Smart aquaculture system: internet of things-based contextual e-service for sustainable aquafarming

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ABSTRACT

A creative and contextual e-service for aquaculture system is developed to handle threats that climate change poses to global ecology and sustainable aquaculture. Therefore,"ICTization framework model," is based on capacity, connectivity, and context across three layers—core, and management, and distribution— has served as the study's guide. These layers support elements of centralization, decentralization, and parallelization hence reduce misconceptions about infrastructure, development, and communication. It incorporates a four-tier conceptual framework for an e-service system based on the internet of things (IoT) that is aimed at appropriately collect and manage environmental data in real time. Each tier of the framework is further elaborated for e-services using contextual information with existing infrastructure preserved while improving synchronization of data, administration, and services. It is able to predict and respond to variations in the quality, temperature, and other vital parameters of the water. The architecture realizes aquaculture as a service by orchestrating all the stakeholders – farmers, researchers, and network operators. E-service based system shall include remote monitoring, automated feeding and water quality assessment in real-time which will significantly improve efficiency reduce cost and increase income. Moreover, improved resource efficiency and less ecological impact made possible through the proposed conceptual framework enables sustainable aquaculture practices.

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1. INTRODUCTION

Fish contributes about 60% of the total animal protein consumed by the people, and thus, it is the major source of dietary protein. With the growing demand for fish throughout the globe, aquaculture has tremendous potential to meet the increasing demand for protein. Bangladesh particularly has very good prospects to become a leading aquaculture exporter. It is the fastest-growing food production sector in the country, contributing to around 3.6% of the country's GDP. The sector is also the backbone of the economy as it sustains livelihoods for around 2 million people through food security and a stable income source.

Bangladesh is highly dependent on water resources but is being severely challenged in the aquaculture industry. Climate change, water contamination, and outbreaks of diseases have been progressively affecting the sector, compromising both productivity and sustainability. An internet of things (IoT)-based contextual e-service for aquaculture is here proposed to solve this problem. Aquaculture, fish, crustacean, and mollusc cultivation was taken into account in the present study as it has now emerged as a promising industry for food production and economic development, especially for nations like Bangladesh, which possess an immense network of rivers, ponds, and coasts. Bangladesh is privileged to have colossal opportunities for aquaculture growth. With IoT, an innovative aquaculture system will be established to monitor and regulate different parameters of fish rearing like water parameters, temperature, and feeding, which will enhance farmers' decision-making as well as overall productivity. This study outlined several study objectives, which are based on the assumptions presented throughout this research:

– A context-aware smart agricultural system should provide practical, structured advice based on a predefined ICT scheme.
– The system should be accessible to users from anywhere in the world at any given time to fulfil their needs.
– This means that the platform should be available to its users in a way that allows for the free utilization of the available material.
– As depicted in the following model, the targeted entities or stakeholders' responsibilities are rewarding and specified.
– To ensure customer satisfaction, the model must be set up to deliver timely support and services.

There are numerous article that cover the application of IoT in aquaculture and how IoT can boost productivity, sustainability, as well as solve industry challenges. Studies have recommended employing sensors in IoT-based system to measure water quality parameters that affect aquatic animals such as temperature, dissolved oxygen, and pH level. For example, new technologies like real-time cloud platforms for data processing and IoT water quality sensors with data acquisition have been a primary contributory factor for the success of aquaculture.

At the moment, fish growth, waste reduction, and feeding efficiency have all benefited from the development of innovative fish feeding systems that utilize IoT technologies. Cordova-Rozas *et al.* [1] conducted experiments to identify the pH sensor error rate with focus on two significant water parameters: pH sensors error rate with the focus two significant water parameter: pH and temperature. After that, Adriman *et al.* [2] integrated a set of essential components in the system of their ultrasonic sensor for pond water level sensing, pH sensing, and salinity sensing all controlled by an ESP32 microprocessor. Now study used to Raspberry Pi model as a processing core which talked to various sensors like pH, temperature, turbidity, dissolved oxygen, and water level sensors. Actuators were interfaced for automatic control, like water inlet/outlet motors and oxygen boosters [3].

Chen *et al.* [4] developed an autonomous fish feeding system and investigated wireless data transmission via ZigBee technology. Another paper employed a tree topology in a wireless sensor network (WSN) to improve the reliability of data transmission and reduce packet loss [5]. Hongpin *et al.* [6] combined ZigBee and GPRS modules to send real-time data to a remote monitoring centre.

