Wireless Sensor Network for River Water Quality Monitoring in India

K. A. Unnikrishna Menon[1], Divya P[2], Maneesha V. Ramesh[3]
Amrita Centre for Wireless Networks & Applications,
Amrita Vishwa Vidyapeetham ,
Kerala, India.
[1]kaumenon@am.amrita.edu, [2] divyap282@gmail.com , [3]maneesha@am.amrita.edu

Abstract- **Water is an important natural resource which needs constant quality monitoring for ensuring its safe use. This paper introduces a river water quality monitoring system based on wireless sensor network which helps in continuous and remote monitoring of the water quality data in India. The wireless sensor node in the system is designed for monitoring the pH of water, which is one of the main parameters that affect the quality of water. The proposed sensor node design mainly comprises of a signal conditioning module, processing module, wireless communication module and the power module. The sensed pH value will be wirelessly transmitted to the base station using Zigbee communication after the required signal conditioning and processing techniques. The circuit for the sensor node is designed, simulated and the hardware prototype is developed using the appropriate components which minimize the power requirement of the system and provides a cost effective platform for monitoring water quality.**

Keywords- Water quality monitoring; pH sensor; signal conditioning; processing module; Zigbee communication

I. INTRODUCTION

India is a country in which many of the rivers are considered to be holy, but water pollution in India has greatly affected the sanctity of these rivers. Apart from that, the pollution of the water bodies has reached such an extent which has made many of the rivers too undesirable to use. Many rivers have been deemed to be unsafe for human consumption and this leads to water scarcity. It has been estimated that water pollution is the leading worldwide cause of deaths and diseases and it accounts for the deaths of more than 14,000 people daily. Water pollution in India affects the children more severely than any other group of people. About one million children under the age of five die every year from diarrhea in India as a direct result of water related diseases. So there need to be a continuous check on the pollution of various water bodies in order to control them. All these facts demand the need for constantly monitoring the water quality of the various water bodies so that it helps in evaluating the extent of pollution control needed. Water quality monitoring also helps in characterizing and identifying the changes in water quality over time.

Traditionally, the water quality detection has been carried out manually wherein the water samples are collected and taken to the laboratories for analysis. Since these methods fail to deliver real time data, we propose a system which can sense the water quality parameter continuously and send the data real time to the monitoring station using wireless technology. This paper also presents a novel approach for the design of a pH sensor node in which the data obtained from the sensor is conditioned and amplified to the required level and fed to the processing unit for performing the necessary computations. The result from the microcontroller unit is then wirelessly transmitted using Zigbee.

The rest of the paper is as follows. Section II gives an overview of the related work. Section III gives the proposed system architecture for River Water Quality Monitoring while the design of the sensor node is detailed in section IV. Section V describes the experimentation and results. The conclusion and future work is presented in section VI.

II. RELATED WORKS

For resolving the problem of the manual analytical method adopted in water quality detection with lack of real-time time data, a novel type of Remote Water Quality Measuring and Monitoring System based on WSN is introduced in [1], where the sensor nodes in the system enter the sleep mode when it does not collect the data so as to reduce the power consumption. Another Wireless Sensor Network (WSN) platform developed by “Smart Coast” Multi Sensor System for water quality monitoring is explained in [2] which allows for the integration of the different sensors like water-temperature, phosphate, dissolved oxygen, conductivity, pH, turbidity and water level. The system uses Zigbee communication to meet the low power requirements of the deployment scenario. The Smart Coast project also developed a portable, field deployable sensor for long-term monitoring of phosphate levels in natural water which was set with a limit of detection of 0.3 mg/L.

Reference [3] details the development and testing of a multi-sensor heterogeneous real-time water monitoring system which was deployed in the River Lee Co. Cork, Ireland to monitor water quality parameters such as pH, temperature, conductivity, turbidity and dissolved oxygen. Sensor interface infrastructure (incorporating Programmable System on Chip - PSOC technology) and data telemetry systems compatible with the Zigbee data transmission system were developed which is capable of transmitting the data to the Smart Coast server, which processed the data for transmission to the web. The PSOC system accommodates the output magnitude from the sensors and processes the data in order to make it generic for the communication and processing unit of the system.

A water quality measurement system based on thick-film technology multisensory is described in [4] which is used for sensing pH, temperature, oxidation reduction potential (ORP), conductivity and turbidity. Other sensors are being developed for, organic contamination, dissolved oxygen and diversions. Here, the entire system is coated with a transparent resin, with the exception of the sensor area which must be in direct contact with the water, for serving the purpose of sensing.

