Design and implementation of a distributed IoT system for the monitoring of water quality in aquaculture

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***Abstract*—In this work we present the prototype and proof of concept of a distributed monitoring system of the most important variables in aquaculture water quality. This is of great importance because aquaculture is a lagging area of technology compared to other areas such as agriculture. So it is important to solve the problems that are in this area with the support of technology. Among the problems is the slow response time in the care of water quality, the waste of resources and losses. The system proposed in this work monitors the water quality based on wireless sensor networks and on the Internet of Things (IoT). This information is important for the development of this area, since it allows sharing the different conditions in the breeding of aquatic organisms between different breeders and organizations. This information is useful to know the conditions in which there is a better development of a product, worse development, what conditions can mean a possible disaster in the environment and how to optimize resources for the care of the pond.**

***Keywords*—Internet of Things, Wireless Sensor Networks, Aquaculture, Mobile & Cloud Computing, Global Wireless Services, Business & Applications.**

I. Introduction

Aquaculture consists of the set of activities, knowledge and techniques for the breeding of aquatic plants and some species of animals. This activity has a great importance in economic development and food production. Continuous monitoring of the physical, chemical and biological parameters of pond water helps not only to predict and control the negative conditions of aquaculture, but also to avoid environmental damage and the collapse of the production process. The monitoring of physical and chemical variables such as: oxygen, temperature and pH in water are vital to maintain adequate conditions and avoid undesirable situations that may lead to the collapse of aquaculture systems [1].

Among the technologies that can support this problem in aquaculture are the wireless sensors networks composed of a large number of self-organized sensors deployed in a monitoring region that perceive, collect, transmit and process information from supervised objects from the area covered in a coordinated manner. These networks have a very important commercial value, with the continuous development of wireless sensors networks, more and more countries and companies of software showed great interest [2].

Thanks to the development and improvement of electronics, microelectronics, digital systems, microcontrollers, telecommunications and information technologies, it can be seen the fast development of information systems and mobile applications for the control and supervision [3]. In this era of mobile technology and the interconnectivity of devices, the concept of the Internet of Things (IoT) is born, which consists of having interconnectivity and communication with objects. This provides a smart service, this by the combination of Internet and a network of sensors. In simple terms, it is an interdisciplinary piece of research that gets not only people but also connected objects [4].

Aquaculture pond monitoring procedures are currently inefficient; according to the experience of breeders this consumes a lot of time and costs in terms of human resources. The measurement of conditions is usually only done when the aquaculture has discovered an abnormal condition in the water or there is a drastic change in environmental factors. When the phenomenon occurs, the process to stabilize the system is usually very expensive and very complex. This causes environmental factors to be monitored inefficiently [5]. Among the main problems in aquaculture are the presence of diseases, uncertainty in water quality, high costs of operation and waste.

The aim of this work is design and implements a distributed system for aquaculture water quality care through remote monitoring of dissolved oxygen, pH and temperature. This work will contribute remote monitoring distributed system through what is known as the Internet of Things to monitoring water quality in ponds. The system is modular, portable, low cost, versatile and allows sharing information through the cloud that can be used for the development and improvement of aquaculture activities.

The application of this technology in aquaculture will provide the following benefits [6]:
1. Production close to market demand.
2. Improved environmental control.

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3. Reduction of damage caused by major disasters.
4. Reduction of environmental management costs.
5. Reduction of production costs.
6. Improves the quality of aquatic products.

The system can be implemented in aquaculture farms to be able to monitor in real time the most important physical-chemical variables of the water. With this having a faster response with respect to what actions to take when conditions arise in the water quality of the ponds. Some other applications where water quality is important are:

- Irrigation in agriculture: it is a very important factor when making decisions about the choice of irrigation system, determination of the components of the installation and of the irrigation and crop management itself in order to avoid problems of salinity, water infiltration In soil, of toxicity to plants or other derivatives of the seals in localized irrigation systems.

- Industrial use: Water quality allows production operations to be optimized, to have a better product if it contains water or simply to keep piping and containers in good condition.

