The LabWindows/CVI software platform created the graphical user interface (GUI) to enable users to view, study, and analyze the scientific and correctness of parameters in an aquaculture setting [39]. The authors created a method for two sensor network nodes installed in fishponds and analyzed the results for six months. The results indicate that the power management and networking solutions used in practice result in optimal monitoring, control, and recording of the aquaculture system. It significantly mitigates the danger of high fish mortality by allowing for continuous monitoring of crucial parameters in the aquaculture environment. This condition benefits aquaculture economically, boosts consumer confidence, and improves consumer safety, all while lowering labor costs and energy usage.

[23] developed an Electronic Pond Management System for freshwater prawn/fish agriculture. The system continuously monitors and controls a variety of hydro biological factors critical to fish growth, including DO, pH, BOD, temperature, and feed. The system is composed of a centralized monitoring and presentation of numerous metrics and is intelligent enough to forecast the stress factor on-line via a Predictive Decision Support System (PDSS). When multiple ponds are located in separate locations, the system enables centralized control and display capabilities via pond networking. The technique conceptualized following extensive was consultations with Indian aquaculture farmers and scientists conducting research on freshwater aquaculture.

[17] collaborated on the development and implementation of a smart monitoring system for fish farm water quality. The purpose of this work is to design a low-cost system for monitoring the behavior of the fish farm's water (pH and temperature). They designed and developed the entire intelligent monitoring system (receiver and transmitter). The prototype transmitter circuit was

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created to monitor the pH and temperature of fish farm water, and the Arduino Uno was used as the microcontroller, reading sensor data and transmitting the results over Bluetooth to the receiver. Bluetooth enables the receiver and transmitter to communicate wirelessly.

The receiver component is a new smartphone application created with MIT App Inventor 2 and compatible with any Android smartphone. It collects data on the pH and temperature of the water in the fish farm and displays it on the application. MIT App Inventor 2 is a Google software (open source) that enables the rapid development of Android applications. The entire system has been successfully tested in the laboratory. Additionally, they state that future development should focus on transitioning the wireless system from Bluetooth to IOT, as IOT technology is the future of communication for intelligent devices. Pusha et al[3] built a prototype of an IoT-based Smart Aquarium Monitoring System for maintaining fresh water in fish aguariums. The technology is designed to monitor fresh water to ensure a healthy fish habitat. The designed system makes use of Arduino MEGA and NodeMCU controllers. Wi-Fi communication on the NodeMCU is utilized to govern the operation between the smartphone and the controller. The analog pH sensor is used to

determine the pH of water and to display the reading on the Liquid Crystal Display (LCD). The system was meant to monitor the pH value appropriate for the type of fish life and to control fish feeding. Khairunisa et al[12] created a system to simplify the task of keeping fish in an aquarium. This aquarium is capable of performing a variety of tasks, including automatic fish feeding via an Android device. To move the fish feeding valve, it utilizes a servo motor and a relay as an on/off aquarium decorative light. Fish feed machines can automatically feed fish if the user forgets to feed them.

#### Implementation

The following materials were used for prototyping based on flexibility, security, and convenience.

- a. Arduino IDE: a C/C++ programming environment for the Arduino Uno Microcontroller
- b. Visual Studio Code was used to write the backend server code hosted on Heroku and frontend using JavaScript.
- c. **MQTTX** was used to test the Thingspeak platform's MQTT endpoint.

The architecture of the proposed system is show in Figure 1.



Figure 1. Architecture of the proposed system

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# **Overview of the Design**

- The proposed system is an IoT-based system that is designed to support the following:
- b. Sensing of water quality parameters (temperature in Celsius, TDS and pH).
- c. Real-time dashboard displaying sensed data.
- d. Push notification showing recommendations.

# System Implementation

This phase is split into five components namely: IoT device construction and programming, ThingSpeak dashboard integration, Mobile application development, REST API development, and Database implementation respectively. The schematic in Figure 2 covers the first two phases.



Figure 2. Schematic of the IoT construction The interfacing of the various components in the schematic is as shown in Table 1.

