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A Review of Internet of Things-based Water Quality Monitoring Systems in Aquaculture

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ABSTRACT Monitoring of aquaculture water quality parameters has become imperative in recent times in view of the colossal impact of disease outbreak to fish farming businesses. Traditional methods of monitoring aquaculture parameters such as chemical sampling Methods as well as experience Method have since given way to the era of Wireless Sensor network based monitoring systems. Which in more recent times is been improved upon with the paradigm of Internet of Things (IoT). This paper surveys different works on the use of IoT in monitoring aquaculture parameters. Works were reviewed based on power consumption, data security concerns, and cost. The works were also compared based on their sensor node architectures, the type of microcontrollers used and the wireless communication standards adopted. It was found at the end of the study that IoT offers good prospects for water quality monitoring in aquaculture. Some of the existing work had limitations of high power consumption. More recent architectures have solved the problem of power consumption to a significant degree. However opportunities exist for improvement in the areas of data security and cost of deployment.

Keywords: WSN**s,** IoT, Water Quality Monitoring, Aquaculture

1. Introduction

Fish farming is a sector that has been growing significantly in many countries around the world. Fish remains a vital source of protein with little or no side effects (FAO, 2000). Aquaculture is a modern method of fish farming which involves the cultivation of freshwater and saltwater aquatic species such as crustaceans, molluscs and aquatic plant under controlled conditions (Hempel, 1993). Factors like quick harvesting Cycle(between 3 to 6months), low technology requirement , and the possibility of using artificial plastic containers, concrete ponds to rear fish domestically makes fish farming attractive in most countries of the world (Idachaba *et al*., 2017). Modern aquaculture practice requires water quality monitoring. Adequate and timely control of water quality has to be done to keep the concentrations of water environment parameters in the optimal range. Water quality refers to the measure of the suitability of water for a particular application based on its chemical, biological and physical characteristics. Certain set of parameters can be used to measure the quality of water available to fish in aquaculture, prime among these parameters are , dissolved oxygen, pH , unionized ammonia, carbon dioxide, nitrite and nitrate concentration, turbidity, oxidation reduction potential, electrical conductivity and water level.

Water quality determines the feeding rate, growth rate and the overall health status of the fish. The need to monitor aquaculture parameters become imperative due to the associated diseases and the poor yield that may result from poor water quality.

In recent times Wireless Sensor Network (WSN) based Methods have been employed in different fields of application, including air monitoring, environmental monitoring, climatic monitoring and water quality monitoring. The WSN based water quality Monitoring in aquaculture has been effective in view of the limitations of traditional methods, which are based on experience or fixed time chemical sampling Methods. The experience method involves some level of guess work which is subject to errors and it is an artificial judgment. The fixed time chemical sampling methods involves the problem of labour intensity, lack of sufficient data samples and so on. Both methods however cannot provide real-time data. However in more recent times, the Internet of Things (IoT) paradigm has emerged as an improvement on the WSNs (Ali *et al*., 2015) especially in the ubiquitous range of communication using the platform of the internet. This paper intends to make a review of the applications of IoT for the purpose of water quality monitoring in aquaculture.

