WIRELESS SENSOR NETWORK ARCHITECTURAL MODEL FOR WATER QUALITY MONITORING FOR AQUACULTURE

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WIRELESS SENSOR NETWORK ARCHITECTURAL MODEL FOR WATER QUALITY MONITORING FOR AQUACULTURE

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ABSTRACT

Wireless sensor network (WSN)-based techniques are evolving to alleviate the problems of monitoring, coverage, and energy management in different application areas. Traditional methods of monitoring water for Aquaculture have proved to be ineffective since they are laborious, time consuming and lacks real-time results to promote proactive response to water contamination. Wireless sensor networks (WSN) model, therefore, have since been considered as a promising alternative to complement conventional monitoring processes. These networks are relatively affordable and allow measurements to be taken remotely, in real-time and with minimal human intervention. The inclusion of the Internet of Things (IoT) in WSN techniques has further led to improvement in delivering of real time, effective and efficient water-monitoring for aquaculture. The purpose of this paper was to develop a wireless sensor architectural model for monitoring water quality for Aquaculture in fish ponds. Design aspects considered are: Scalability, Fault Tolerance, Security, and energy efficiency. To facilitate their realization as the architecture's constructs and sub-constructs, the associated variables were grouped under theme notions. Furthermore, a survey on communalities after performing factor analysis was done to determine the indicators which are forming the components of the architecture. Prototype evaluation was used in addition to expert evaluation to verify the created Wireless Sensor Network Architectural Model (WSNAM). The tool was taken to different fish ponds to test the Turbidity, pH, Temperature and the dissolved Oxygen of water. The developed architecture can give accuracy data at 74.3%. Besides, the Wireless Sensor Network Architectural Model (WSNAM) for fish ponds developed satisfies all the validation conditions from the IT experts. It is a low cost, lightweight system and has low power consumption as analyzed in the research work. Moreover, the system is able to log bulk data and transfer to remote locations. The model developed is capable of monitoring the following water indicators namely; Turbidity, Dissolved oxygen, Temperature and pH. The sensor unit effectively transmits real time data to the central processing unit for further analysis regarding water quality.

Key Words: *Wireless sensor network, Water quality monitoring, Aquaculture*

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INTRODUCTION

Aquacultures is a rapidly developing food-producing sector with economic significance, accounting for 50% of global food production (Greene & Devillers 2017). It is widely recognized as an essential component in the quest for global food security and economic development. However, some practices adopted by farmers in developing countries to improve yield production are very traditional and need improvement in order to get higher yields. Besides, Aquaculture reproduction in fish ponds suffers a setback of inadequate water quality monitoring, which leads to death of fish. Mass fish production in the Aquaculture business is therefore a major challenge due to restricted technology for effective water quality monitoring (Hardw & Yang, 2018).

Wireless Sensor Networks (WSNs) have gained popularity within research community because they provide a promising infrastructure for numerous control and monitoring applications. These simple low-cost networks allow monitoring processes to be conducted remotely, in real-time and with minimal human intervention, (Bhateria, 2021). Recently, there has been an uptake on the application of wireless sensor networks (WSNs) in water quality monitoring. The methods used in these applications are improving with time and keep advancing with improvements in technology and communication protocols, (Ertiirk, 2021). The WSN's ability to capture, analyze, transmit, and display water quality data has proven to be effective and instantaneous, (Chitra & Deepika, 2019). Developing a WSN for water quality monitoring provides an efficient and scalable solution for continuous monitoring of environmental parameters in real-time. The WSN model integrates advanced sensing technologies, wireless communication, and data analytics, offering a cost-effective approach to ensuring safe water quality for aquaculture. A WSN model can enable real-time data collection and continuous monitoring, providing up-to-date information that helps in timely intervention to prevent environmental disasters or health risks. As new environmental challenges arise, research can improve the model's scalability, making it more adaptable to different geographical areas and water bodies. This warrants the study on developing a WSN architectural model for water quality monitoring for aquaculture.

Objective

- To develop a WSN architectural model for water quality monitoring for Aquaculture

LITERATURE REVIEW

WSNs have proven to be the best alternative to traditional methods when adapted for monitoring freshwater bodies and marine environments. Research in water environment monitoring classifies the monitoring process into water quality monitoring and ocean/marine environment monitoring sensor nodes collect parameters such as water temperature, pH, dissolved oxygen, turbidity and others in freshwater sources. It also measures parameters such as the sea level and marine environment pollution, (Myint, Gopal, & Aung, 2022). The data is transmitted to a base station through a communication architecture.

Wireless Sensor networks

A wireless sensor network comprises of densely dispersed nodes that aid in sensing, signal processing, embedded computing, and connection (Sandeep & Shivarolel, 2020). The sensors are placed in various configurations. It may be a point-to-point master-slave combination, a short-hop, or a multi-hop. Design approaches are required for a variety of disciplines, including information processing, network and operational management, confidentiality, integrity, availability, and in-network/local processing.

A wireless sensor network nodes assist with sensing, signal processing, embedded computing, and connection (Sandeep & Shivarolel, 2018). The sensors are installed in various configurations. It might be a master-slave combination, a short-hop, or a multi-hop. Design approaches are required in a variety of disciplines, including information processing, network and operational management, confidentiality, integrity, availability, and in-network or local processing.

