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Development of Low-Cost Multiparameter Sensors for MonitoringWater Quality in Fish Ponds

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ABSTRACT: Water monitoring in ponds is the daily observation and analysis of water parameter to ensure provisional water quality and quantity by adopting good water quality management and strategies and as well ensure its supply in adequacy through appropriate channels of flow as well as it acceptability of fish culture. The infrastructure requirements for setting up fish farms include a source of clean water, an avenue for discharging the waste water and reliable water containment systems. The challenges faced by the operators of these fish ponds include the need for regular monitoring of the water quality and the changing of the water when the quality becomes unhealthy for the fish. In the countries like Nigeria, its full potential is yet to beexploited. In view of this,we have designed and presented a wireless multiparameter sensors network monitoring and control system for fish ponds. The system can detect water quality parameters such as temperature, dissolved oxygen content, pH value, turbidity, conductivity and water level in real-time. The sensor nodes collect the water quality parameters and transmit them to owners through short messages from the base station via the Global System for Mobile (GSM) module for notification. The experimental evaluation of the network performance metrics of quality of communication link, battery performance and data aggregation was presented. The experimental results show that the system has great prospect when used to operate in real world environment for optimum control of aquaculture environment.

KEYWORDS: Pond, water parameter, multiparameter, monitoring

I. INTRODUCTION

The proper management of pond water quality plays a significant role for the success of aquaculture operations. Each water quality parameter alone can directly affect the aquaticanimals' health. Exposure of fish to improper levels of dissolved oxygen, ammonia, nitrite or hydrogen sulfide leads to stress and disease. However, in the complex and dynamic environment of aquaculture ponds, water quality parameters also influence each other. Unbalanced levels of temperature and pH can increase the toxicity of ammonia and hydrogen sulfide. Thus, maintaining balanced levels of water quality parameters is fundamental for both the health and growth of culture organisms [1]. It is recommended to monitor and assess water quality parameters on a routine basis.The most important parameters to bemonitored and controlled in an aquaculture systeminclude temperature, dissolved oxygen, pH, ammonia,nitrates, salinity, and alkalinity, since they directly affectaquatic animal health, feed utilization, growth rates and carryingcapacities.Water temperature affects the feeding pattern andgrowth of fish. Fish generally experience stress anddisease breakout when temperature is chronically neartheir maximum tolerance or fluctuates suddenly. Warmwater holds less dissolved oxygen than cool water.Oxygen consumption is directly linked to size of fish,feeding rate, activity level and pond temperature. Theamount of dissolved oxygen in water increases astemperature reduces, and decreases when salinityincreases. Low dissolved oxygen concentration isrecognized as a major cause of stress, poor appetite, slowgrowth, disease susceptibility and mortality inaquaculture animals [2]. It is generally accepted that theminimum daily dissolved-oxygen concentration in pondculture systems is of greatest concern. Not only isdissolved oxygen important for fish respiration, it is alsoimportant for the survival of phytoplankton, the organismwhich breaks down toxic ammonia into harmless forms.The acceptable range of pH for fish culture is usuallybetween pH 6.5 to pH 9.0. When water is very alkaline (>pH 9), ammonium in water is converted to toxic ammonia,which can kill fish. On the other hand, acidic water (< pH5) leaches metals from rocks and sediments. These metalshave an adverse effect on the fish's metabolism rates andability to take in water through their gills, and can be fatalas well [3]. Since failure of any component can causecatastrophic losses within a short period of time, thesystem must be reliable and constantly monitored. Thus,precise measurements and controls are necessary for thesuccess of an intensive aquaculture system [4]-[5].However, there are few applications of systems whichcould carry out real-time water quality monitoringcontinuously. According to the conventionalmethods of water quality monitoring, samples of waterare taken and transported to a chemical laboratory toanalyze the hazardous substances. On the other hand, themaintenance of the measurements and control process ismanual influenced by the personal experience [6].How to realize real-time data collection in a secure, robust, manageable and low -cost manner without longdistance cable connections is still a bottleneck in thedevelopment of information monitoring in fish culture [7].Modern aquaculture environment detection and controltechnology achieves high-quality, high yield, improvesthe basic environmental conditions and is one of the keymeans to promote fish production through the integratedapplication of bio engineering and computer technologyto make the appropriate adjustments, according to thevariation of indicators, increase production, andguarantee reliable income [8]-[9]. A properly-controlledsystem will also be energy efficient since production canbe optimized with respect to the various inputs. So asustainable development of aquaculture environmentalfactors monitoring and control system for intensive fishfarming is inevitable.

II. IMPACT OF WATER QUALITY PARAMETERS

In this research work, the most important water quality parameters such as dissolved oxygen, pH, temperature, conductivity, water level and turbidity are described with insights on how these parameters influence each other. Table 1 gives an overview of the water quality parameters with their standard values.