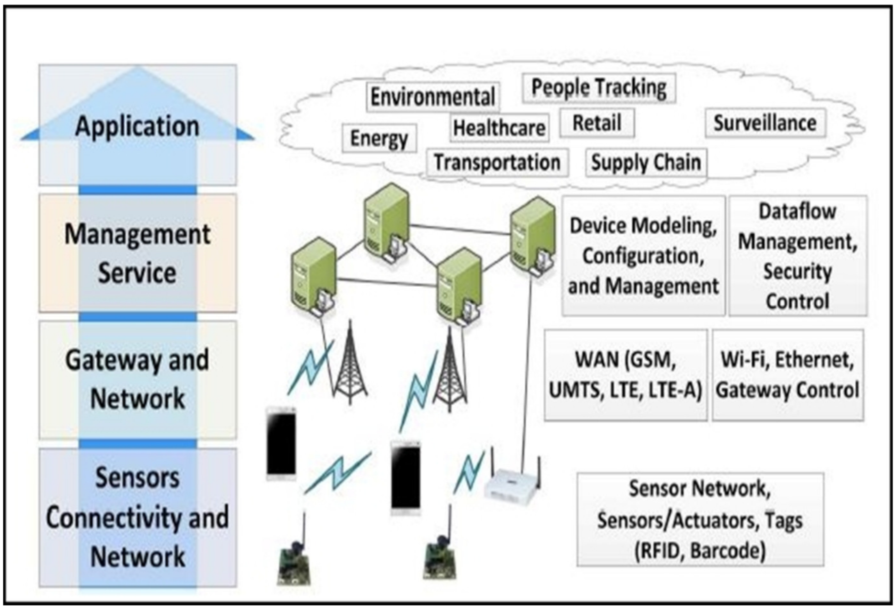

Figure 1: The framework for IoT connectivity and technology
(Retrieved from https://opentechdiary.wordpress.com/tag/internet-of-things)

1.1 The Internet of Things Framework and Technology

The Global Standard initiative on internet of things (IOT–GSI, 2015) defined internet of things connectivity (IOTC) as the networking of physical devices, wireless sensors, actuators, network facilities with embedded systems. This enables the objects to gather and exchange data or information over the internet. Many wireless devices have been developed to overcome the shortcoming of interconnectivities, interoperability and communications among things. Examples as Bluetooth low energy, BLE, Zigbee, Z-wave, WIFI, 6 lowPAN, Thread, 3G and 4G cellular. An illustration of the model for IoT layers and wireless protocols involved as shown in figure 10. An IoT System can therefore be realized through the integration of enabling technologies ranging from RFID, wireless sensor networks to data analytics, cloud computing and internet protocols (Gubii *et al.,* 2013).

Application areas of IoT in recent times range from smart agriculture, livestock management, food supply chain management, industrial sewage treatment, water quality monitoring both for human consumption and for aquaculture. The significance of water quality monitoring in aquaculture according to (Encinas *et al.,* 2017) is to:

a) Provide production close to Market demand,
b) Improved environmental control,
c) Reduction of damages caused by disease outbreak,
d) Reduction of environmental management Costs, and
e) Improvement in the quality of aquaculture products.

1.2 Common Physico-Chemical Water quality Parameters in Aquaculture

1.2.1 pH

pH is a measure of the degree of acidity or alkalinity of a solution. A pH of 7 is neutral, while that below and above neutral is considered acidic and alkaline, respectively. For aquaculture ponds, a pH that is between 7.5 and 8.5 is normally recommended.

1.2.2 Electrical conductivity

This is a measure of a solution's capability to pass electrical current. Conductivity is used as an indication of the concentration of conductive ions that normally come from dissolved salts and other inorganic material. The more the dissolved salts present, the higher the conductivity. Distilled water has a conductivity of 0.5 to 3µS/cm. while streams range between 50 to 1500µSm/cm. Freshwater Streams Should have conductivity ranging between 150 to 500µS/cm. this range will be healthy for aquaculture.

1.2.3 Oxidation reduction potential (ORP)

ORP measures how strongly electrons are transferred between component species in a solution. This indicates the ability of water to rid itself of contaminants. Healthy water normally has very high ORP readings.

1.2.4 Turbidity
This indicates the concentration of suspended and colloidal material in water and it is measured in nephelometric turbidity units (NTU) or Jacksons Turbidity units. Drinking water should have turbidity that is less than 1NTU.Aquatic life can survive successfully within a turbidity range of between 5NTU to 50NTU.