Sensor Node Components

The sensor node is an important and vital component of WSNs since it can process, gather useful information, and communicate with other nodes in the network. Every node in the wireless network can transport information over a wireless link. The Global Positioning System on the node aids in determining the correct placement of nodes inside the given domain (Sandeep & Shivarolel, 2018). The sensor nodes' design includes embedded software for sensor processing, energy monitoring, location, and other functions. The embedded software works on the application layer, defining numerous interfaces on a sensor node. The many interfaces aid in the construction of a structured platform that adheres to the standards and simplifies the implementation process. Sensor networks contain a number of nodes, known as detection stations, which are compact and portable. There are two types of sensor nodes utilized in WSNs: one is installed alone to detect phenomenal changes in the surrounding region, and the other serves as an interface gateway for a larger sensor network system. Each sensor node contains a sensor/transducer, a microprocessor, a transceiver, and a power supply. The transducer detects physical changes and generates electrical impulses. These signals are sent to the microprocessor for processing. A central computer delivers commands to the transceiver, which then transmits data to the computer.

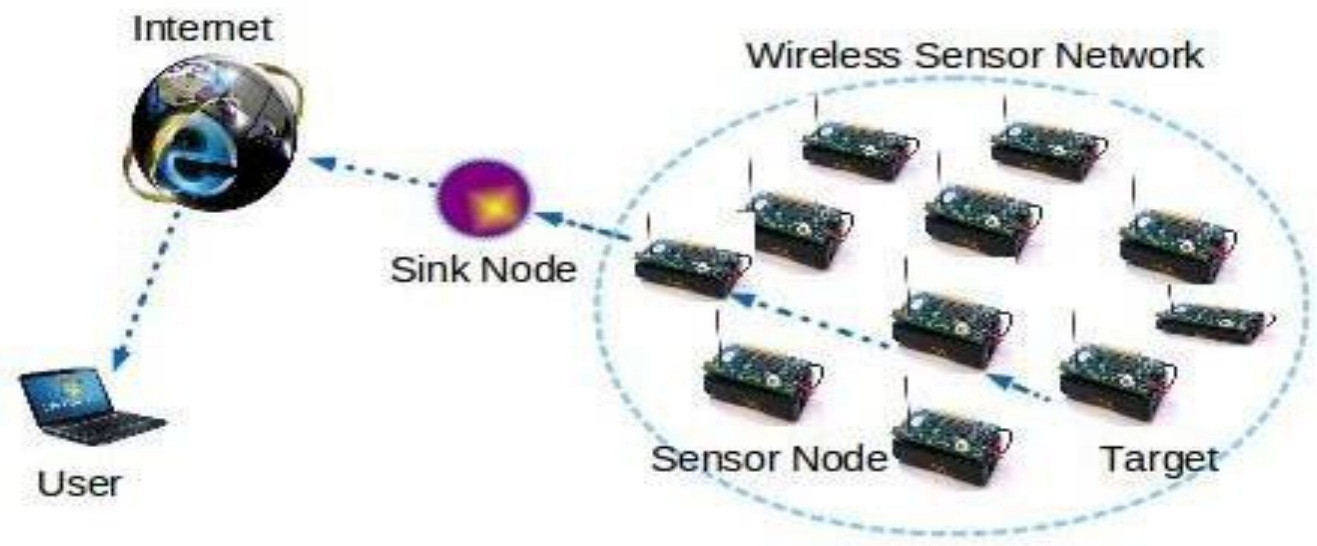

***Figure 1:** Components of WSN*

Source: Wireless, *Sensor Network: Concept and Compounds ,2022*

WSNs are made up of the following components: sensing, processing, external memory, and communication. The Sensing Subsystem is made up of microscopic sensors that perceive voltage changes and feed them to an ADC (Analog to Digital Converter), which then sends the digitally transformed signal to the CPU (Central Processing Unit) for further processing. The shrimp culture may produce better results if sensors are deployed to monitor water quality and provide early warnings of toxins in the water.

WSNs are further made up of the following components: Sensing Subsystem, Processing Subsystem, External Memory Subsystem, and Communication Subsystem. The Sensing Subsystem is made up of microscopic sensors that monitor voltage changes and pass them to an ADC (Analog to Digital Converter), after which the digitally transformed, signal is sent to the CPU (Central Processing Unit) for further processing.

Processing of Transmission Signals

Subsystem is a microcontroller of the node, having a central processing unit and an embedded Analog to Digital Converter (ADC). It's able to respond to different orders like reprogramming, reconfiguration, (Ali, Mustafa, & Ibdahahim, 2015). The External Memory Subsystem contains the main types of memory (program, data and flash memories). The Communication Subsystem is a transceiver having a wireless antenna, responsible of transmitting the radio signals using the optical signals or infrared waves as a medium, operates in ISM (Industrial, Scientific and Medical purposes) band. In most countries, it communicates using a free radio frequency specified in the international frequency allocation chart found in Article 5 of the radio laws (volume 1). The energy supply source for wireless sensor nodes is batteries of limited size, but some are fueled by solar energy systems or other forms of renewable energy sources (Akyldiz, 2021).

Memory is used to store program code and memory buffers. The microcontroller, or CPU, contains memory or storage capacity. It performs several functions such as controlling communication with other components within the sensor in order to read and process data. Elangovan (2008) defines battery as the source of energy used to operate the unit. The sensor nodes take the appropriate measures around the sensors, establish a wireless connection across the available media, collect data, and deliver it back to the user via the sink, which functions as a base station. The sink or base station located closer acts as a message receiving center, routing data between sensor nodes, the internet, and users. The task manager node oversees the data storage, analysis, display, and control procedures, as well as the interface needs (Ali et al, 2015).

Wireless Sensor Functional Process

The sensor inputs will transmit the sensed data to the CPU node's signal processing units. The signals will be processed and analyzed using hardwired multiplexing and amplification circuitry before being translated to their appropriate forms via analog/digital conversion. This processed information is stored in memory and delivered via transceivers to the appropriate destinations inside the WSN nodes (Maguire & Rhind, 2018).