The creation of a sea-current-driven propeller system with energy-harvesting capabilities, the AppliConSeaModem, and related hardware integrations was described by Cario *et al.* [7]. Hu *et al.* [8] further developed this work, suggesting an automatic fish feeding system based on computer vision and deep learning (DL) technology.

Information and communication technology (ICT) models have also been applied in aquaculture. Mahmud and Sattar [9] evaluated and ranked ICT influence factors, with a focus on the adoption of existing infrastructure through context information and ICTization paradigms to enhance system performance. For enhancing survival rates of water animals, Tsai *et al.* [10] proposed an IoT-based smart aquaculture system (ISAS) with water quality monitoring and independent aeration control.

Al-Mutairi and Al-Aubidy [11] designed and implemented an IoT real-time monitoring, control, and management system for aquaculture with the help of a cloud-based use case that is aided in the objectives of the Horizon2020 Project [12]. Tolentino *et al.* [13] created a system to track six important water quality factors through sensors, microcontrollers, and a web-based tool. The system uses solenoid valves, water pumps, heaters, and sodium bicarbonate distribution motors as automatic control units to give the best conditions for fish growth. Although Nasir and Mumtazah [14] suggested several types of sensors applied to aquaculture water quality monitoring, Rosaline and Sathyalakshimi [15] introduced an IoT is remote monitoring system for aquaculture environments.

Olanubi *et al.* [16] designed an IoT-enabled smart water quality management system to measure parameters like temperature, pH, and turbidity. Similar IoT-based approaches have been employed to continuously monitor aquaculture needs and automate resource supply [17]. There are Hu *et al.* [18] investigated intelligent aquaculture applications, including the data collection and preprocessing using sensor networks enhanced with noise reduction techniques.

Systems used in aquaculture also have to be integrated with AI. Mustafa [19] used- artificial neural network (ANN) to help manage fish hatcheries by simulation the human brain process. An IoT based monitoring system was created by Irawan *et al.* [20] using the flow temperature and pH sensors (PH-4502C, DS18B20), which were processed by an ESP32 module. An intuitive application was created to show these readings via LCD and Bluetooth so that a decision could be made in real time [21].

Kim *et al.* [22] proposed an advanced fish growth prediction model by developing a preprocessing approach and a probabilistic model using mixed data sampling (MIDAS) and overlapping mixtures of gaussian processes (OMGP). Finally, Adel [23] examined intelligent service quality, emphasizing the role of customer co-creation in shaping effective intelligent service ecosystems. Using the support vector machine (SVM) Model, Ahmed *et al.* [24] introduce an image-based technique for identifying fish disease with an accuracy of 91.42 and 94.12%. Mamun *et al.* [25] utilized the VGG16 and VGG19 ensemble models to identify fish disease with the best accuracy, 99.64%, and a 99.28% detection rate using a pre-trained model, ResNet-50.

While previous studies analyzed the impact of innovations in smart aquaculture technology, the majority of them have focused on decisions made by aquaculture managers, fish farmers, and network operators to monitor and control in real-time. Some of these trends have been crafted through enhanced use by fish farmers and aquaculture organizations of ICT. The justification for using ICT is to enhance socio-economic development and improve the technological advancement of aquaculture. Such intelligent aquaculture services that have been discussed above are e-service based, and they have to be regulated by the government. During the development of such a system, one has to know all the user expectations on the user's side. Also, the service they need has to be cost-effective and beneficial. Failure at any moment in the delivery of service results in enormous loss to the aquaculture farmer, which at times may be unrecoverable.

However, we proposed an e-services-based contextual smart aquaculture system that can help create a more efficient e-services-based aquaculture system by decreasing costs, increasing fish farmer satisfaction, and improving aquaculture results. Based on a study to improve the quality of service (QoS), combinations and clarifications have been merged. Several hypotheses for this research are specified as:

H1: Deploying the E-service-based contextual smart aquaculture system will significantly improve resource management and operational efficiency.

H2: Real-time monitoring through IoT-based technologies will enhance farmers' decision-making capabilities.

H3: Tailoring the smart aquaculture system to the local context will increase user satisfaction and promote higher adoption rates.

H4: By incorporating e-services and mobile applications into the suggested intelligent system, accessibility will be enhanced, allowing farmers to efficiently monitor and manage operations from any location and make data-driven decisions remotely.