2. Methodology

The approach in the Survey is to review and analyse the works of various authors in the research domain of water quality monitoring in aquaculture, using internet of things (IoT.) Three essential criteria were used in comparing the works, which are:

i. Power consumption. This refers to amount of energy resources needed to run the monitoring system. Power is consumed in the sensing of parameters, the processing of data in microcontrollers, and also the communication phase in which data is sent to a remote monitor.

ii. Data security. Data security in our sense refers to the level of reliability of transferring and receiving data from one end to the other i.e. from the sending end to the monitoring end.

iii. Cost of deployment. The cost refers to the financial implications of deploying the designed systems. This refers to the cost of sensors controllers; transmission modules etc. Cost becomes a challenge when a large scale deployment is to be embarked upon.

The works were also compared based on the sensor node architectures, the type of microcontrollers used and the wireless communication standards adopted the limitations of various works were identified for further improvement

2.1 Review of Work on Water Quality Monitoring in Aquaculture

A WSN-based system was developed by Zhu et al (2010). The system employed Code Division Multiple Access (CDMA) to transmit data to a base station while Virtual Private Network (VPN) with IPsec security framework, Was employed to achieve remote monitoring. The System was applied for modern intensive fish farming in China. It also applied artificial neural networks to forecast aquaculture parameters. The prototype system of two nodes was tested for a period of twenty two months and a statistical reliability of 95.2% was achieved. However the system was found to have high power consumption.

Zang and Wang (2011) work on WSN-based monitoring System for water quality combined with expert knowledge. The data acquisition nodes employ Zigbee to send the collected data a router node, which the employs GSM to forward it to the monitoring station. The system was used in crab ponds in the Yixing Jiagsu Province of China. The use of Zigbee for data acquisition has a low range of communication of about 100+m, while GSM has a long range of communication but it is prone to data loss when the network is down.

In another related work on the prototype of an 'Aquaculture Information System' based on Internet of things E-nose (Ma *et al.,* 2012), the Architecture consists of an on-site sense and control platform which senses various pond water quality parameters and controls the actuators to adjust the parameters accordingly. A special GPRS-RTU technology was designed to transmit data to a central node and then to transmit to centre servers. The data on servers is stored on server databases and can be shared using a run and service internet platform to various users, the run and service platform is also able to forecast aquaculture environment and diseases. Zang and Wang (2013) work on the Application effect of IoT System investigated the econometric gains of Using IoT based Aquaculture Monitoring in the Jiangsu Province of China. Data from farmers who used IoT aquaculture monitoring was compared was compared with data from farmers who did not use it. It was found that the use of IoT technology to monitor fish farms reduced labour cost by about1768.62 yaun/ha, it increased crab production by 88.72 Kg/Ha. And it improved the revenue from crab sales by 15.5%.

Similarly in the work of Chen *et al*, (2013), they proposed a system that contained essentially water checking system, environmental monitoring, web surveillance system and power monitoring. The architecture consists of various Sensors sending their information to a data collector after which WI-FI technology is used to transmit from the collector to a monitoring computer. Which is connected to the internet, this enables online monitoring of water quality parameters and the environment, Alarm messaging and remote controlling of the system are also made possible via an integrated system (with GSM).

However, Duy *et al,* (2013) used a MP430 microcontroller to process sensor Data coupled with a CC2530 Zigbee module to transmit the *Data Lab* view Graphical user interface (GUI), the data is thereafter uploaded to the internet via Google Spreadsheets Application. There is also a provision an SMS gateway which sends alerts to enable user interventions when needed. The beauty of the System is in the combination of internet and GSM platform for data communication. Because of that, the proposed system was useful in saving the cost of hiring labour. It also reduces electricity usage. The design could be easily adapted to versatile, low-cost, and commercial version which is suitable for small to medium sized farming operations as it does not require any refitting or reconstruction of the pond.