The sensor inputs drive the sensed information to the CPU node's signal processing units. The signals will be processed and analyzed using hardwired multiplexing and amplification circuitry before being translated to their appropriate forms via analog/digital conversion. This processed information is stored in memory and delivered via transceivers to the relevant destinations inside the WSN nodes (Maguire & Rhind, 2018). Wireless Sensor Network Topology can be defined based on the physical or logical geometry organization. The architecture of wireless sensor networks is critical since energy, range, and data rate are all significant characteristics for network performance. Common topologies used in wireless sensor networks are: Point-to-Point Piconet as Bluetooth Topology, (Star Topology, as in WIFI WSNs and ZigBee WSNs technologies), Mesh for ZigBee Topology, Hybrid Technology, and Tree for ZigBee Topology (Ali, Mustafa, & Ibdahahim, 2015).

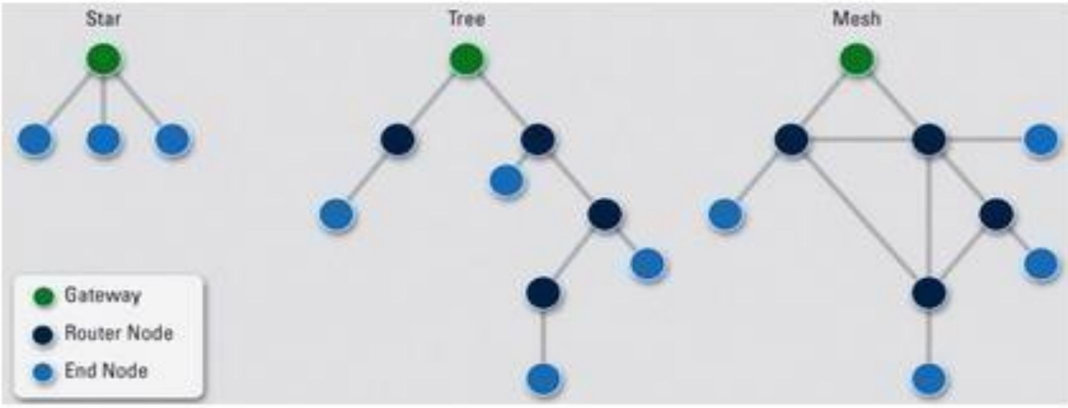

***Figure 2:** Wireless Sensor Network Topologies*
Source: Hybrid Topology Optimization, 2013

Wireless Sensor Routing Protocol

Routing protocols is a set of rules that specify how routers identify and forward packets along the network path. Routing protocol is important in WSNs because the parameters can be controlled to be adaptive to the current network conditions and energy level. The main routing devices are: Coordinator, Routers and End device, (Elangovan, 2020). The coordinator is the "master" device, which governs all the network operation. Routers, route the information which is sent by the end devices, by looking to the destination if it's sleeping or awakened up, it will decide to send packets. The End device (the notes), sensor nodes, take the information from the environment. WSNs routing and can be divided into three main categories according to the system architecture and functionality in routing protocols which are explained.

According to Joe (2017), one of the key stacks in WSNs protocol contains the following layers: Physical layer, whose first priority is to minimize energy usage, with the responsibility of modulation techniques such as carrier frequency generation, selection, and signal detection. The data link layer is responsible for multiplexing, frame detection, transmission medium access, and error control using MAC protocols. Its two goals are to provide organized communication links between a large number of nodes and to efficiently share resources between these nodes, (Buzai & Robinson, 2017).

The network layer prioritizes communication between two selected nodes at the specified time. The transport layer enables the system to communicate over a wider area. The application layer enables lower levels to communicate using software and hardwire applications. In real time, WSNs will serve as a gateway or router, allowing clients outside the network to communicate with sensor nodes.

The communicator which demonstrates communication process within the nodes, dealing with so much messages per time delay, packet information, controlling process and having the ability to determine the priorities. The Software is characterized by relatively small memory size, need of high energy optimization, self-organizing and fast computation to evaluate the environmental dynamic conditions, (Greene & Devillers, 2021). The communicator illustrates the communication process within the nodes, including handling a large number of messages per time delay, packet information, process regulation, and the ability to set priorities. The software is differentiated by its small memory size, the need for high energy optimization, self-organization, and rapid computing to assess environmental dynamic conditions (Greene & Devillers, 2017).

The data Processing Approach

Sensing, processing, and communication are the three major components of data processing. The client sends or waits for the necessary information within the surface conditions of the area of interest. Proxy handles the request using defined protocols to communicate with dispersed nodes (Calvert & Pearce, 2016). The nodes are deployed in various places, they are received or sensed, and the data collected is processed and provided to the proxy. The proxy gathers messages delivered by nodes, translates them into standardized protocols, and then sends them back to clients who are interested in the data. The customers receive the required information for analysis and produce useful information to be shared. These data processing approaches need a flexible architecture of nodes, software to make it easy for appropriated interfaces system to diverse applications devices of minimum run time and utilization environment, efficient use of system resources, (Buzai R., 2017). To ease the nodes data processing, the node software is divided into three main tasks, the operating system, the sensor driver task and the middleware management.

The operating system manages device duties such as booting, hardware, initialization, scheduling, and memory management/processing. The nature of the node defines which operational tasks are necessary. The Sensor driver task sets up the sensor hardware and its performance for measurement. The Middleware Management Task manages a variety of modules, including routing and security. Having the node software in these components makes management easier because each item it is handled individually and then statically connected together by scaling (Chiroco & Noorquist, 2010). WSNs are anticipated to operate over an extended period of time without human intervention and must be capable of achieving their distant nature in a flexible, efficient, and cost-effective manner.