A. Dissolved Oxygen (DO)

The relevance of monitoring the level of dissolved oxygen in ponds is very important. For the African catfish, a farmer should try as much as possible to maintain dissolved oxygen levels at between 4mg/liter to saturation levels in the pond.Gas bubble disease can happen to the fish when DO levels are consistently too high and the water is super-saturated to well above 300 per cent. When DO level is consistently between 1.5mg/liter to 5mg/liter, fish will be alive, but feed intake will reduce. Growth rate will also reduce and high Feed Conversion Ratios (FCR) will be recorded. When DO levels are lower than 1.5mg/liter, fish will be stressed and they will die. The periods of achieving desired weights in fish will be lengthened and ultimate loss on investment will occur.Infact, I can categorically emphasize that with consistently low levels of DO in ponds, the use of low quality feed might even be a waste of money. This is simply because of the fact that fish breathe in oxygen for general body metabolism. DO is needed to help breakdown any potentially harmful metabolic waste into less harmful forms, e.g ammonia (NH3) broken down into nitrites (NO2) and then into nitrates (NO3).

B. Temperature

Unlike man that is warm blooded, fish are cold blooded. The metabolism which occurs in their bodies is greatly influenced by the water temperature.For the African Catfish, an acceptable temperature range is between 26ºC to 32ºC.When water temperature in the ponds consistently stays between 16ºC and 26ºC, feed intake reduces and fish growth rate also drags tremendously. A farmer will record high FCR, and the fish will also be stressed. Prolonged stress can open up the fish to opportunistic infections. When fish are consistently exposed to temperatures below 15ºC, fish growth will ultimately stop and death is just around the corner. Low temperature negatively affects rates at which wastes are converted in the water. However, when water temperature is above 32ºC, the resultant effect on the African Catfish in not good at all. This is because of the fact that Oxygen is not readily soluble in very warm water. High temperature in ponds will stress the fish and eventually lead to death.

C. pH

pH is the level of the Hydrogen ion present in the water. For the fish in the pond, acceptable pH value is between 6.5 to 7.5. When it is below 4, fish will die due to water acidity.When pH is constantly between 4 to 6, fish will be alive, but, due to stress, will experience slow growth. Feed intake will be highly staggered and reduced. FCR will also be very high.Infact, for the observant fish farmer, low pH in pond water is an indication of high CO_2, (carbon dioxide) in the water.High pH values of between 9 to 11 in pond water will also retard fish growth. Fish will ultimately die when pH levels rise above 11. Low pH aids higher proportions of ionized ammonia which is less toxic to fish. The reverse is the case with high pH in water.There is nothing as painful as being ignorant of these facts. These water parameters play a major role in the overall business of profitable fish farming.Making profit from fish farming really goes beyond just giving food to the fishes. Water Quality parameters must be monitored and acceptable ranges must be maintained.Growth time of fish in ponds must be within acceptable times. Nothing is as painful as keeping fish in ponds for an unnecessary long period of time while money is being wasted on feed.

D. TURBIDITY

Turbidity can be caused either by planktonic organisms or by suspended soil particles. The turbidity due to silt and clay particles is also known as inorganic turbidity and can interfere with the penetration of light and by absorbing nutrients present in the water and in turns affects the growth of benthos. This can cause uneasiness and stress to the shrimp leading to disease. Suspended clay particles (>4% by volume) damage the gills of prawns by clogging it. In certain cases, oxygen deficiency has also been reported as a result of sudden increase in turbidity. Turbidity due to both plankton density and suspended silt and clay particles can be measured in terms of transparency using Secchi disc. High value of transparency (>60 cm) is indicative of poor plankton density and therefore water should be fertilized with right kind of fertilizers. Low value indicates high density of plankton and hence fertilization rate and frequency should be reduced. The optimum range of transparency is 25 – 35 cm. Transparency less than 20 indicates that the water is unsuitable for shrimp culture and should be changed immediately to flush out excess bloom. It is wrong notion that intake of plankton rich water is good for initial filling. Clear water is best suited. Sometimes, ponds, which develop clear water condition, are repeatedly fertilized with high doses of inorganic fertilizers with the hope to produce bloom. Once the benthic algae develop, it is useless to fertilize the ponds

E. CONDUCTIVITY

Conductivity is a good rough guide to the condition of ponds. It measures how much ‘stuff’ there is dissolved in the water. And ponds which are polluted usually have more ‘stuff’ dissolved in them than those that are clean.The good thing about conductivity is that with a portable meter you can get a result that’s almost as good as a laboratory can produce. This isn’t true for most other pollution measurements where to get a useful result you usually need to get an expensive laboratory test. Conductivity below about 250 and the pond will usually turn out to be in pretty good shape. Over 600, and usually there will be problems. Between these two values and you need to look carefully. I was looking at a village pond with conductivity of 1100 the other day – and that definitely has problems. Not so far from here, we were looking at a possible site for Million Ponds clean water ponds. The water had a conductivity of 700 and so not much chance it would be unpolluted.As water chemistry specialists will know conductivity is only a rough guide to pollutant levels – but you can make surprisingly good assessments of the overall impact of pollution is you interpret it carefully