H5: IoT technology will enhance sustainability and lower operating expenses.

2. MATERIALS AND METHODS

The core goal of this framework is to let smart devices look at facts well and give fitting response based on the case. The plan is to boost the carry-out skill of IoT tools by making them better at spotting and judging their setting. The stress is on building paths for the single tool smarts to help each other without much fuss, work together to accomplish several tasks, and always be fed with the necessary data about their cooperation. This improves the systems overall performance and increases the effectiveness of the devices that are connected to it. Supporting the integration of IoT as a system inside current structures at different professional, social, and technological levels is one advantage of this system. Additionally, the framework outlined makes it possible to seamlessly integrate existing systems IoT-based solutions. The delivery of complex services and applications that are both practical and realistic is thereby made easier. The objective is to build a network of linked smart devices in the future that communicate and plan their activities. Coordination at this level will enhance the effectiveness of day-to-day processes and facilitate a response to global concerns, including climate change. These devices will integrate with cloud computing technology to analyze large datasets and make informed, suitable, and environmentally friendly decisions. Finally, the framework even anticipates that technology will enhance human wellness and advance the earth's future.

2.1. Background of the conceptual framework

The entire network will be divided into four layers, each of which will collect and share raw data from IoT devices in Figure 1 [9]. These layers will establish a comprehensive framework that does not alter the existing network setup but instead introduces a new method for interacting with services and devices.

2.1.1. Connectivity layer

This layer connects physical devices such as sensors and other gadgets. The future of the internet depends on connecting these devices to create a network accessible from anywhere so that it can be near to hand, personally identifiable, and controlled. Inventory management helps track all devices and networks within the system. These devices often have limited resources, so they need to be used efficiently. This layer enables the sharing of information across different networks. Radio frequency identification (RFID) tags are small devices that can identify and track objects. They can be powered by sunlight, so they do not need batteries. Combining multiple RFID tags with a few smart devices can create a network that sends data over long distances to reach the main gateway [9].

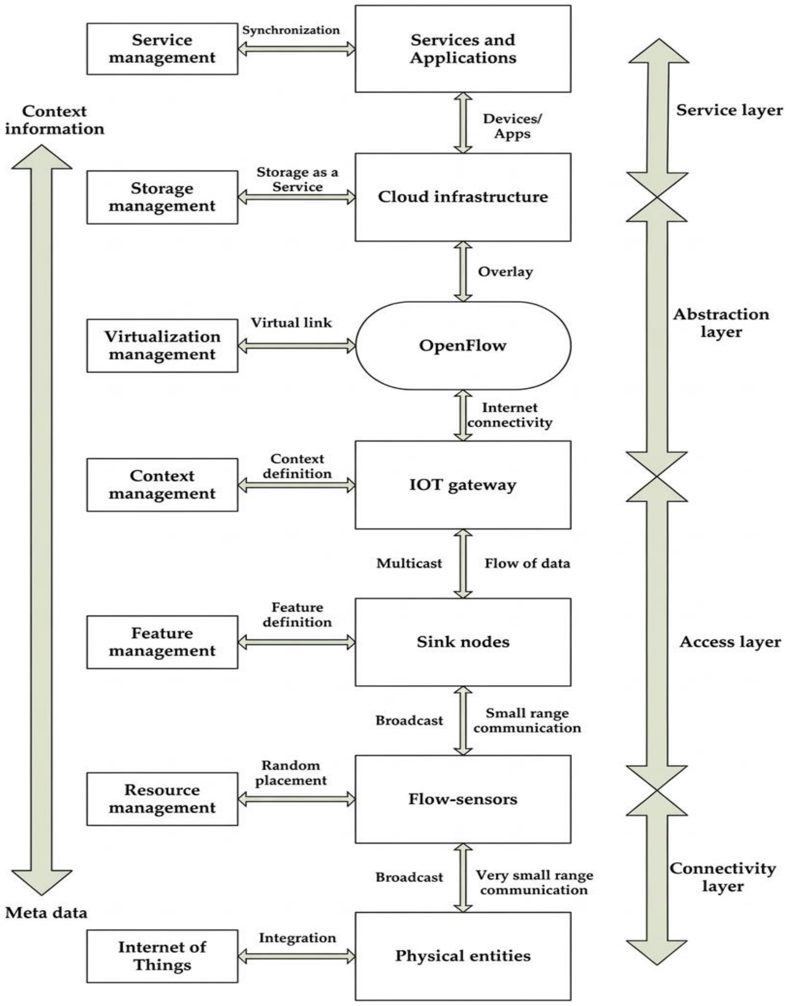

Figure 1. The background of the conceptual framework [9]