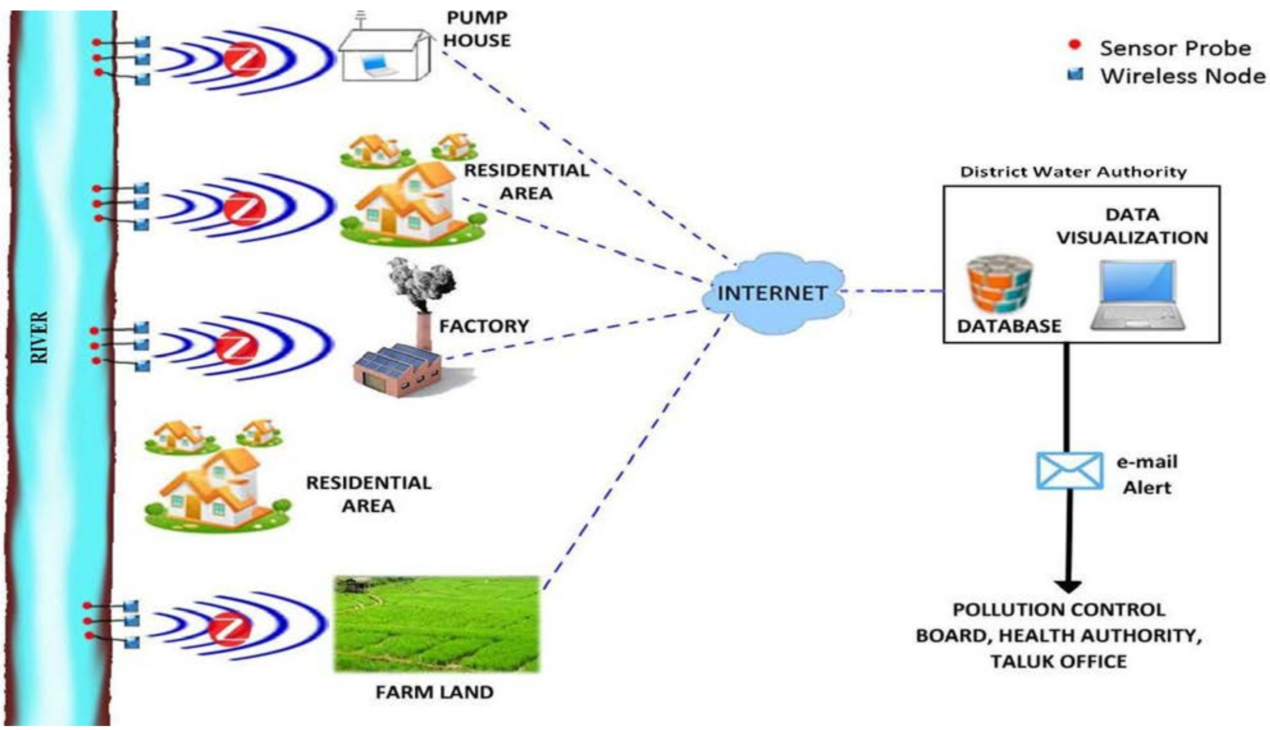

Fig. 1. Proposed Architecture of the River Water Quality Monitoring System

III. Proposed Ststem Architecture

Our network architecture shown in Fig. 1 above is designed based on hierarchical topology. The monitoring scenario is divided into four general areas viz. area near water pump house (A1), near factory/industry (A2), near agricultural/farmland (A3), and near residential areas (A4) as shown in Fig. 2. Thus each monitoring area forms a cluster comprising of several wireless sensor nodes responsible for sensing, data collection & processing and communication. Each sensor node can contain the sensors for monitoring the basic water quality parameters like pH, conductivity, temperature, dissolved oxygen and turbidity.

Deployement Strategy

In each monitoring area, a cluster of nodes will be present with the cluster heads located in the water pump house, in the industry, in the farmland and in a house in the residential area respectively for the clusters A1, A2, A3 and A4. Each cluster consists of about 15 to 20 nodes placed along the river bank. There will be around 3-6 monitoring points in each cluster which will be at a distance of approximately 10 meters from each other. The number of monitoring points can vary depending on the area under consideration. For instance, the area near the pump house needs more monitoring points compared to the farmland as the water from the pump house is taken for supplying to rural and urban areas for domestic consumption. The water properties can also vary with depth of the river as the water conditions prevailing in the lower layers near to the river bed will be different from the water conditions in the upper layers. Thus at each monitoring point, 3 sensor nodes corresponding to 3 different depths (top layer,