Table 1: Water quality parameters and their standard values

Parameters	**Designated Use**	**Standard values**	**Recommended Agency**
PH	General Agriculture	6.0 – 8.5	USEPA
	Irrigation water	4.5 – 9.0	USEPA
	Human Consumption	5.0 – 9.0	WHO/ICMR
	Freshwater aquatic life	6.5 – 9.0	WHO/ICMR
	Marine aquatic life	6.5 – 8.5	USEPA
Turbidity (NTU)	Human Consumption	1 – 5	WHO/ICMR

	Freshwater aquatic life	1 – 50	USEPA
Conductivity (S/m)	Human Consumption	30 – 80	WHO/ICMR
Dissolved Oxygen (m/l)	Human Consumption	5	WHO/ICMR
	Freshwater aquatic life	5 – 7	USEPA
Temperature (^{o}C)	Freshwater aquatic life	26 – 30	Literature
Water level (m)	ND	ND	ND

III. RELEATED WORK

A limited number of on-line, reagent-free water monitoring systems exist (e.g. Hach HST Guardian Blue [10], JMAR BioSentry [11]), but these systems are bulky (sensors are installed in flow cells located in cabinets) and remain cost prohibitive for large scale deployments. A chemical sensor array for water quality monitoring based on thick film technology is presented in [12], [13] ,[14]and [15] these sensors are very low cost, though they have limited lifetime (few months) and require a conventional glass reference electrode to operate accurately. A limited number of on-line, reagent-free water monitoring systems exist (e.g. Hach HST Guardian Blue [10], JMAR BioSentry [11]), but these systems are bulky (sensors are installed in flow cells located in cabinets) and remain cost prohibitive for large scale multiparametric sensor array based on semiconductor ruthenium oxide nanostructures is proposed in [16]. [17]Multi-sensor heterogeneous real time water monitoring system using the parameters like ph, temperature, conductivity, turbidity and dissolved oxygen was proposed. [18] Used a satellite with chlorophyll concentration and neural network to predict status of lakes and reservoirs. Postolache et al. [19] used GPRS and a Kohonen SOM (Self organizing Map) to monitor water quality in real time. Brockmann and Stelzer [20] introduced water quality monitoring of coastlines. Wang et al [21] deployed Zigbee technology to construct water monitoring system.

The above research papers studied so far, demonstrate the effective use of sensor network for water monitoring and contamination detection. However, most of the papers have proposed various schemes to make this system effective andefficient but some of these schemes are costly due to high cost of sensors and some of the sensors used have short life time.

Papers where field deployment is done that is not suitable for some of the important parameters of water quality. So it is necessary to design and implement a system by taking the requirement of multiple parameters of water quality using low cost sensor and system design

IV. SYSTEM DESIGN AND DEVELOPMENT

Figure 1 shows the general blocks diagram of water quality monitoring system. Three main subsystems identified include

1. Data collection subsystem consists of multi-parameter sensors and optional wireless communication device to transmit the sensor information to the controller. A controller gathers the data and processes the same.
2. Data management subsystem which accesses the data and displays the same to the end user.
3. Data transmission subsystem consists of a wireless communication device which transmits the data from the controller to data storage.

The following materials were used to develop the system for water quality monitoring, Sensors, Amplifiers, Analog-to-digital converters, Arduino Microcontroller, Transmitters, Receivers, Micro SD, shield +TF card, PC, Display unit and Timer.

All these components were connected together and appropriate embedded program using MickroC platform for decoding. Various parameters of water quality were automatically detected under the control of single chip microcontroller. The microcontroller will get signals from different sensors then process and analyze them as shown in block diagram in figure 1. Then, the data was instantaneously sent to monitoring center through GPRS (General Packet Radio Service) network. The system realize the automation of water quality monitoring, intelligence of data analyzing, networking of information transfer and fast dissemination of information to relevant stakeholders for making timely decisions