The operating system primarily handles device activities, such as booting. Power consumption is a critical issue in the operation of wireless sensor networks (WSNs). It is made up of small battery-powered sensors with extremely extended life cycles that assure the endurance of the installed network. This necessitates a WSN design, which reduces total power usage by managing device's active/awake period, such as a radio or microcontroller, and lowers current flow when it is asleep. The networks vary in terms of power settings based on the device modes, such as always on/standby or hibernation (Solario and Derrci, 2021).

The transceivers are the main power-consuming component of WSNs, and they normally operate in three modes: transmission, which consumes the most power, receiving, idle, listening, and ready to react. When it is turned off or where there is low power consumption, Nodes components sleep when not in use, use renewable sources of energy, have a good algorithm. using energy harvesting. Hardware development is one of the most efficient techniques. To address WSN power consumption issues, more renewable and energy harvesting-based autonomous wireless sensor nodes are becoming industrially available. These devices enable the deployment of additional WSNs in remote and harsh environments, while the energy-saving method could play a significant role in addressing WSN energy source difficulties in many underdeveloped nations (Frances, 2010).

METHODOLOGY

The study utilized a Design Science research design. According to Dannels, (2018), A Design Science involves a meticulous process of creating artefacts to address issues that have been noticed, participating in research, assessing designs, and presenting the findings to the right audiences. The target population consisted of Aquaculture farmers and respondents who used the system and were directly affected by it. These were twenty farmers and five agricultural officers. Purposive with snowballing sampling technique was used in this study. The research employed questionnaire and content review to collect data for the research. Instruments were tested for reliability and validity. Inferential and descriptive statistics were utilized. Then tested the validity and reliability of the model.

FINDINGS

Development of Wireless Sensor Network Architectural Model for Aquatic

Architecture Development Principle

Creating new architectures is a challenging task. According to Gidey et al., (2017), the use of previous experience on architecture development is inevitable for the development of the meaningful architecture. Grounded theory is the most popular theory that guides the researchers in coming up with the new designs (Strauss, 2017). The theory highlights how knowledge or information is inferred or emerges from data in order to create a theory, model, or architecture. Rather than providing an objective, static description that is solely expressed in terms of causality, this method creates a context-based, process-oriented description and explanation of the occurrence. Design aspects considered are: Scalability, Fault Tolerance, Security, and energy efficiency.

Components of the Architecture

The architecture's building blocks were ascertained by identifying the variables that loaded collectively on a certain component using factor analysis. To facilitate their realization as the architecture's constructs and sub-constructs, the associated variables were grouped under theme notions. Furthermore, a survey on communalities after performing factor analysis was done to determine the indicators which are forming the components of the architecture.

Table 1: Communalities

	Initial	Extraction
Water quality parameters are inconsistent (i.e. temperature, oxygen, pH etc.)	1.000	.850
I have got some trainings about water quality monitoring on fish ponds	1.000	.421
I know the importance of monitor quality of water on fish ponds	1.000	.308
I have access to water quality monitoring facilities	1.000	.558
The testing facilities are adequate/ reliable	1.000	.801
I can use monitoring equipment any time I want	1.000	.747
I frequently test the quality of water on my fishpond	1.000	.812
I have the tendency of testing quality of water on my fish pond	1.000	.855
Computer	1.000	.789
Sensor	1.000	.612
Power Supply	1.000	.711
Gateway Device	1.000	.820
Microcontrollers	1.000	.675
Network Connectivity	1.000	.768
Edge Computing	1.000	.902
Firmware	1.000	.800
Communication Layer/ Protocols	1.000	.701
Data Aggregation SW	1.000	.634
Data Storage	1.000	.518
URL	1.000	.654

Extraction Method: Principal Component Analysis.

A survey on communalities extractions indicates that some of the indicators had the extraction values coefficient of less than 0.5. This indicating that these indicators should not be retained. A factor loading number greater than 0.5, and preferably 0.7 or higher, was considered satisfactory (Hair et al., 2010). Therefore, the indicators with the factor loading of less than 0.5

were not be used during the development of the architecture.

Monitoring Challenges variable had four constructs which were; Knowledge Constraint, Inadequate Water Quality Parameters, Inadequate Monitoring equipment and Time Constr. -Water Quality Monitoring Challenges Factor Analysis. Knowledge Construct had two indicators with the loading coefficients .806 and .789. It was found that, these indicators had extraction values which were less than 0.5 Communalities. This implies that this construct was not among the building blocks for the developed architecture.

Moreover, Inconsistent Water Quality Parameters construct had one indicator with the loading coefficient.839, Water Quality Monitoring Challenges Factor Analysis. This construct was retained for architecture development since its extraction value was greater than 0.5. Furthermore, Inadequate Monitoring equipment construct had three indicators with the loading coefficients .729, .684 and .782 Water Quality Monitoring Challenges Factor Analysis. The indicators were also retained for the architecture development since their extraction values were greater than 0.5, The average among the loading coefficients of the indicators was (.729 + .684 + .782) / 3 = .732.

Lastly Time Constraint Construct had two indicators with the loading coefficients .748 and .698 Water Quality Monitoring Challenges Factor Analysis. The indicators were also retained for the architecture development since their extraction values were greater than 0.5, The average among the loading coefficients of the indicators was (.748 + .698) / 2 = .723

The three constructs: Inconsistent Water Quality Parameters (IWQP), Inadequate Water Monitoring Equipment (IWMI) and Time Constraint (TC) can be combined and form a Sub Architecture as shown on - Monitoring Challenges Sub-Architecture.