2.1.2. Access layer

The IoT gateway serves as the conduit for relaying unprocessed data between the immediate equipment and the internet. This layer is tasked with designing a network topology, initiating the network, and defining the domain. The access layer includes functions such as communication setup, within- and inter-domain conversations, network organization, flow sensor delivery, and packet sending from the IoT gateway. At this point, a user filter is employed to find pertinent context while eliminating extraneous information, which is essential for effective feature management. Although several sensors have multiple characteristics, only certain of these characteristics are necessary to produce contextual data. By eliminating pointless data interchange and streamlining the processing of pertinent information, the filter connection is crucial for lowering processing costs and power usage. The application specifications and the particular data type involved determine how many attributes are needed. Control over data storage in the database controller and synchronization node, as well as control over data values and thresholds, are all included in the context management that is assigned to a server. Two sets of values are defined for the time being, the data values that are currently accepted and the typical values, often known as permissive limits. Furthermore, the server will only maintain fresh values; it cannot store the same values [9].

2.1.3. Abstract layer

Compatibility is another key component of OpenFlow, which allows the digital layer to be integrated into the layers of the current system while maintaining the general structure of the entire network. The network and the core device are nearly identical physically, but the addition of flow indicators will allow for continuous service delivery. According to this viewpoint, a centralized framework makes it easier to manage all types of network traffic, which improves mapping, bandwidth, network dependability, and other factors that determine a higher QoS. Because data packets are sent across multiple nearby nodes when using multi-hop, traffic is higher on nodes that are closer to the access point than on those that are farther away. If these vital nodes ever malfunction or are deactivated, the network may come to an abrupt end. However, the suggested virtual link-enabled communication technique at the entrance point between two sensor networks allows sensor nodes to be digitally present, thereby addressing the previously noted issues [9].

2.1.4. Service layer

Handling many kinds of data, including common, unknown, and other significant data types, as well as innovations that enable the storage system to be flexible and effective, are all included in storage management. It functions as a tool for protecting data as well as archiving. To improve business intelligence analysis and processing in general, appropriate access to data is also required, and the resources that are already available must be increased. However, by managing a number of IT problems and challenges typically encountered by major corporations, the cloud computing architecture offers services to companies, particularly small businesses. Because this infrastructure makes it possible to apply the majority of conventional business practices, businesses' suppliers, employees, and customers can all profit substantially from it. They will have a greater social and economic effect if these services are integrated. This study suggests a completely novel, cutting-edge aquaculture system based on e-services that makes use of the IoT and tackles economic and social problems, including safety precautions, environmental assessment, climate change, and modernization of agriculture. The simplicity of implementing intelligent fish farming services then makes it possible to map the anticipated context. This framework makes it simpler to choose computing technologies and keep network and cloud applications operating smoothly by allowing the use of a variety of strategies and control techniques.

2.2. Framework for ICTization

A number of clearly defined national and international frameworks are required for national ICT strategies in order to create an efficient and all-encompassing ICT system. This process system will simultaneously reduce uncertainty, improve delivery, enhance progress, facilitate effective communication, streamline management, and increase service participation. It extends current thinking by providing context-aware, service-based intelligent service design. In this context, distribution, management, and process architecture ensure the control and management of service integration, as depicted in Figure 2. This is slightly simplified in Figure 3 to a three-layer service-based architecture defining the interaction between planning and receiving services. While operational definition and development occur at the distribution level, the management level is concerned with decision support and certification. Data analysis is conducted at the main stage. A brief description of each layer, outlining its specific function, is provided below [9].