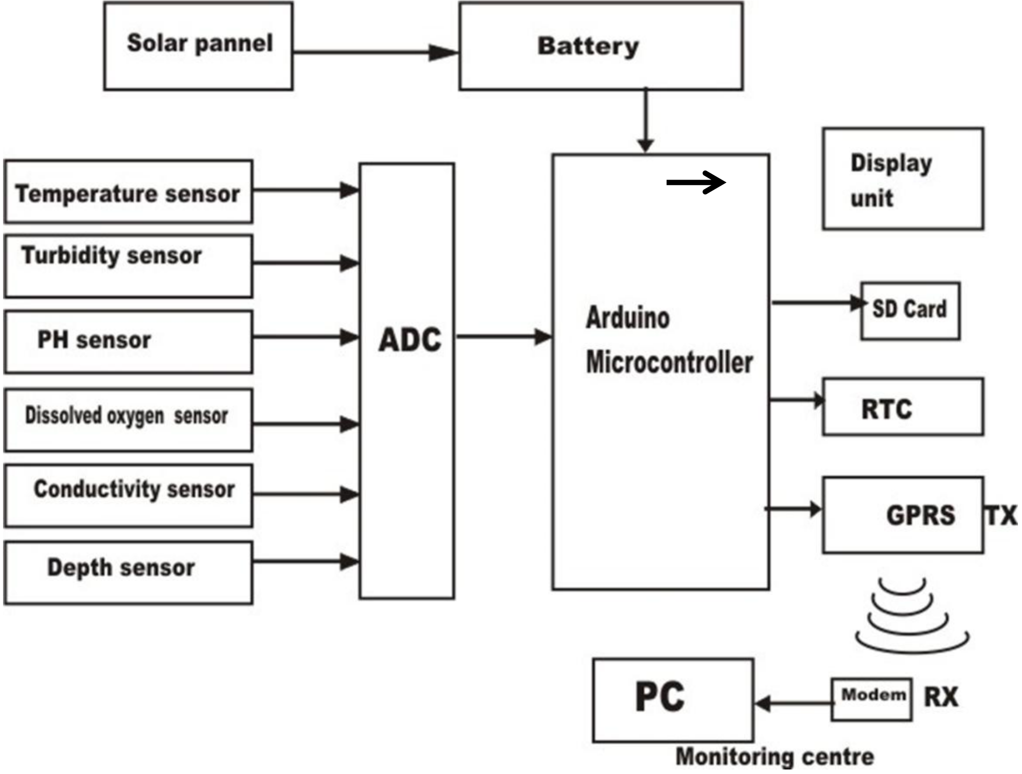


Figure 1: Block Diagram of multi-parameter water quality monitoring system

The system was built around Ardiuno mega microcontroller as the heart. This Ardiuno mega microcontroller because of its processor speed and core memory is capable of processing signals from sensors using a speed of 40Mhz. it consists of digitals and analogs pins which make interfacing (connections pheripherals) easy.

Six sensors were connected to ADC pins of the Ardiuno mega microcontroller. The circuit diagram of the system is shown in figure 2. The display unit, SD card, RTC and GSM module were also connected to the Ardiuno mega microcontroller. Arduino software (C++) were used to program the microcontroller, this made it possible for the microcontroller to supervised the sensors by collecting signal from them and fomite to data which are times stamped and stored in excel format or CSV. Figure 2 shows the completed system in which the sensors were connected to the Arduino Mega microcontroller board.A 15watt, 12v solar panel were connected to charge a LEAD acid battery rated 6v, 4.5Ah. This battery powered the entire system. A voltage regulator module LM 2596 DC-DC was used to limit the excessive voltage from sola panel to the required 7.2v.

Another voltage regulator LM7805 DC-DC was used to regulate the voltage from the battery to 5v which is the maximum required voltage for the system with the exception of GSM module which operates between 3.7v to 4v. A new method of powering a GSM module alone were devised by using two (2) silicon diode and one (1) resistor.

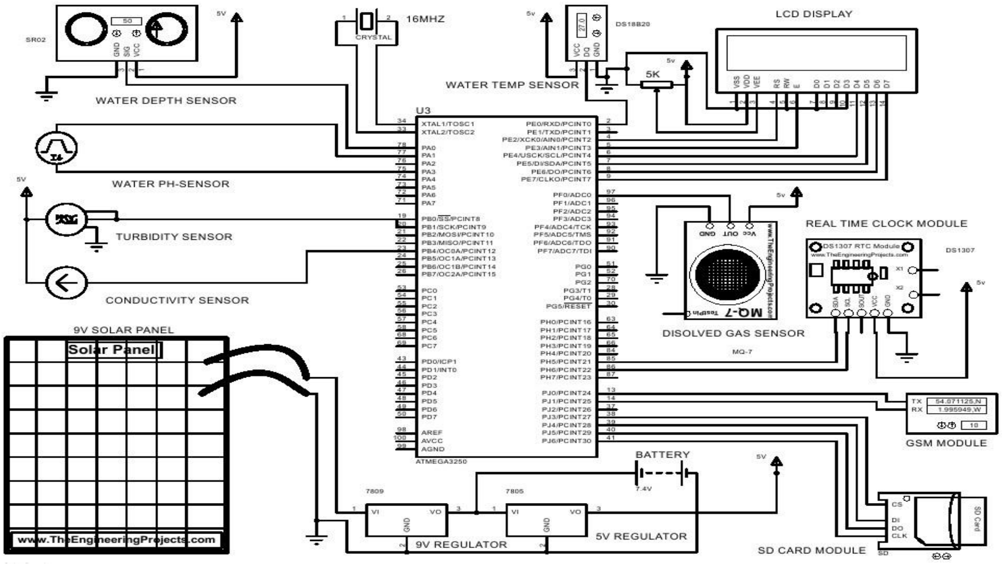


Figure 2: Circuit diagram of the multiparameter water monitoring system

When the system was switched on, it configures all its sensors and modules, then it sent AT command to GSM (AT is a special command used by microcontroller to set modules to desired configuration). This command switches the GSM module to the desired mode of operation at a particular time depending on which operation to be carried out. In this work there are two mode of operation required from GSM module.