- Human consumption: Water is a source of life and health. Water is indispensable for life. Its quality is intimately related to the standard of living and the sanitary level of a country.

- Ambient water: Identify water bodies in need of improvement, evaluate the effectiveness of pollution abatement plans as well as provide scientific data for making planning decisions.

In this paper we present several sections as a first step an introduction to be in context with the subject of aquaculture, what problems exist in this area, how to solve them and the benefits. The state of the art where we present several works about aquaculture systems and what are the niches of opportunity in this area and which of these will be treated in this work. The section of Method we present the architecture of the system and a brief explanation of the software and hardware. Experimental Results shows the functionality, some images and the results obtained using the system. Conclusion we comment about this work. Future work we propose the next stages for this work and present the benefits.

II. State of the art

We investigated related works in the subject to identify the most important points in the area and the niches of opportunity that are in the state of the art of this type of systems.

The author ShaoHue Hu performed a work which is entitled Dynamic Monitoring Based on Wireless Sensor Networks of IoT [7]. This was published in 2015. The paper consists of a system that combines the Internet of Things with aquaculture monitoring systems showing an algorithm for the sampling of information sensed in aquaculture and optimize the energy consumption in the networks of Sensors. An algorithm is implemented by simulation to save energy when sampling the parameters of the ponds. It is proposed as future work that it is necessary to update the algorithms for a greater number of variables to be measured, to obtain a correlation between temperature and humidity; this means more information about the environment and allows performing an analysis of patterns and characteristics using machine learning techniques. Another future work is optimizing the sampling to save energy. As a result, energy consumption is reduced. This concludes that reducing the number of samples can save energy. The benefits in this energy saving consist in the reduction of costs and the optimization of the monitoring processes.

In the work Automated Monitoring and Control System for Shrimp Farms Based on Embedded System and Wireless Sensor Network [8] published by Nguyen et al. [8] in 2015, a low-cost, versatile and prototype system is developed to elaborate a commercial product in aquaculture. A distributed system was implemented using ZigBee, GSM, Cloud, MSP430 and LabVIEW technologies. This system monitors three variables which are pH, Oxygen and Temperature in two shrimp farms. It is concluded that the implemented system is scalable, intuitive and low cost. We recomend to add more sensors to obtain more information on the state of the water quality and to be able to carry out a more complete analysis and give more reliability to the system through validation with commercial measurement instruments.

The Research on Wireless Sensor Network in Aquaculture [9] contributes to an intelligent system based on wireless sensor networks for monitoring. It implements an architecture using different types of sensors in a node known as sensing node, this node communicates through the ZigBee protocol to a Sink. In this part the information is taken to a server which uploads the information to the cloud and is requested by a computer by the user. This system has a manual control system and a smart control system. The system resulted in measurements with errors less than 0.3. In conclusion, an adequate monitoring and control system for the monitoring and control of aquaculture water quality was implemented. As future work is planned to apply this type of systems in the field and industry to validate their functionality in the wild and verify their robustness and reliability.

A monitoring system for water quality in aquaculture ponds is mentioned in the publication A Mobile Platform for Remote Monitoring of Water Quality on Live Fish Transport Containers: Lessons Learned [10]. The contribution is a mobile sensor platform for monitoring ponds. This system consists of the following architecture. It has the sensing node of each pond connected to a sink; this sink sends the information to a mobile application to have a visualization of the data in real time. This information is transmitted via GSM / 3G to the Internet, it can be monitored remotely and the information is stored in a database. In the results the data of the ponds were shown remotely and the measures were corroborated by the transport staff. In conclusion, the monitoring platform showed excellent performance and precision in the test phase. In future works it is proposed to integrate artificial intelligence into the system to optimize and improve its functionality. This allows the system to be able to optimize resources using machine learning to analyze organisms and water conditions, in order to have an efficient control.