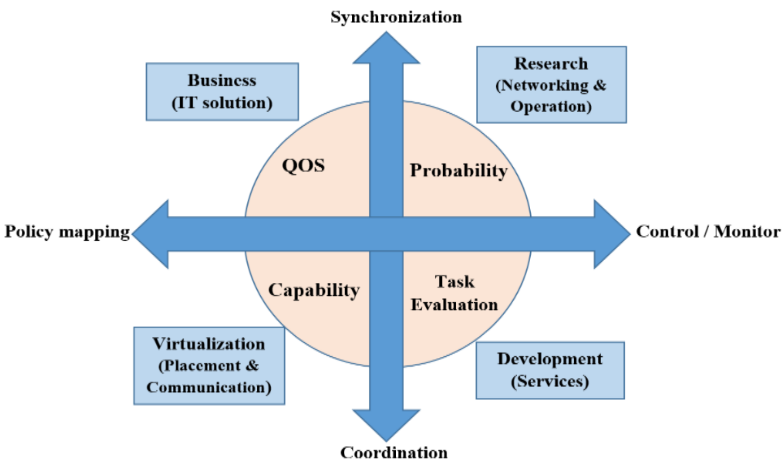

Figure 2. ICTization framework [9]

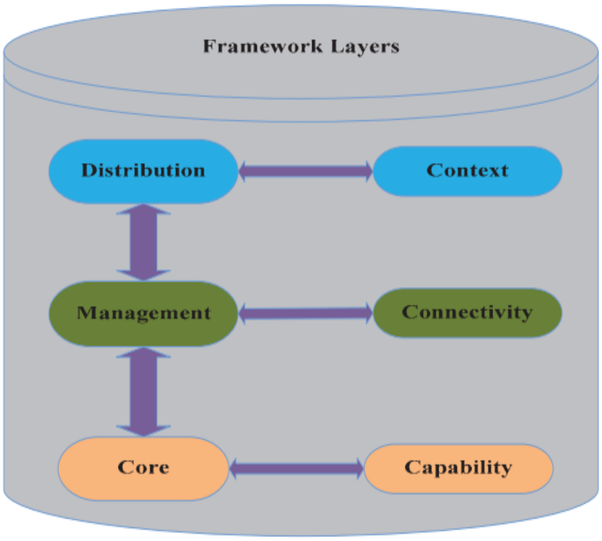

Figure 3. Framework layers for ICTization [9]

2.2.1. Distribution layer

The distribution layer defines the location and state of entities in an environment. As for the third component, the interaction described between the user and the service is quite limited and mostly depends on preferences and the need for key information, such as identification, local context, and geographic location. When it comes to pooling resources, adding new services, and enhancing service quality, this layer of an IoT network has much promise. Additionally, it makes use of virtualization techniques to improve workflow execution, network assessment, and communication, offering integrated IT solutions for enterprises. It may enhance the system by enabling role switching and dynamic temporal changes in the parameters of operation. Furthermore, the suggested innovative aquaculture can operate as an online service in this layer, offering data based on the user's choices and current circumstances.

2.2.2. Management layer

Connections and system service availability are managed by this layer. It combines multiple services to provide expense, time, energy, and other advantages related to the perspectives users and supplies. It addresses cost, flexibility, and other organizational IT concerns by forming strategic alliances. This benefits corporations, their employees, customers, distributors, and other stakeholders in the corporate world. This layer also encompasses space and network control, as well as the portrayal of rules, timing plans, and working plans. Implementing a new user interface makes it easier to incorporate major services and logistical solutions. These newly integrated services focus on achieving target socio-economic objectives to enhance services in postgraduate disciplines by addressing climate change, security evaluation, environmental regulation, aquaculture development, and other related issues.

2.2.3. Core layer

At the initial level, control is primarily situated at the level of the main process, encompassing decision-making and evaluation. This process estimates the success rate in completing the task and the possibility of an error. They have significant value in the involvement of two critical technologies and information initiatives that are essential for machines to measure and operate. It is essential to note that the primary responsibilities of this position include information retrieval and data privacy protection. It is useful in controlling unauthorized data access, linking data, maintaining service availability, facilitating analysis of key service data, and, particularly, maintaining good work in the field.

3. RESULT AND DISCUSSION

The system depicted in Figures 4 and 5 comprises six key components: user, IoT gateway, internet service provider, application server, service application, and environment. all of these entities have the following roles:

- Incorporating IoT devices which can transmit data collected by sensors via an IoT gateway, environment data characterizes the fish farming situation in which the infrastructure is deployed.
- Information is sent to the application server via an IoT gateway, which also notifies the system of any negative events affecting the aquaculture. To perform these activities, it can connect with the internet service provider via 3G or 4G network services.
- It connects mobile devices to ISPs and keeps track of network user IDs.
- Besides managing user requests, the application server is additionally in assigned to data processing and maintenance. Easily and access the data from the server by allowing user. The multi-layered service application gives a layer that takes user commands and converts them into requests for the application server to the previously described query interface. It gives consumers the data that are looking for and informs them.
- Users who get data on ecological variables including water quality, temperature, and the condition of fish include aquaculture officers and fish farmers. The summary statistics will help aquaculture supervisors monitor and assess the entire environment of the farms, and data from that database may enable fish farmers take the necessary actions.