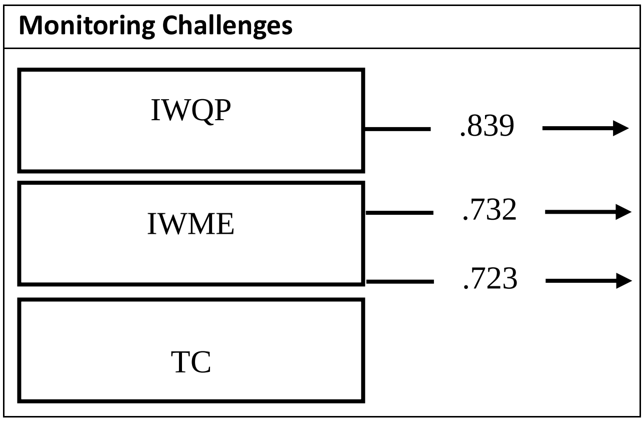

Figure 3: Monitoring Challenges Sub-Architecture
Source: Researcher, (2024)

Technological Infrastructure Requirements variable had four constructs; Hardware Requirements, Software Requirements, Central System and User Access. Hardware Requirements had six indicators with the loading coefficients; .978, .897, .862, .805, .786 and .738. The indicators also retained for the architecture development since their extraction values were greater than 0.5 as shown on Table 1 Communalities. The average among the loading coefficients of the indicators was (.978 + .897 + .862 + .805 + .786 + .738) / 6 = .844. Therefore, Hardware Requirements sub-construct has an average factor loading of .844. This can be illustrated as depicted on Figure 4 Hardware Requirement (HWR) Sub-Component

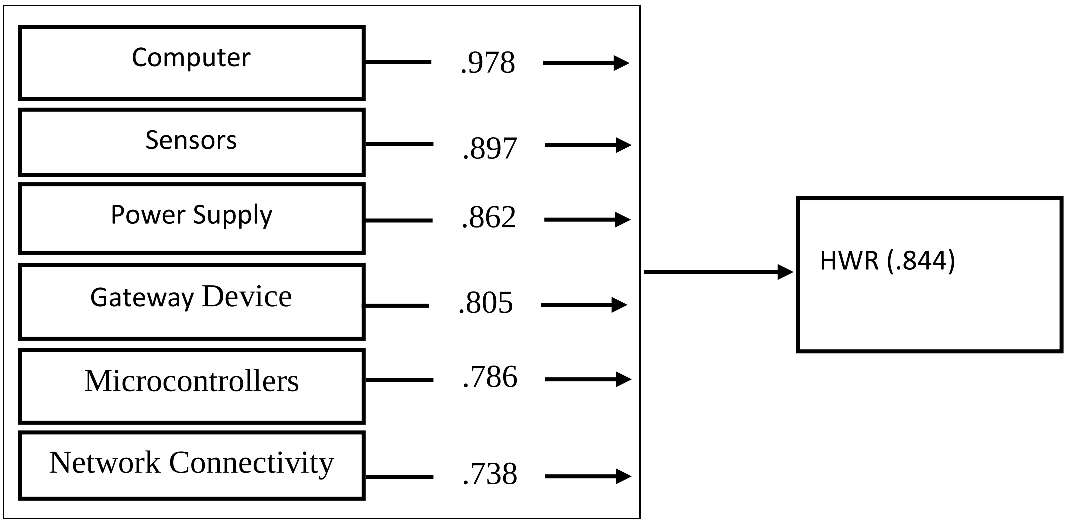

Figure 4: Hardware Requirement Sub- Component
Source: Researcher, (2024)

Software Requirements had four indicators with the loading coefficients; .882, .861, .836 and .801 as depicted on Table 2 Technological Infrastructure Requirements Factor Analysis. The indicators also were retained for the architecture development since their extraction values were greater than 0.5 as shown on Table 1 Communalities. The average among the loading coefficients of the indicators was (.882 + .861 + .836 + .801) / 4 = .845.

Software Requirements sub-construct has an average factor loading of .845. This can be illustrated as depicted on Figure 5 Software Requirement (SWR) Sub-Component.

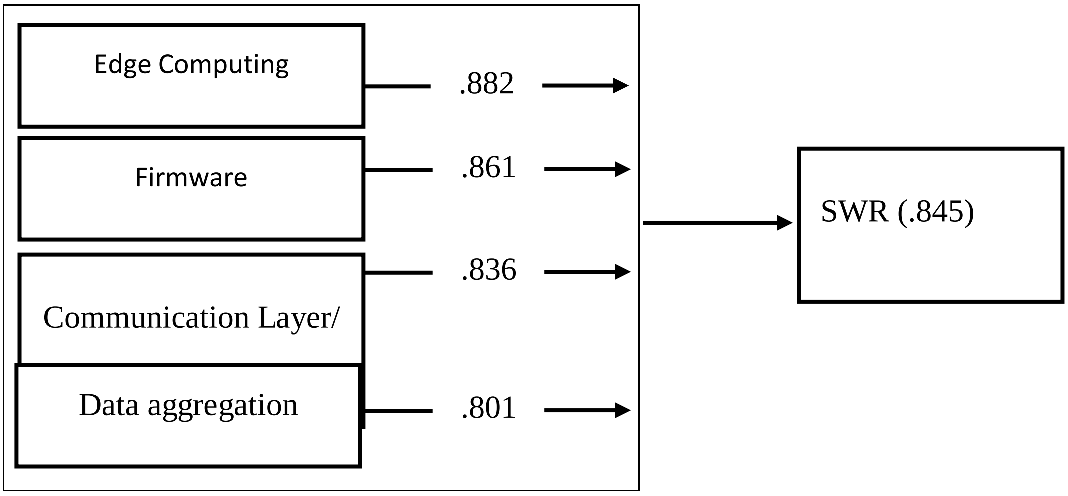

Figure5: Software Requirement (SWR) Sub-Component
Source: Researcher, (2024)

Moreover, Central System Requirement construct had one indicator with the loading coefficient .708. Technological Infrastructure Requirements Factor Analysis. This construct was retained for architecture development since its extraction value was greater than 0.5 Central System potent.