In another study, Vijayakumar and Ramya (2015), designed and developed a low cost, real-time water quality monitoring system using internet of things (IoT) technologies. The node was powered with a raspberry Pi Model B+ micro-processor with several water quality Sensors connected to it. The system was able to present real-time water quality data on the internet. However the use of raspberry Pi microprocessor coupled with the use of Linux operating system to run the processor results in high power consumption for the system. Adamo *et al* (2015) also proposed a 'Smart Sensor Network for Monitoring Sea water Quality'. Many water quality parameters were measured using a single probe sensor. The authors stated that the implementation of this system will lead to an improvement of surface water quality monitoring. However using a single probe to detect many water quality parameters is not reliable since all data will be lost when the probe malfunctions. Encinas *et al.* (2017) in their work on design and implementation of a distributed IoT system for the monitoring of water quality in Aquaculture, proposed a system in which probe sensors manufactured were used to measure temperature, pH and dissolved oxygen. Arduino core was used as the processor, which uses Zigbee module to forward data to a remote mysql database on a desktop computer where the data can be visualized, the data is then uploaded to the cloud from where it can be accessed by mobile application devices. The high cost of probe sensors is one drawback of this implementation considering the huge cost that would be incurred if thousands of Sensors were to be deployed in large fish farming centers.

Parra *et al.* (2017) worked on design and deployment of low cost sensors for monitoring the water quality and fish behaviour in aquaculture tanks, during the feeding process. The proposed system was meant to monitor data like water quality parameters, tank status, the fish falling rate, the fish swimming depth and velocity. The system also includes a smart algorithm to reduce power wastages when sending information from the sensor nodes to the database. It employed a smart algorithm to detect abnormal values and send alarms when they happen. The database is connected to the internet. The strength of the system is the Deployment of low cost sensors and the implementation of smart algorithm for power management.

The work of Cario *et al.* (2017) focused on designing a long lasting environmental monitoring in underwater fish farming. The system composed of a Software Defined communication stack (SDCS) created by SUNSET Software. The SDCS provides networking capability to underwater sensor nodes. The sensor nodes are Hydrolab Series 5 probes used to monitor water quality parameters. The system implemented sleep and wake-up power management algorithms to reduce energy consumption during signal transmission and the system was connected to the internet to allow users to connect to the underwater system from anywhere. The results from the implementation showed that the system is suitable for long term monitoring providing a robust data collection system.

In a related work, Idachaba *et al.* (2017) developed an IoT enabled Real–time Fish pond Management System. The management system consists essentially of a microcontroller and a network of Sensors for monitoring water quality, a fish feeding mechanism, and also a water changing system. It incorporated an IP based CCTV camera which covers activities around the pond to provide video images which can be accessed remotely to increase the security of the pond. The communication link between the sensor nodes and the remote centre is the GSM network. All forms of data are transmitted to the cloud through the GSM link form where it is processed and accessed by mobile users via their mobile applications. Also control commands are sent through the GSM network. The system did not make provision for a Local Data Centre (server). Therefore, there will be data losses in the event of the failure of the GSM network.

Table2.2: Review of Work with limitation of power consumption

Author	Ye ar	Title of Paper	Features	Limitation
Zhu *et al.*	20 10	A remote wireless system for water quality online monitoring in intensive fish culture	Use PRINCE 2.0 core processing Chip. Uses an IP-sec based virtual private network to monitor water quality parameters. Uses CDMA as the transmission technology. Uses Artificial Nueral Networks to forecast water quality parameters.	Use of Wi-Fi for local data collection imposes high power requirements. High cost implications. CDMA has short range (20-30km) and prone to call drops.
Vijayakumar and Ramya	20 15	The real time monitoring of water quality in IoT environment.	Made use of raspberry Pi B+ model processor. Was able to present water quality parameters on the internet.	Energy resources are quickly depleted since processor runs on Linux operating system.

3. Findings from Reviewed Literature

3.1 Power Consumption

From the reviewed work, studies such as that of Zhu *et al.* (2017) and Vijayakumar and Ramya (2015), showed a limitation of high energy consumption, this remains one of the challenges of using WSNs and IoTs for real time remote monitoring of aquaculture parameters. The energy consumption is determined by many factors including; the Transmission technology employed e.g. Zigbee and Bluetooth low energy consume less energy than technologies like Wi-fi and 3G, and 4G. Also the kind of microprocessor used also determines the level of energy consumption. For example the design of vijayakumar and Ramya (2015) employed raspberry pi which consumes energy because it is run on a linux operating system.