Arduino Uno	ESP8266	DS18B20	E-201-C	Photoresistor (LDR)	Analog TDS sensor
A0	-	-	-		A0
A1	-	-	P0		-
A2	-	-	-	A0	
A3	-	-	-	-	-
A4	-	-	-	-	-
A5	-	-	-	-	-
D7	RX	-	-	-	-

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Arduino Uno	ESP8266	DS18B20	E-201-C	Photoresistor (LDR)	Analog TDS sensor
D6	ΤX	-	-	-	-
D4	-	Do	-		-
GND	-	GND	GND	GND	GND
Vcc (5V)	-	Vcc	Vcc	Vcc	Vcc
Vcc (3.3V)	Vcc and EN	-	-		-

#### Connection of the ESP8266 module

Interfacing the ESP8266 with Arduino UNO and the bread board was in accordance with the schematic in Figure 2. Following the connection of the Wi-Fi module, the Arduino UNO was programmed to send data to ThingSpeak. See Figure 1-2.



Figure 1. ESP8266 connection to breadboard

# Connection of the DS18B20

# Connection and calibration of the E-201-C

The E-201-C analog pH sensor must undergo calibration before it can properly reading values. The calibration is required to convert 10bit analog value to 0 - 5 voltage range (V) correctly. Since pH ranges from 0 to 14, it is mapped to 5 volts so that pH 7 equals 2.5 V, pH 14 equals 5, and pH 0 equals 0V. Calibration will reveal the ambiguity in the measurements, since pH 7 may not provide a precise 2.5V value during conversion. The output value should be 2.5, since the short circuit has a pH of 7. Three buffer solutions were collected in order to properly calibrate the sensor (pH of 9.18, 4.0 and 6.8). The voltage measurement from the pH sensor during the calibration procedure is shown in Table 2.

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Connecting the DS18B20 sensor to the Arduino UNO via the bread board was also in accordance with the schematic diagram shown in Figure 2. After connecting the sensor, the Arduino uno was programmed to receive values from it. The sensor was placed in a variety of different water solutions with varying temperatures (cold, room temperature, and almost boiling) to see if it responded properly.



Figure 2. DS18B20 Connection to breadboard

Table	2.	pН	and	Voltage	Reading	during
Calibra	tion					

Voltage
2.94
3.44
2.53







Figure 3. pH against Voltage Scatter Plot

From the equation of the line (y = mx + c) shown in Figure 3, the accruate pH reading can be calculated where the value of x is the voltage reading. The equation below show how the pH reading was calculated

*phValue* = -5.6933 \* *voltageValue* + 23.589.....(1)



Figure 4. E-201-C connection to breadboard

# Connection of the TDS Sensor

The analog TDS sensor was connected to the Arduino Uno and breadboard in this setup. Since the TDS value is temperature-dependent. The DS18B20 temperature measurement was utilized in conjunction with the TDS sensor to calibrate and compensate for the reading with high precision (see Figure 5).



Figure 5. TDS sensor connection to breadboard

#### Thingspeak Dashboard Implementation

The Arduino Uno data was collected and displayed on the dashboard using ThingSpeak. After the channel was established, four separate fields were generated: temperature (in degrees Celsius), ec (for electrical conductivity in microsiemens per centimetre), tds (for total dissolved soot in parts per million), and pH. Following that, each field was assigned a chart that depicted its value with time.

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ngSpeak™	Channels <del>-</del>	Apps <del>-</del>	Devices -	Support <del>-</del>		Commer	cial Use Hov
Field 1 Chart			<b>5</b> 2	8 ×	Field 2 Chart		в р <i>(</i>
ŝ 50	Temperature	Reading		_	1000	TDS Reading	
stature (Celsi					(mdd) 500		
0	04:00 T	06:00 Time	08:00 ThingSpeak	k.com	0	04:00 06:00 Time	08:00 ThingSpeak.co
Field 3 Chart			<b>6</b> D	1 ×	Field 4 Chart		6 Q Ø
Elea	ctrical Conduc	tivity Read	ling	_		pH Reading	
EC (hs / cm)			-	4.	10 E		

# Figure 6. ThingSpeak dashboard

<b>□, ThingSpeak</b> ™	Channels 🗸	Apps 👻	Devices <del>-</del>	Support <del>-</del>	
Channel Settir		Help			
Percentage complete	85%				Channels store all the data that a T eight fields that can hold any type (
Channel ID	1470725			status data. Once you collect data i visualize it.	
Name	Water monitorin	ng		Channel Settings	
Description	Intelligent IoT b and segregation	ased System	<ul> <li>Percentage complete: Calcu channel. Enter the name, de channel.</li> </ul>		
Field 1	temperature				Channel Name: Enter a unique
			_		<ul> <li>Description: Enter a descript</li> </ul>
Field 2	tds				<ul> <li>Field#: Check the box to ena channel can have up to 8 fiel</li> </ul>
Field 3	ec				Metadata: Enter information
Field 4	рН				• Tags: Enter keywords that id
rield 4					• Link to External Site: If you h
Field 5					ThingSpeak channel, specify
Field 6					Latitude: Specify the l     latitude of the city of
Field 7					<ul> <li>Longitude: Specify the longitude of the city c</li> </ul>
Field 8					• Elevation: Specify the the city of London is 3

Figure 7. Details of the dashboard created

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The mobile app showed charts and widgets from ThingsSpeak and received push notifications from

the backend REST API when the criteria was met.