1. GPRS mode:- This is used to log data to the internet (www.thingspeak. com)

2. GSM mode: - This is used to send sms sensors update to the user with the preprogrammed GSM number. A registered sim card with internet data and prepaid airtime were inserted into the GSM module. When the system is switches on, the display module (LCD display) will displayed the sensors reading for initial reading. The user will allow the sensors to get acclimatized with the water before recording the initial reading. After this the system will be switched off and formatted card will be inserted into the card reader slot where reading will be stored in every 1minute interval. The whole system was built and housing inside waterproof Styrofoam, this makes it buoyant to flow on water easily. Figure 3 shows the architecture designed of the System.

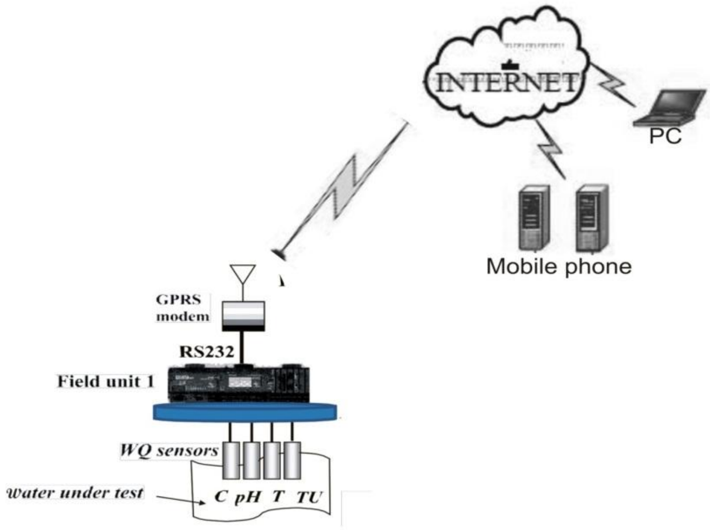


Figure 3: Architecture designed of the Water quality Monitoring System

V. SYSTEM IMPLEMENTATION

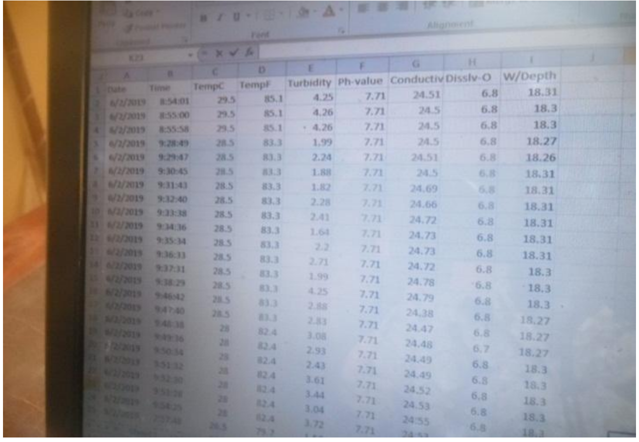
The system (figure 4) was implemented in constructed pond, opposite Junior staff quarters, National Institute for Freshwater Fisheries Research, New Bussa, Niger State, Nigeria.Several field trials were conducted from June 11, 2019 to November11, 2019 on an earthen pond of15ft x 10ft x 7ft in dimension which was constructed and stocked with 2000 Clariasgariepinus. During the period of each experiment, pH, temperature, turbidity, dissolved oxygen, conductivity and water depth data were collected with a constant time interval

Figure 4: Showing the monitoring of water quality parameters of an earthen pond

The system was tested connecting the sensors to the modules and the receiver node to the monitoring device, installation of sensor nodes in the fish ponds and their operation.

VI. RESULTS AND DISCUSSION

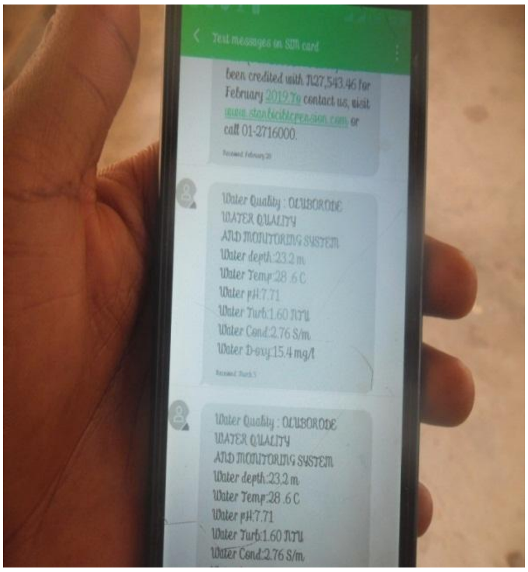
Storing data in the database of aquaculture environmental information sent from each sensor nodes in real time and also monitoring data so that the user can have access to aquaculture environmental information. The database for storing sensor values consists of one table for all sensors where the index, date, time and sensor values are stored. The monitoring program can be configured to store data every selected time interval in seconds. The monitoring program displays an instrument panel with the latest values stored into the database and automatically updates to display the new values.