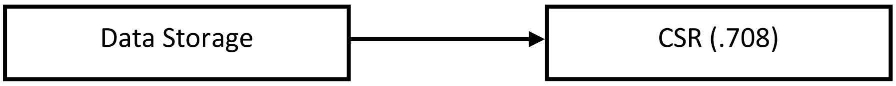

Figure 6: Central System Requirement (CSR) Sub-Component
Source: Researcher, (2024)

Finally, User Access construct had one indicator with the loading coefficient .869 as depicted on Table 2- Technological Infrastructure Requirements Factor Analysis.

Table 2: Technological Infrastructure Requirements Factor Analysis

Component Matrix[a]

	Component			
	1	2	3	4
Computer	.978			
Sensor	.897			
Power Supply	.862			
Gateway Device	.805			
Microcontrollers	.786			
Network Connectivity	.738			
Edge Computing		.882		
Firmware		.861		
Communication Layer/ Protocols		.836		
Data Aggregation SW		.801		
Data Storage			.708	
URL				.869

Extraction Method: Principal Component Analysis.
a. 4 components extracted.

This construct was also Requirement (UAR) Sub-Component

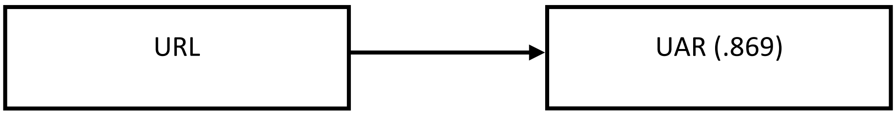

Figure 7: User Access Requirement (UAR) Sub-Component
Source: Researcher, (2024)

The Technological Infrastructure Requirements can be combined as shown

Technological Infrastructure Requirements Sub-Architecture.

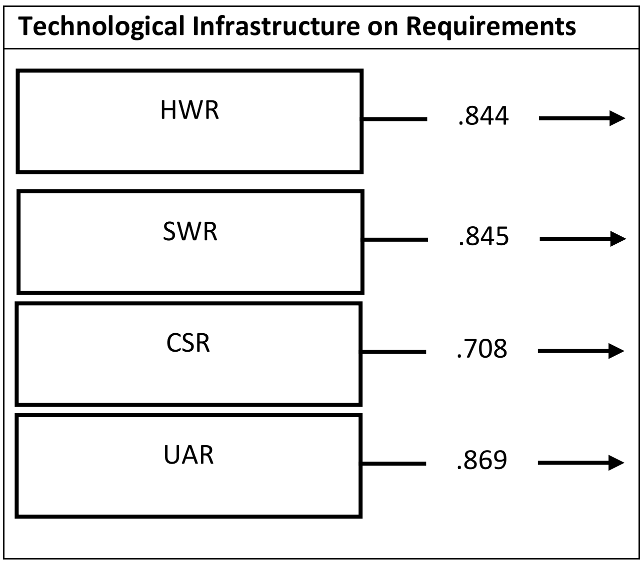

Figure 8: Technological Infrastructure Requirements Sub-Architecture
Source: Researcher, (2024)

Basing on the findings, Wireless Sensor Network Architectural Model (WSNAM) Factor Loadings summarizing the components of the Architecture and the weights they contribute to the developed Architecture. The two Sub -Architectures as depicted on Figure 3- Monitoring Challenges Sub-Architecture and Figure 8- Technological Infrastructure Requirements Sub-Architecture can be combined to form the Architecture as shown on Table 3- Wireless Sensor Network Architectural Model (WSNAM) Factor Loadings.

Table 3: Wireless Sensor Network Architectural Model (WSNAM) Factor Loadings

Architecture Components	Factor Loading	Total Loading	Weight
Monitoring Challenges		**2.294**	**.413**
Inconsistent Water Quality Parameters (IWQP)	.839		
Inadequate Water Monitoring Equipment (IWME)	.732		
Time Constraint (TC)	.723		
Technological Infrastructure Requirements		**3.266**	**.587**
Hardware Requirements (HWR)	.844		
Software Requirements (SWR)	.845		
Central System Requirements (CSR)	.708		
User Access Requirements (UAR)	.869		
Total		**5.560**	

Source: Researcher, (2024)

Wireless Sensor Network Architectural Model (WSNAM) Factor Loadings indicate the components of the architecture to be developed and the weights contributed to the developed architecture. The architecture will consist of two main components which are Monitoring Challenges and will contribute .413 weight and Technological Infrastructure Requirements which contribute .587 weight.

Wireless Sensor Network Architectural Model (WSNAM) Development

The most widely used theory that directs researchers in creating new designs is grounded theory (The principle of the architecture development). According to Gidey et al., (2017), the use of previous experience on architecture design is inevitable for the development of the meaningful architecture.

Therefore, this part describes the development of the Wireless Sensor Network Architectural Model for monitoring quality of water in fish ponds. Achieving this, different components were combined to develop the architecture. These components were obtained through rotation process with component factor analysis. Through the process, the researcher extracted two main components of the architecture which were Monitoring challenges which contributed a weight of .413 and Technological Infrastructure Requirements which contributed a weight of .587 as depicted on Table 3- Wireless Sensor Network Architectural Model (WSNAM) Factor Loadings.

Water Quality Monitoring Challenges Component had a total loading of 2.294 as shown on Table 3 Wireless Sensor Network Architectural Model (WSNAM) Factor Loadings. The total loading was obtained by summing up the factor loadings of its constructs (IWQP= .839), (IWME= .732) and (TC= .23). However, Technological Infrastructure Requirements had a total loading of 3.266. Wireless Sensor Network Architectural Model (WSNAM) Factor Loadings. The total loading was obtained by summing up the factor loadings of its constructs as (HWR= .844), (SWR= .845), (CSR= .708) and (UAR= .869).