The system that was implemented in a research project in 2014 entitled Remote fish aquaculture monitoring system based on wireless transmission technology [11] contributes with an autonomous remote monitoring system in real time for aquaculture. This system consists of a surveillance network combined with mobile devices and a remote platform to collect real-time information on aquaculture farms. The system architecture is based on a wireless sensor network with the ZigBee protocol which communicates with a coordinator and this information to a server. This server uploads the information to the internet and in this way is requested from the mobile devices. The system records the values of the measured variables with time and date. This system presents different measurement and monitoring systems to optimize resources and reduce costs. In future works it is proposed to use other technologies to improve the system.

The paper Application Effect of Aquaculture IOT System [12] addresses a Monitoring System for water quality as the IoT systems. An experiment is carried out on farms where IoT systems are used and the costs and resources in which they do not use are compared. As results the costs between farms where systems are used is reduced between 19.34%, 6.03%, 3.98%. In conclusion IoT-based systems in aquaculture provide economic benefits in this area.

A research titled Wireless Sensor Network System Design using Raspberry Pi and Arduino for Environmental Monitoring Applications [13] shows how wireless sensor networks are an important technology to innovate in different applications. Mainly this research focuses on a monitoring system based on Raspberry Pi and Arduino for monitoring environments. The architecture consists of sensing nodes through a WSN using the ZigBee protocol. These nodes are coordinated in a base station which sends the information by an application to a database and to a web server. Subsequently the information is uploaded to the internet through a router where it can be deployed in devices such as cell phones and computers. An improvement to this work would be add IoT to the system, so that other devices that can control the environment and not only monitoring it. In addition to a better storage of the information a server is used and the sharing of this information to allow other experts and organization realize an analysis of the data.

The paper Design and deployment of wireless sensor networks for aquaculture monitoring and control based on virtual instruments [14] presents a system based on sensor networks for real time monitoring in aquaculture. The system consists of nodes that sense the ph, temperature and dissolved oxygen in the water. These sensing nodes send the information to a coordinator and this sends the information to a computer to be visualized. This system effectively reduces the high risk of organism mortality through constant monitoring of the most critical parameters in the enviroment.

Development of Embedded Wireless Network and Water Quality Measurement Systems for Aquaculture [15] this work presents the development and implementation of a system for the monitoring of water quality in ponds, which consists of floats that have a system for sensing and transmitting values of pH, temperature, dissolved oxygen and conductivity. This information is uploaded to the Internet and is displayed in a desktop application in Labview. However, it does not mention the use of a database for the storage of information or a mobile application.

Compared with some of the mentioned works, this work has the integrated and mobile detection node which allows the system to be changed to different ponds. They have different mobile and desktop applications since the software of this system displays information, stores it in a database and uploads it to the cloud. In addition to the development of this prototype, it is designed to integrate artificial intelligence to control the water quality of ponds and to analyze the data. This work in contrast to others, takes the information to carry out a more specific analysis of the cases that occur in the aquaculture due to the use of Internet of the Things. These include optimum development of aquatic organisms, optimization of resources and exchange of information with other organizations. All this is of great importance for aquaculturists and organizations, as this provides optimization of resources, efficient processes, reduction in costs of production and products of better quality.

III. Method

This section consists of three subsections which are the architecture of the system where the technologies required for the development of the system are presented, the hardware design showing the devices that were used for the implementation and finally the software design which consists of a description of the functionality.

A. System architecture

This system uses different technologies, among these Arduino module, Sensors, database, Web Services, mobile application and Desktop application. Figure 1 shows the data flow and the three general blocks of the system: Sensors, Connectivity and Deployment.

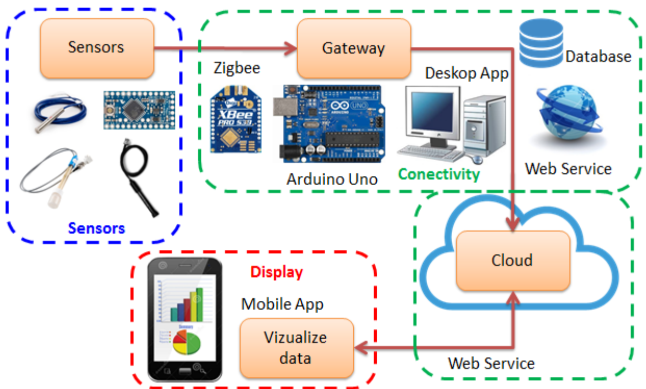

Fig. 1. System general blocks and data flow.