Date	Time	TempC	TempF	Turbidity	Ph-value	Conductiv	Disslv-O	W/Depth
6/2/2019	8:54:01	29.5	85.1	4.25	7.71	24.51	6.8	18.31
6/2/2019	8:55:00	29.5	85.1	4.26	7.71	24.5	6.8	18.3
6/2/2019	8:55:58	29.5	85.1	4.26	7.71	24.5	6.8	18.3
6/2/2019	9:28:49	28.5	83.3	1.99	7.71	24.5	6.8	18.27
6/2/2019	9:29:47	28.5	83.3	2.24	7.71	24.51	6.8	18.26
6/2/2019	9:30:45	28.5	83.3	1.88	7.71	24.5	6.8	18.31
6/2/2019	9:31:43	28.5	83.3	1.82	7.71	24.69	6.8	18.31
6/2/2019	9:32:40	28.5	83.3	2.28	7.71	24.66	6.8	18.31
6/2/2019	9:33:38	28.5	83.3	2.41	7.71	24.72	6.8	18.31
6/2/2019	9:34:36	28.5	83.3	1.64	7.71	24.73	6.8	18.31
6/2/2019	9:35:34	28.5	83.3	2.2	7.71	24.73	6.8	18.31
6/2/2019	9:36:33	28.5	83.3	2.71	7.71	24.72	6.8	18.3
6/2/2019	9:37:31	28.5	83.3	1.99	7.71	24.78	6.8	18.3
6/2/2019	9:38:29	28.5	83.3	4.25	7.71	24.79	6.8	18.3
6/2/2019	9:46:42	28.5	83.3	2.88	7.71	24.38	6.8	18.27
6/2/2019	9:47:40	28.5	83.3	2.83	7.71	24.47	6.8	18.27
6/2/2019	9:48:38	28	82.4	3.08	7.71	24.48	6.7	18.27
6/2/2019	9:49:36	28	82.4	2.93	7.71	24.49	6.8	18.3
6/2/2019	9:50:34	28	82.4	2.43	7.71	24.49	6.8	18.3
6/2/2019	9:51:32	28	82.4	3.61	7.71	24.52	6.8	18.3
6/2/2019	9:52:30	28	82.4	3.44	7.71	24.53	6.8	18.3
6/2/2019	9:53:28	28	82.4	3.04	7.71	24:55	6.8	18.3
6/2/2019	9:54:25	28	82.4	3.72	7.71			

Figure 5: Data Login into the card

The measured data change consistently and reasonably reflecting the values from field sensors.The user interface allows us to convey the analyzed data in the form of a message to the fish farmers in their respective local languages to their Mobile Phones and alerts them in unhygienicenvironmental conditions figure 6. With this even semi-literate farmers can interact with the system and can understand the information in order to take suitable actions.



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Water Quality : OLUBORODE
WATER QUALITY
AND MONITORING SYSTEM
Water depth:23.2 m
Water Temp:28 .6 C
Water pH:7.71
Water Turb:1.60 NTU
Water Cond:2.76 S/m
Water D-oxy:15.4 mg/l

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Figure 6: Data sent through SMS to farmer's Mobile Phone

The nodes were working properly providing some assurance of the robustness of the system. Table 2 shows the performance of the system for various parameters in six months. The system was automatically switching on/off whenever the parameters were outside preset range. The status light emitting diodes (LEDs) at the GUI were used to indicate the status of GSM communication, data transmission, relay states and terminal states. Additional functions of the system for performing sensor calibration, data saving, report generation and help options were functioning properly. It also allows manual starting and stopping the relays by pressing the relay knobs in respective positions.

Data transmission of the system was function properly. After detecting, processing and analyzing, the data was communicated to the users. The GSM module sent data through SMS messages to the user every 30minutes interval. The sent data during the operation is shown in figure 6. The system also login the data in excel format into SD card in every minute interval as shown in figure 5.

Water temperature, dissolved oxygen, turbidity, conductivity, water depth and pH were regularly monitored by this system. The smart sensor nodes are small, low cost, efficient and suitable for deployment in harsh environment. The nodes were protective watertight housing and weatherproof. Making it resistant to environmental factors like rain and heat. It was easy to move the nodes to the desired point of interest whenever needed.

The experimental results monthly variations in the water quality of the aquaculture pond were presented in Tables 2, figure 7, 8, 9 and 10. It shows that the power management and networking solutions were adopted to work in practice. This increased economic benefit for aquaculture by improving production process in quality and quantity, consumer confidence and safety. This system could prove to be helpful in the event of a failure to take rapid actions to prevent the damage that could be caused to the fish stock.

Table 2: Summary of sensor data between June, 2019 to November, 2019.