#### The Mobile Application Development

ReactJS was used to build the mobile application. ReactJs is a JavaScript package that enables the creation of graphical user interfaces.

### WMCMS



Figure 8. Auth and Dashboard Screen on the Mobile App

#### **REST API development**

Back-end API development is the process of creating server-side logic that drives websites and mobile applications from the behind the scenes. It contains all of the code necessary for developing the database, server, and application. The REST API was deployed to Heroku. The following are some of the core nodeJS packages used in during development: ExpressJS (NodeJS framework); TypeScript; TypeORM, and PostgreSQL database driver package.

# Database implementation

The database's requirements were:

- A relational database management system that supports objectrelationships. PostgreSQL 3 was used as the database server for the implementation. This database server software includes a number of useful utilities, including the pgAdmin (a database management software)
- 2. A compatible operating system with the database server software. Although the development and testing were conducted using

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Microsoft Windows 10/64-bit software, the 64-bit version of Microsoft Windows 2018/2019 is preferred.

- A network-ready PC/Server equipped with at least a core i5 CPU running at 2.5 GHz, 8GB RAM, and 500GB storage.
- 4. Internet connection.

All database tables, keys, and referential integrity were built using model classes. When model classes were run, the database was updated. Through a PostgreSQL connection string and a database ORM (Object-Relational Mapping) called TypeORM, the backend API had simple access to the transactional database. ORM is a method that enables object-oriented querying and manipulation of data stored in a database.

The pgAdmin tool was beneficial for administering and maintaining the database in an

Table 3. Sample of data gathered

environment other than the development environment. Additionally, it may be used to build and manage database connections, indexes, processes, and functions, as well as other physical database features.

# Test and Evaluation Validation of the System

The aquatic environment monitoring component was validated against user criteria specified by five experts from different Faculties of Agriculture in Nigerian Universities. The validation was based on the consistency of the outputs from the systems with set operational metrics.

# Sample of accessed from ThingSpeak

Table 3. show a sample of the data gathered on ThingSpeak during the time of testing the system. The sample data has been modified to only reflect the needed data.

	Table 9: Oample of data gathered									
Date Entered			Temperature (Celsius)	TDS (ppm)	Electrical Conductivity	рН	Light intensity(l ux)			
	2023-08-19 UTC	11:37:46	27.5625	11.84428	23.68856	8.31905	30.50			
	2023-08-19 UTC	11:38:29	27.5625	23.48923	46.97847	8.34222	30.50			
	2023-08-19 UTC	11:39:02	27.875	38.49347	76.98693	8.30052	30.75			
	2023-08-19 UTC	11:39:32	27.5625	15.74761	31.49521	8.34685	30.25			
	2023-08-19 UTC	11:40:08	27.375	21.63903	43.27806	8.38392	29.50			
	2023-08-19 UTC	11:40:29	27.3125	17.77562	35.55124	8.35148	27.30			

#### CONCLUSION

A low-cost IoT solution offers a promising approach towards mitigating cannibalism in catfish farming thereby improving sustainability in production. Having considered the documented metrics that increase catfish cannibalism, we considered an automated IoT solution that would monitor and manage these factors, such as water quality and stocking density, so that farmers can effectively reduce the incidence of cannibalism and improve overall production outcomes. Our study has demonstrated the feasibility of using IoT devices to collect real-time data on critical parameters affecting fish behavior and welfare. Through continuous monitoring and automated alerts, farmers can intervene promptly to prevent adverse conditions that may trigger cannibalistic behavior

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among catfish populations. The affordability and accessibility of our proposed IoT solution make it particularly well-suited for small-scale farmers in Nigeria, who often lack access to advanced technologies and resources. By providing farmers with tools to optimize stocking densities, feeding practices, and environmental conditions, our study contributes to the sustainability and profitability of catfish aquaculture in the region. Going forward, further study and field trials will be needed to refine and validate the effectiveness and efficiency of the proposed solution. Furthermore, efforts to promote awareness and adoption of IoT solution among farmers will be essential to realizing the full potential of these innovations in improving aquaculture practices and fostering sustainable food production in Nigeria.

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