These elements help the aquaculture ecosystem's decision-making and communication processes.

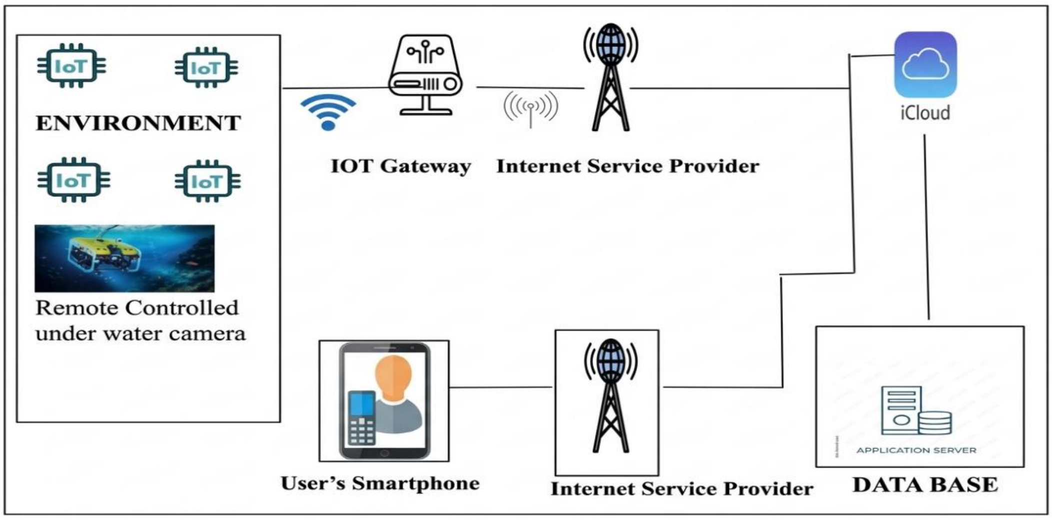

Figure 4. Network architecture

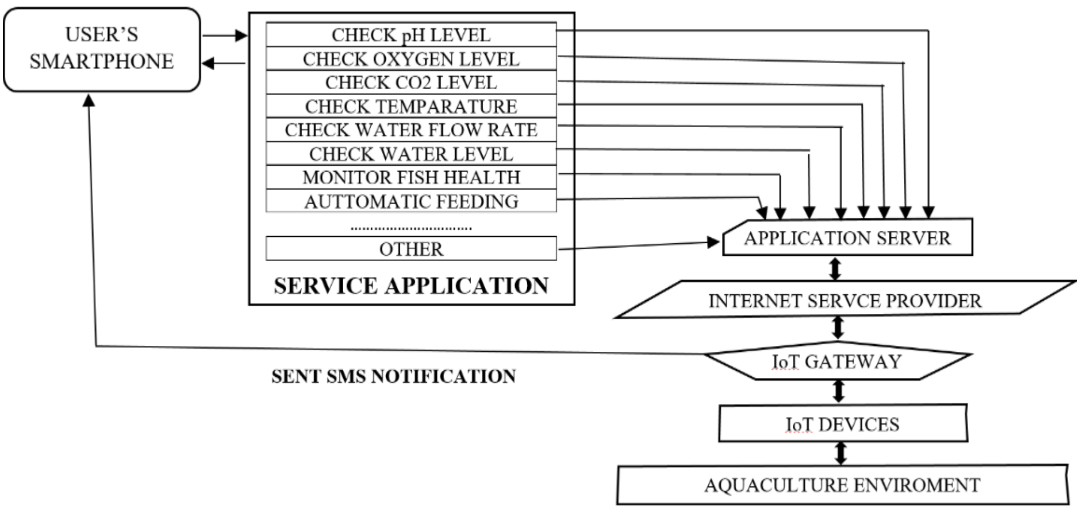

Figure 5. Smart aquaculture system architecture

For example, suppose a fish farmer wants to assess the quality of water in the aquaculture environment. Then the fish farmer can start the service application and click the 'check water quality' option Figure 6, and the application will send the present water parameters to the application server. At the same time, IoT devices gather data from water condition sensors. The application server further analyses the data provided in its raw form to the service application. If the water temperature or dissolved oxygen levels drop or rise sharply, or if any form of pollution is detected, the system will send a message or alarm through the IoT gateway to inform the farmer to take action to prevent the loss of fish stock. The smart aquaculture system maintains a continuous connection with its users and the aquaculture environment, monitoring events and situations in real time.