Parameters	**Jun-11**	**Jul-11**	**Aug-11**	**Sep-11**	**Oct-11**	**Nov-11**
Turbidity(NTU)	36.9	48.9	60.4	84.3	98.9	106
PH	6.7	6.9	7.1	7.25	7.88	7.9
Conductivity(S/m)	350	356	375	393	422	430

Water Temperature(^{o}C)	29.60	30. 60	31.85	32.9	34	34 9
Water Level(m)	1.5	2. 0	2.5	2.3	1.8	.0.90
Dissolved Oxygen(mg/l)	6.8	6.41	6.1	5.7	5.3	4.6

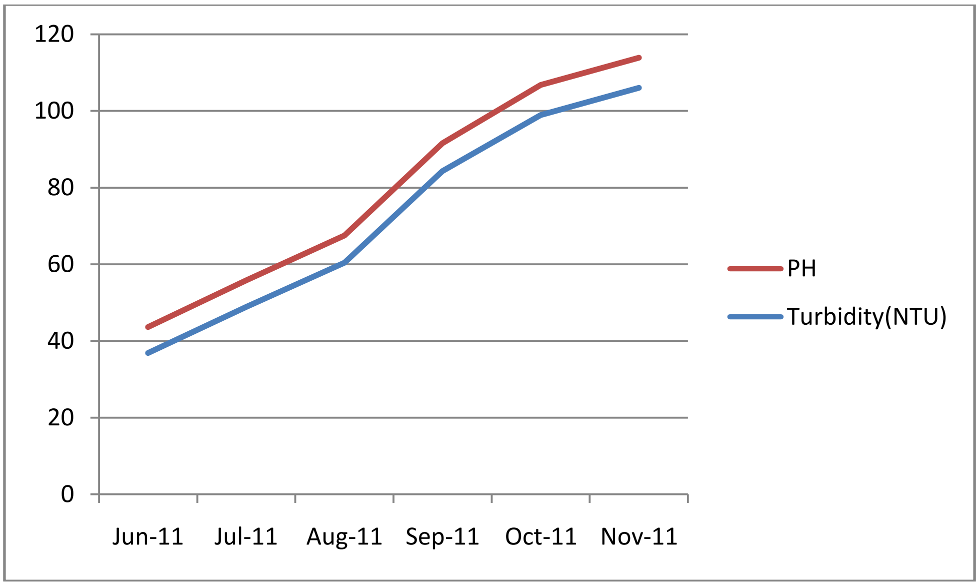

Figure 7: PH and Turbidity variation for the period of six months

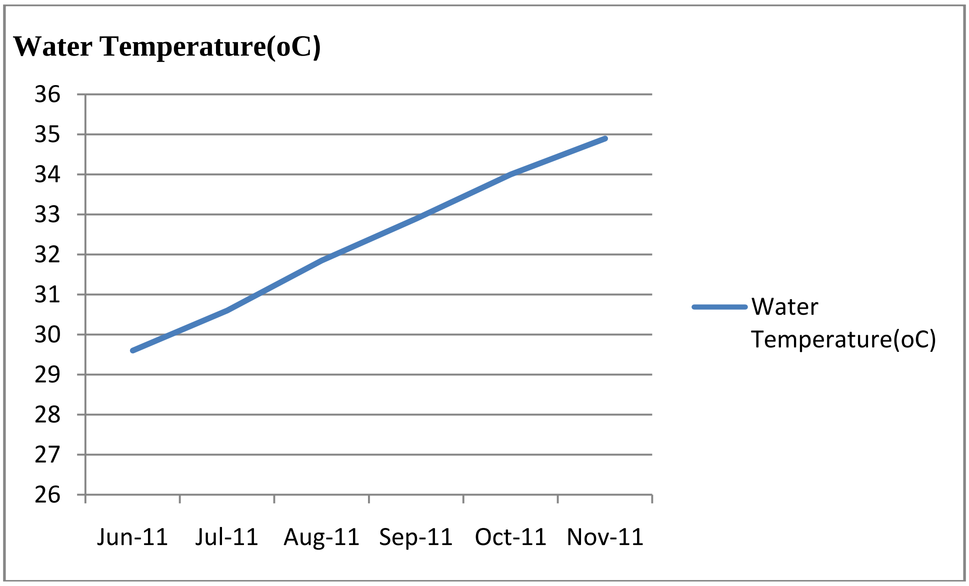

Figure 8: Temperature variation for the period of six months

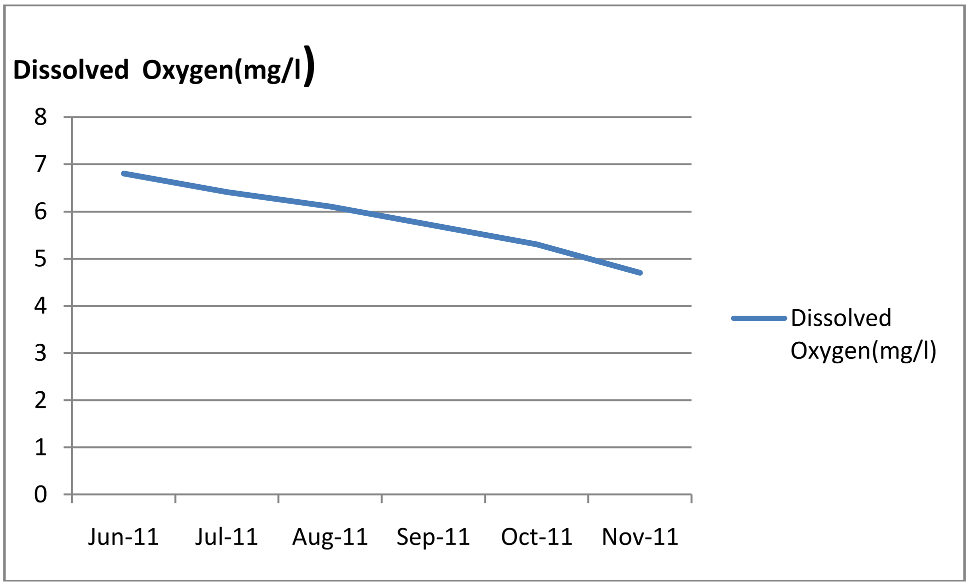

Figure 9: Dissolved oxygen variation for the period of six months

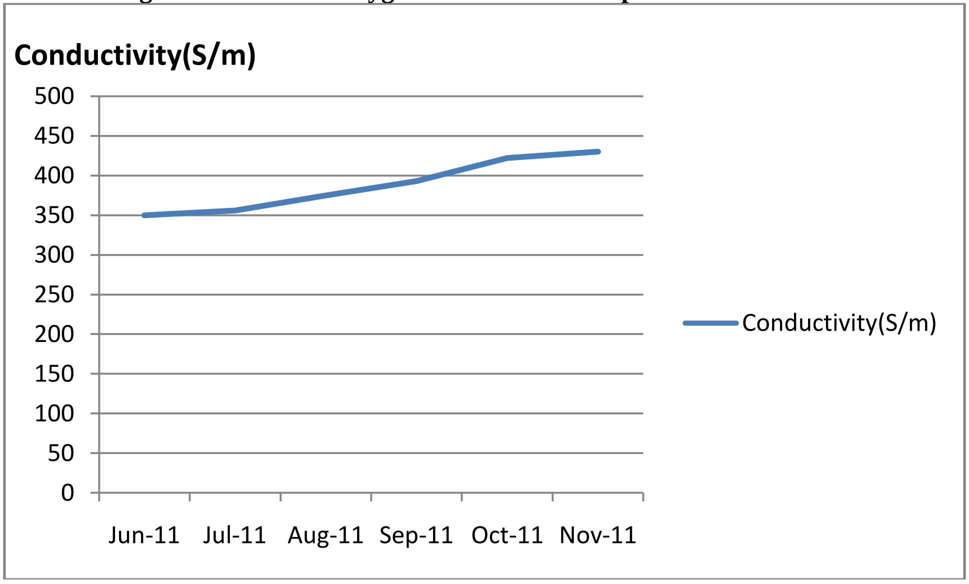

Figure 10: Conductivity variation for the period of six months

The turbidity of the pond ranged from 36.9 to 106.0 NTU (Figure 7, Table 2) with an average of 62.28 NTU. Turbidity is a measure of the ability of the water to transmit light. Inability to transmit light may be caused by suspended clay particles, dispersed plankton organisms, particulate organic matter and pigments caused by decomposition of organic matter. A value of 30 to 40 NTU is considered optimum for a good fish culture [23]. Turbidity levels as low as 5 NTU can begin to stress fish within a few hours (VWF, 2017). The turbidity values of the pond were fairly high.Concentration of dissolved oxygen in the pond ranged from the highest of 6.8 mg/l to the lowest of 4.6 mg/l (Table 2 and figure 9).

Lowest pH of 6.7 was obtained in the pond in June andhighest pH of 7.9 was recorded in November (Table 2, Figure 7). Temperature fluctuations ranged between29.60 to 34.9 °C in the pond. Figure 10 shows that the conductivity of the pond increased with the time. Lowest and highest electricalconductivity, pH andtemperature were obtained in month June and November respectively in the pond. The conductivity values of the pond gave a goodestimate of the condition of pond under thedifferent culture systems. Conductivity is an indexof the total ionic content of water

The concentrations of parameters such as turbidity, PH, conductivity and temperature increasedwith time in the pond while the concentration of dissolved oxygen decreased with the time. Highest and lowestconcentrations of dissolved oxygen were obtained in June and November respectively.

VII. CONCLUSIONS

This research work provides the development a low-cost water quality monitoring and control system for aquaculture based on wireless sensor networks and single chip microcontroller technology as a base in the actual operation. It realizes the monitoring of the water environmental parameters for intensive aquaculture and alarm notification through short message when monitored variables take anomalous values and is suitable for long-term stability under growth conditions thus increasing yield per unit area. The system monitoring temperature, conductivity, turbidity, dissolved oxygen, pH, and water level continuously and in real-time. With the use of GPRS network and mobile phones platforms, the values of the parameters to be measured were displayed in easy-to-comprehend graphical and tabular formats anytime and anywhere. Two nodes have been implemented for six months to evaluate the system feasibility. The sensor data, battery performance and network performance metrics have been analyzed and presented. Experimental results thus obtained using this system shows that the system is reliable for large scale deployments Future works should be enhancing the system remote access to the sensor nodes using internet and data transmission for further analysis

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