The weight of .413 for the Water Quality Monitoring challenges was obtained by finding a ratio of its total factor loading (2.294) and the sum of total factor loadings of water quality monitoring challenges and total loading for Technological

Infrastructure. Requirement. All these are shown on Table 3 Wireless Sensor Network Architectural Model (WSNAM) Factor Loadings. This was given by (2.294/ 5.560). Also, a weight of .587 for technological Infrastructure Requirements was obtained by a ratio of its total factor loading (3.266) and the sum of total factor loadings for monitoring challenges and that of technological infrastructure requirements as highlighted on Table 3- Wireless Sensor Network Architectural Model (WSNAM) Factor Loadings. That is (3.266/ 5.560).

Combining the ratios, brings a balanced contribution to the Wireless Sensor Network Architectural Model. That is, summing up the weights for Monitoring challenges (.413) and that of technological Infrastructure Requirements (.587) brings 1.000.

Therefore, these components can be put in an illustration to form a Wireless Sensor Network Architectural Model as depicted on Figure 9. Wireless Sensor Network Architectural Model (WSNAM).

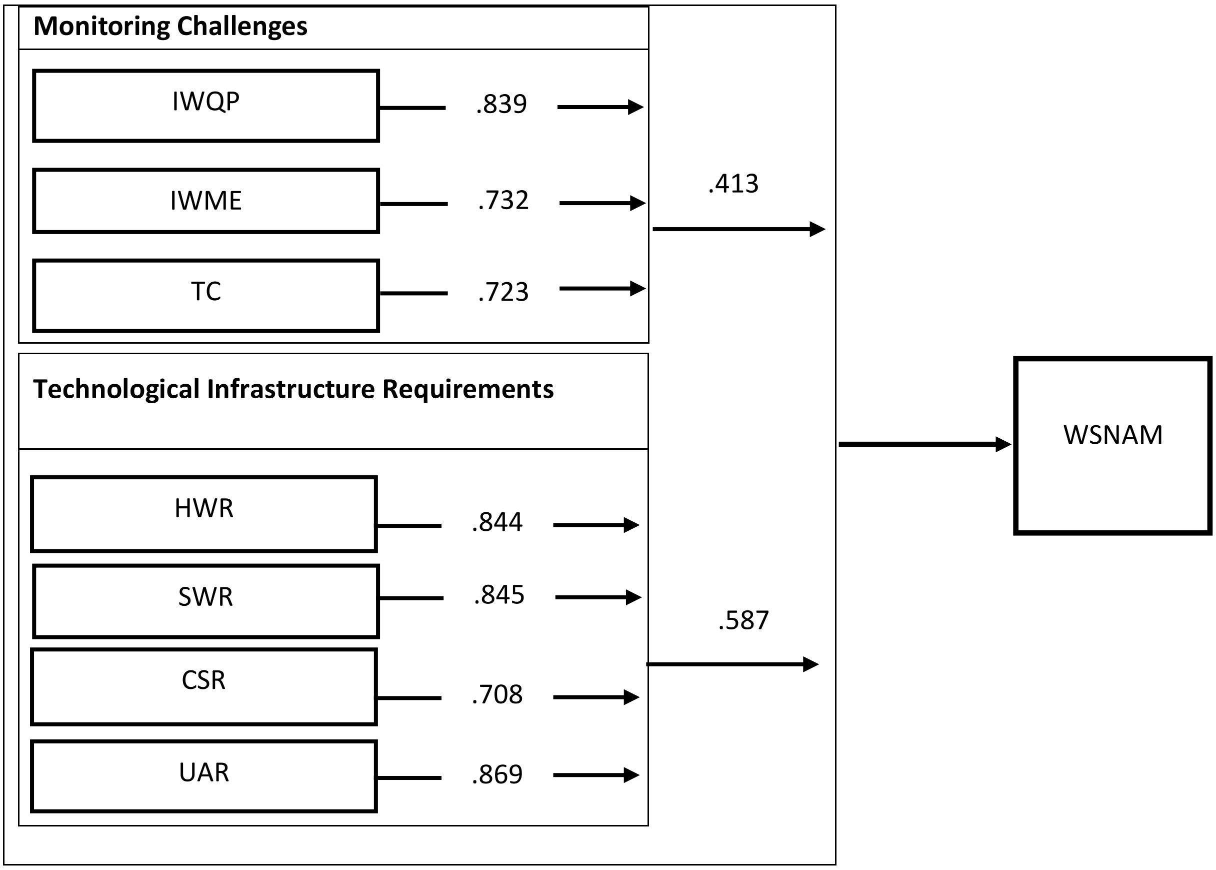

Figure 9: Wireless Sensor Network Architectural Model (WSNAM)
Source: Researcher, (2024)

Key:
IWQP: Inconsistent Water Quality Parameters
IWME: Inadequate Water Monitoring Equipment
TC: Time Constraint
HWR: Hardware Requirements
SWR: Software Requirements
CSR: Central System Requirements
UAR: User Access Requirements
WSNAM: Wireless Sensor Network Architectural Model

Basing on the developed Architecture as depicted on Figure 9.- Wireless Sensor Network Architectural Model (WSNAM), the developed architecture can be implemented to solve the challenges faced by farmers in monitoring quality of water to improve Aquaculture life in fish ponds.

Architecture Validation

This section verifies the architecture that was built. It aimed at determining if the established architecture and its principles made sense to other academicians and practitioners in addition to the researcher. Consequently, this phase was done to make sure the architecture created was correct enough for the intended use. Prototyping and expert evaluation were utilized in this study to verify the architecture. In order to replicate the architecture, the prototype was given to the farmers who owned fish ponds for testing. The architecture was presented to IT specialists for evaluation through focus group discussions, after which they were asked to provide their professional judgement on a questionnaire. This process allowed experts to assess the architecture.