Sensors: In this section three sensors are used which are an analog temperature sensor, Atlas Ph Probe digital sensor and Atlas Dissolved Oxygen Probe.The sensors transmit their information via UART (Universal Asynchronous Transmitter-Receiver) Each of these sensors is submerged in the pond where the measurement is taken.

Connectivity: Sensing information is transmitted via the Zigbee protocol. Zigbee protocol uses IEEE802.15.4 specification as the medium access layer (MAC) and Physical Layer (PHY). Zigbee works in 2.4 GHz frequency band. The data transfer rate for ZigBee standard is 10-250kbps and the transmission distance 300 feet to 1 mile. The maximum length of data packets for IEEE802.15.4 MAC is 127 bytes.

The Arduino module is used as the communication coordinator. The sensing node sends the information through a Xbee transmitter module to the computer where it is received by the receiver Xbee module, through serial communication this data is read by an application developed in C sharp.

The data in the application is deployed, stored in a local database in MySQL and sent to a web service where it is available in the cloud. This web service consist in SOAP (Simple Object Access Protocol) a lightweight protocol intended for exchanging structured information in a decentralized, distributed environment. SOAP uses XML technologies to define an extensible messaging framework, which provides a message construct that can be exchanged over a variety of underlying protocols. The framework has been designed to be independent of any particular programming model and other implementation specific semantics. The system architecture and the different wireless technologies are shown in figure 2.

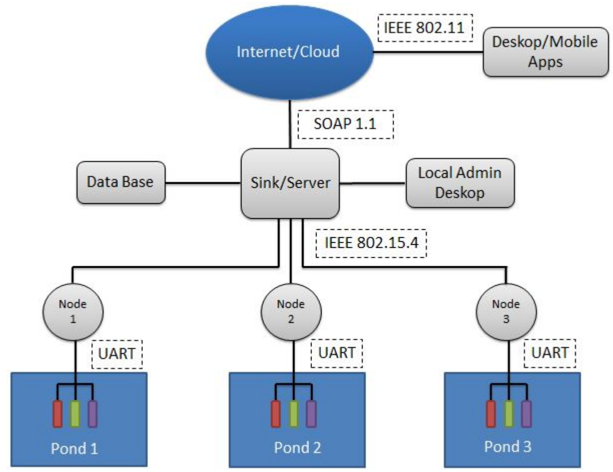

Fig. 2. System architecture

Deployment: Desktop applications and mobile application.

The information flow of the system consists of taking information from the critical variables of the pond from the temperature, oxygen and pH sensors. Previously these sensors were calibrated according to their specifications plus each one has its integrated circuit that provides the characterization of each sensor, in this way it has that the measured data are reliable.

The Arduino module coordinates the time in which the information of each sensor is taken and how it is transmitted to the Xbee module. This coordination consists of control signals for a multiplexer. This multiplexer has as input the data as UART for each of the different sensors and as output the Xbee module. This information is transmitted by the Xbee module transmiter of the measurement node to another Xbee module receiver that is connected in a computer, through the serial port Communicates with the data reading application. The application stores the information in a database and uploads the information to the cloud through a web service. The mobile application asks the web service for the data to be displayed.

B. Hardware design

In the hardware development a 22x14x9 cm plastic cabinet is used. In this cabinet are placed 3 rechargeable 9v batteries, Arduino One, Xbee Serie 1, multiplexer, pH sensor, temperature sensor and dissolved oxygen sensor. Figure 3 shows the diagram of the hardware in the cabinet.

This diagram shows the different general components of the system. Starting with the power supply which is responsible for supplying power to all the electronic devices in this node.