3.2 Data Security

Data security in our own sense refers to the level of reliability of transferring and receiving data from one end to another. From reviewed literature many designs based on IoT for remote monitoring of aquaculture parameters have the limitation of data security. The work of Duy *et al.* (2013) for example was based on wired network architecture, therefore data could not be easily transmitted over long ranges and the network was difficult to expand. Also in the work of Adamo *et al.* (2015), a single probe sensor was used to measure multiple aquaculture parameters at the same time. The problem with this is that all data will be lost when probe sensor malfunctions. Also in the design of Idachaba *et al.* (2017) an Parra et al (2017) in which they were able to successfully transmit data over long distances due to the transmission technologies employed; they had the limitation of not having local data centre, which should serve as storage and back-up for aquaculture data and also for local visualization and analyzing of data. As a result the data cannot the monitored when GSM network outage occurs.

3.3 Cost

Certain designs such as that of Encinas *et al.* (2017), employ high accuracy probe sensor for every parameter that needed to be monitored. Though this is effective for the environment in which they were used, it resulted in huge cost of deployment for the whole system especially if the system were to be deployed in farms with hundreds or thousands of ponds. This translates into millions of dollars. Also the work of Cario *et al.* (2017) also employed hydro lab series 5 probe sensors. The cost of these sensors range between 50 to 500 dollars per sensor which will run into millions of dollars when there is large scale deployment.

4. Conclusion

The review of various works on IoT deployments in monitoring aquaculture parameters has shown impressive results. And also shows good prospects for future use and Applications. Few of the reviewed work were found to have the limitation of high power consumption. While most of the more recent implementations have been able to find a significant level of solution to the problem of power consumption. However opportunities for improvement abound in the areas of data security and the cost of system development. This opens up new research niches in this field of aquaculture parameter monitoring.

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Appendix

Table 2.2 Limitation of Data security and cost

Author	Yr.	Title	Features	Limitation
Duy et al	2013	Automated monitoring and Control system for shrimp farms based on Embedded system and wireless sensor network.	Uses Low Power MSP430 Microcontrollers, Makes Use of a Lab view GUI, and Google spreadsheets application to upload the Data on the internet.	The System is based on a wired Network. So transmission is difficult to expand. The initial investment cost is high(about 300 thousand USD per hectare. It is not suitable for small and medium scale farms.
Adamo *et al.*	2015	A smart sensor network for monitoring sea water quality	A single Probe sensor was used to measure many sea water quality parameters	Using A single Probe Sensor is not reliable since all data will be lost when the probe sensor malfunctions.
Encinas *et al*	2017	Design and implementation of a distributed IoT system for the monitoring of water quality in aquaculture. autonomy of up to 8hrs.	Uses Probe Sensors and An Arduino Core. Uses ZigBee module to forward the information to a My SQL database. Used chargeable batteries that had an autonomy of up to 8hrs.	The cost of using Probe Sensors.
Cario *et al*,	2017	Long lasting under water wireless sensors network for water quality monitoring in fish farms. Employed energy management mechanisms.	Made Use of Hydro Lab Series 5 probes for Data Acquisition.	The cost of Using Probe sensors
Idachaba et al	2017	IoT enabled Real–time Fish pond Management System.	Consisted of water quality monitoring system, fish feeding mechanism, and water changing system. Made use of GSM as the transmission technology and also stored data in the cloud to enable access from multiple devices.	Has no provision for a local data centre for visualizing and analysing data. Data cannot be monitored when GSM network is down.
Parra et al	2017	Design and Deployment of low cost Sensors for Monitoring the water Quality and Fish behaviour in Aquaculture tanks, during the feeding process	Deployment of low cost Sensors. It employed a smart Algorithms to reduce power wastages, Detect abnormal values and send alarms when they happen. It monitors fish behaviour in addition to monitoring water quality parameters	No provision for a local data centre.