Expert Architecture Evaluation

A guiding questionnaire was distributed to the IT Experts to assess the architecture. Following the presentation of the architecture to the ICT professionals, the experts' opinions were gathered using the following sets of validation items, which were rated on a five-point Likert scale. "The architecture accurately reflects the concepts being examined", "Applying or using the architecture is simple", "The architecture is acceptable" and "The real world is reflected in the architecture".

The responses were rated on a 5-point Likert scale and positional weights were assigned, with Strongly Disagree being weighed (1) to Strongly Agree (5), in order to determine the relevance of the responses. The weighted mean on last column was calculated using the formula;

Weighted Mean $= \frac{Y1+2Y2+3Y3+4Y4+5Y5}{8}$; Where:

Y1= Strongly Disagree (SD)

Y2= Disagree (D)

Y3= Neutral (N)

Y4= Agree (A)

Y5= Strongly Agree (SA)

The results of the responses are depicted on Table 4- Expert Validation Responses below;

Table 4: Expert Validation Responses

Items	**SD (1)**	**D (2)**	**N (3)**	**A (4)**	**SA (5)**	**Weighted Mean**
The real world is reflected in the architecture.	0	0	0	4	4	**4.50**
The architecture faithfully captures the concepts being examined.	0	0	1	2	5	**4.50**
Applying or using the architecture is simple.	0	0	0	3	5	**4.63**
The architecture is acceptable	0	0	0	1	7	**4.88**
Average weighted mean						**4.63**

Expert Validation Responses above shows the responses for the eight (8) expertise who were told to evaluate the developed architecture. The analysis depicts that; the respondents agreed that the architecture reflects the real-life situation at the mean of 4.50, the respondents also agreed that the architecture captures the constructs which were to be examined on the study by the mean of 4.50, the respondents also agreed that the developed architecture is easy to use or apply at the mean of 4.63 and also, the respondents agreed that the architecture is acceptable at the mean of 4.88.

The mean average of the weighted mean on the responses was calculated and it was found to be 4.63. This implies that, most of the respondents chose the agree and strongly agree options on the architecture validation items. Therefore, the Wireless Sensor Network Architectural Model

(WSNAM) for fish ponds developed satisfies all the validation conditions from the IT experts.

Prototype Evaluation

Prototype evaluation was used in addition to expert evaluation to verify the created Wireless Sensor Network Architectural Model (WSNAM). The tool was taken to different fish ponds to test the Turbidity, pH, Temperature and the dissolved Oxygen of water. The readings were directed to the URL when the owners could get the results through the link which shared to their mobile phones. The tool collected data using the architecture are tabulated on Table 5- Prototype Validation Data below;

Table 5: Prototype Validation Data

Pond	Turbidity	pH	Temperature °C)	Dissolved Oxygen micrograms/L)
1	5.00	11.69	26.56	1636.00
2	5.00	12.19	24.61	2461.00
3	5.00	12.45	25.56	4666.00
4	5.00	12.05	25.56	5639.00
5	5.00	13.03	27.50	5314.00
6	5.00	11.87	26.50	3734.00
7	5.00	11.93	26.50	7103.00
8	0.44	12.15	28.19	6088.00
9	5.00	13.94	28.19	6371.00
10	5.00	11.91	27.31	5597.00
11	0.46	11.43	27.37	6778.00
12	5.00	12.37	23.37	3892.00
13	5.00	11.61	27.12	3410.00
14	5.00	13.40	26.87	3160.00
15	5.00	13.19	26.00	2553.00

If a measurement produces consistently accurate results with the same values, it is considered trustworthy (Blumberg et al., 2005). Furthermore, reliability can be defined as the level of accuracy and precision of a measurement or instrumentation approach (Kothari, 2010). It indicates how error-free (bias-free) it is, guaranteeing consistent measurement across time and among the many instruments' items (the observed scores). A study measured the degree of accuracy of the developed architecture by subjecting the data to Cronbach Alpha test, the results are shown on Prototype Evaluation Validation below.

Table 6: Prototype Evaluation Validation

Reliability Statistics	
Items	**Cronbach's Alpha Coefficient**
Turbidity	.794
pH	.712
Temperature	.662
Dissolved Oxygen	.802
Average	**.743**

The accuracy of the developed tool was tested using Cronbach's Alpha. The average under the Cronbach Alpha coefficient was calculated and it was found to be .668 as highlighted on Table 6. Prototype Evaluation Validation. This implies that, the developed architecture can give accuracy data at 74.3%.

CONCLUSION

The design and deployment of the real time water quality monitoring system for Aquaculture using Wireless Sensor Network has been presented. Prototype evaluation was used in addition to expert evaluation to verify the created Wireless Sensor Network Architectural Model (WSNAM). The tool was taken to different fish ponds to test the Turbidity, pH, Temperature and the Dissolved Oxygen of water. The readings were directed to the URL when the owners could get the results through the link shared to their mobile phones. The developed model has been field tested in Eldoret for monitoring of water quality parameters. It is a low cost, lightweight system and has low power consumption as analyzed in the research work Moreover, the system is able to log bulk data and transfer to remote locations. This Sensor Network architecture is suitable for monitoring applications. The sensor node architecture can be used for a variety of applications. The various components of the sensor node all contribute to the amount of energy expended during the node's operation in each environment. It's important to note that careful implementation is done to coordinate the sensing, data communication, and computation components that consume most of the sensor nodes' energy to implement WSNs for as a result, when designing Wireless Sensor Network Architectural Model (WSNAM).

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