The arduino one serves as a coordinator, it has two control signals to select which sensor will transmit its information through the Xbee module. Each sensor has its integrated circuit which adjusts the information and transmits it via UART to the multiplexer.

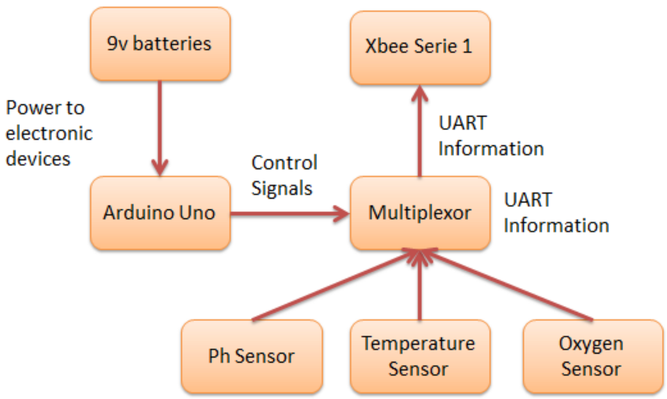

Fig. 3. Hardware diagram.

C. Software design

The desktop application was developed in Visual Studio 2015 in the C sharp language. It was developed to read the serial port of the computer and to enable communication with the hardware. At this point the information is upload to a web service using the SOAP protocol, this was generated on the same platform as the deskop application Visual Studio 2015. The mobile application was developed in Android studio for devices that have an operating system higher than Android 4.0.3 or equivalent.

Figure 4 shows the flowchart of the software. This flow diagram consists of the moment of opening the application is requested to open a port which consists of the Xbee module that will communicate with the sensing node. To enable the port it must be available and the baud rate must be set. Immediately a measurement request is sent and a counter is started which serves to give time to each sensor to measure and to coordinate the requests for information. Subsequently the information is updated in the application where it is store in a database and then uploaded to a web service and it updates the information on the server. To finalize the information is available in the server and this can be requested through the applications of data deployment.

IV. Experimental Results

The proposed system was successfully developed using the proposed hardware, software and architecture. The data is transmitted regularly, without errors and with a very small latency. The system was tested using the system in a local network A in which the computer is connected and is the place where the cabinet with the sensors is located

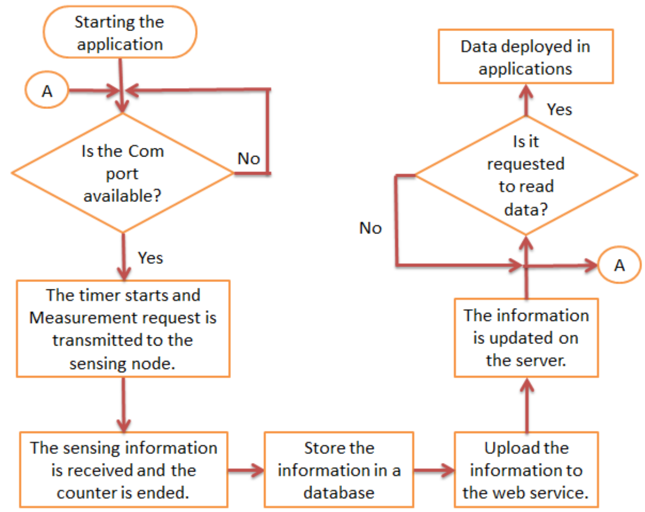

Fig. 4. Software flowchart.

and the information was requested from an external network B.

Figure 5 shows the implemented system. There is the box with its three sensors, the electronic devices and the ignition switch. This box is placed near the pond to which it will be measured its water quality and the three sensors are immersed in said pond.

Fig. 5. Hardware implemented.

This system lasts approximately 8 hours using rechargeable batteries of 200mA / h. This is sufficient for proof of concept of this prototype.

Figure 6 shows the application taking data read. This application consists of opening the Xbee module port that is connected to the computer. The 15 seconds counter is used to take the measurements every 5 seconds. A request is sent to a sensor to take the measurement and when the request of each sensor is sent, the sensed information is sent to the application.