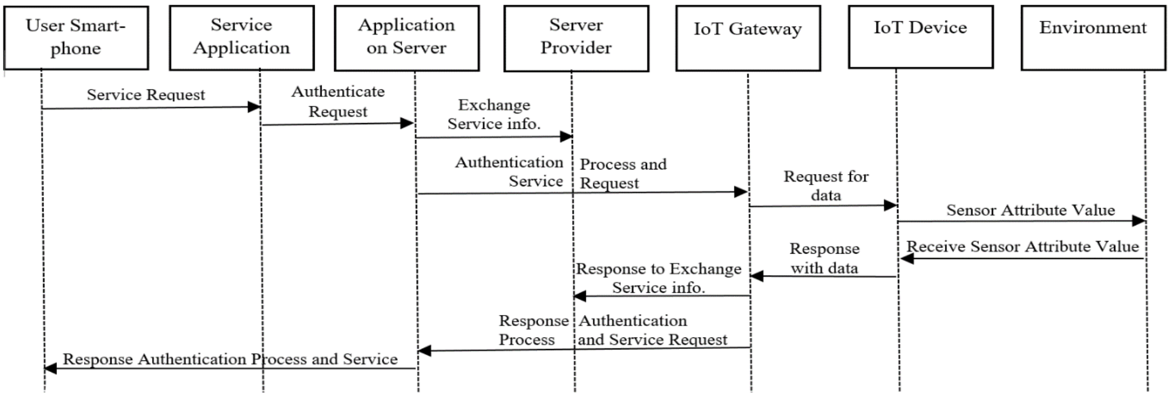

Figure 6. Operations of the smart aquaculture system

In this research, users may track and supervise the fish farms utilizing a smartphone simply due to the smart aquaculture system's series of interrelated operations Figure 6. Before forwarding them to the IoT gateway, the server verified requests for service. The interface gathers environmental monitor data in real time, such as pH values and temperature. Ultimately, a client receives the information that was processed for convenient supervision and analysis.

4. CONCLUSION

This research has demonstrated that smart aquaculture systems can significantly grow and transform the industry to become more sustainable and efficient. Innovative IoT technology, sensors, and data analytics are utilized to achieve sustainability and efficiency in aquaculture operations. The suggested framework can collaborate, examine, and govern separate elements like feeding apparatuses, water quality observation tools, and energy management setups working with solar power to reduce its effect on nature. It may include watching elements like heat levels in water PH dissolved air as well as nutrient amount. Scalability and adaptability of the aquaculture system may also be advanced by the proposed framework. With less expenses, the fish farmers may effectively regulate when IoT devices are located at many places and integrated into different applications. Besides, effective response to environmental changes and contextual knowledge, which is better for future decision-making is also offered by the framework. In future, we will utilize artificial intelligence (AI) to better water condition prediction and detect or predict diseases. When set up in real-time monitoring algorithms, incorporating data gathering pipeline and get historical data from sensors which is predicted outcome from training model. The technology enables disease detection, water standard forecasting, and automated notifications will gradually integrate machine learning. Al makes more effective, quicker and better aquaculture. Thereby, the fishing industry can handle problems like resource scarcity, climate change, and rising food demand by using smart aquaculture solutions, which will also ensure a steady and profitable continuation of aquaculture.

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Jarin Tias Meraj	✓	✓	✓				✓		✓	✓	✓			
Abdus Sattar	✓	✓			✓	✓				✓		✓		

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

All author hereby states that no financial, personal, professional, political, ideological, or religious interests exists that could have influenced the research analysis, or interpretation of the data presented herein. Competing interests if any have been disclosed by all authors, and none impede the impartially of this work.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, [AS], upon reasonable request. The data are not publicly available due to privacy concerns and institutional policy restrictions regarding the handling of sensitive or personally identifiable information.

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