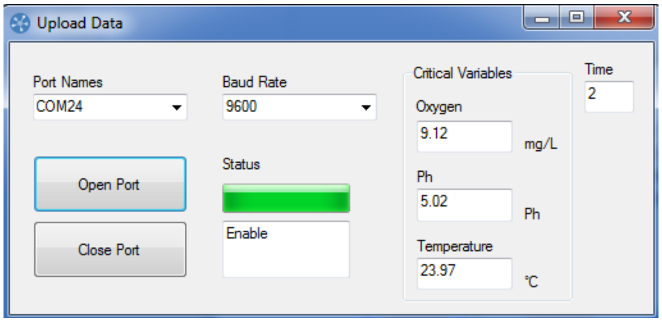

Fig. 6. Desktop application.

In this same application the information is store in a database and then is uploaded to web service. This service updates the server where it can then be requested by the mobile application which is shown in figure 7, where dissolved oxygen, pH and temperature are displayed.

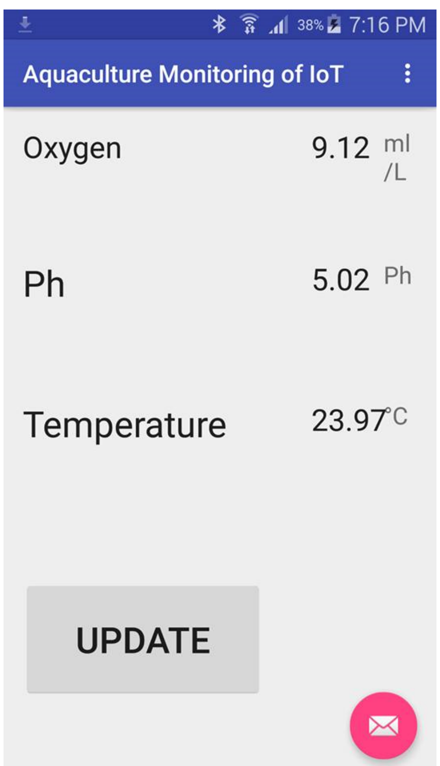

Fig. 7. Mobile application.

This application uses the update button to request the information that is available in the web service.

V. Conclusion

This work presents the implementation of a prototype and a proof of concept about a remote monitoring system applying the concept of IoT among others technologies addressed to aquaculture water quality. This system is low cost, low power consumption, scalable, versatile, distributed, mobile and accurate. This prototype is still under development, in the next section of future work the stage of the system is mentioned in detail and it is still to be implemented.

VI. Future Work

As future work different stages are proposed, in figure 8 a general diagram of the system is shown.

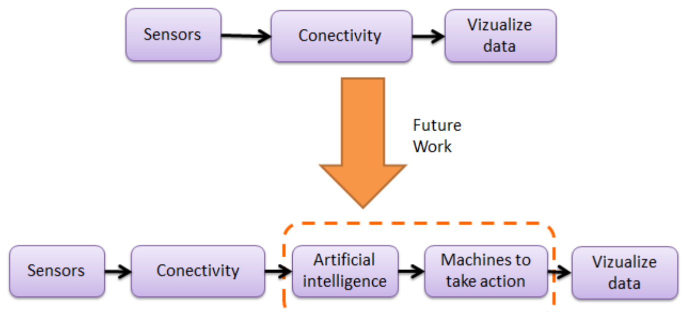

Fig. 8. Future work chart.

The AI module will be developed in python. The module will take the information of the database to infer when to send alarms on the conditions or events important for the care of the ponds. Currently the module is proposed to work with fuzzy logic.

This work will be limited to the development of the prototype for a network of 3 nodes where the artificial intelligence module will have the purpose of detecting events in the water of the ponds or unwanted conditions, in this way the system will notify the user. This will bring the following benefits:
1. Process optimization.
2. Optimization of resources.
3. Features for a better product.
4. Prevention of unwanted conditions.
5. Reduction of losses.

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