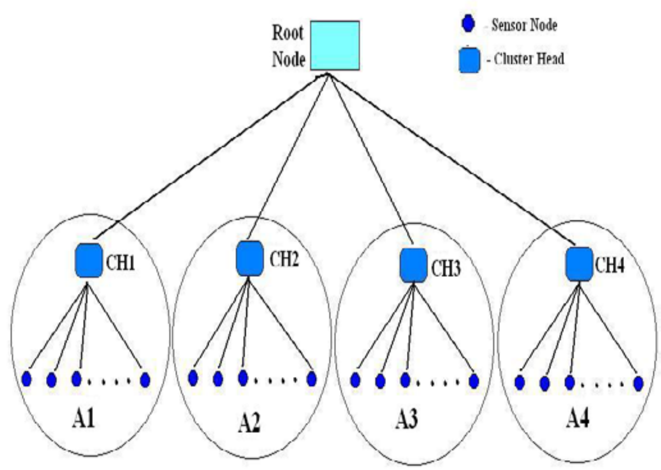

Fig. 2. Hierarchy of nodes

middle layer and lower layer) will be deployed. Also, different type of sensors can be used in each area based on the parameter monitored. For e.g., in the area near the farmland, sensors for detecting phosphates and nitrates can also be used in addition to the basic water quality sensors, as the water in that area can get polluted due to fertilizer run-off. Similarly chemical sensors can also be used in the industrial area for monitoring the chemical run-off from industries. Since the nodes are deployed in open environment, it can also be powered up by using solar cells so that the power module can also make use of the renewable energy from solar power. In case of any failure in the solar cells, a provision can be made such that the node switches onto battery power which will be provided as a backup to solar cells.

Data Monitoring & Transmission

The parameters will be sensed continuously and the data will be send real time to the cluster heads (base station) using Zigbee communication. Since the nodes are deployed in an outdoor environment, the transmission range of the Zigbee can go up to 70 meters. In case our receiving station is out of the transmission range of our Zigbee radio, we can use repeater nodes to relay the data. At the cluster head, data aggregation will be performed to remove redundant data and then it will be sent through the internet to the database for data analysis at the end of each day. The analyzed data can be visualized on a terminal at the district water authority. If the parameter value crosses the set threshold, a warning will be issued at the base station and water authority and the data will also be sent real time to the central monitoring station in case any critical situation arises. The warnings can also be given as E-mail alerts to the pollution control board, local health authorities, etc.

IV. DESIGN OF THE WIRELESS SENSOR NODE

A Wireless Sensor Network is comprised of wireless sensor nodes which are the central elements in the network consisting of the sensing module, processing module, communication module and power module. The proposed architecture of the wireless sensor node is shown below in Fig. 3.

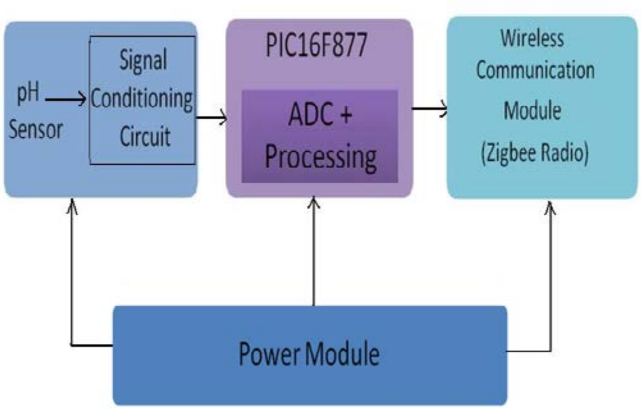

Fig. 3. Wireless Sensor Node for pH monitoring

A. *Sensing Module*

In general, the sensing module integrates one or more physical sensors which can be used for sensing a particular parameter or physical quantity. A physical sensor consists of a device called transducer, which converts one form of energy into another form of energy, typically into an electrical energy (say, voltage or current). So an appropriate sensor device for sensing the pH of water will be contained in this sensing module. The signal from the sensor, i.e. the sensor output will be in the form of either current or voltage signal and usually it will be having a very small magnitude. Hence this signal needs to be manipulated for converting it to a measurable form so that it meets the requirements of the next stage. So the sensor output is fed to a signal conditioning unit which is shown in Fig. 4. Thus our sensing module is comprised of the pH sensor and the signal conditioning circuit.

pH or 'potential of Hydrogen' is a measurement of the potential activity of hydrogen ions (H^+) in the water sample which in turn tells how acidic/ basic(alkaline) the water is. Since pH can be affected by chemicals in the water, it is an important indicator of any chemical changes occurring in water. The pH scale ranges from 0 to 14, with 7 being neutral. pH is defined as the negative logarithm of the hydrogen ion concentration and is mathematically given by the equation [6]:

$$pH = -\log [H+] \quad (1)$$

A pH probe or sensor used for measuring the pH value will produce a potential difference between its reference electrode and measurement electrode. This voltage value will be proportional to the corresponding pH at the instant of measuring. The output voltage produced by a pH sensor is stated by Nernst Equation and is given by

$$E = E_0 - k.T.pH \quad (2)$$

Here, E_0 is a constant potential, k is the Boltzmann constant and T is the temperature in ^oC. Therefore, at a temperature of 25^oC, the output will be

$$E = E_0 - 0.592.pH \quad (3)$$

The above equation, Eq. (3) gives the voltage produced per pH unit as 0.592V or 59.2mV (approx. 60mV).

1) pH Amplifier Circuit: The voltage produced by the pH sensor probe will be proportional to the pH value of water, generally about 60 mV per pH unit. So the sensor output varies from -420mV to+420mV DC as the pH scale ranges from 0 to 14. In order to convert it to a measurable range, the sensor output is amplified using TL082 op-amp. The voltage signal is amplified using a suitable gain such that output will now be in the range -2V to +2V.

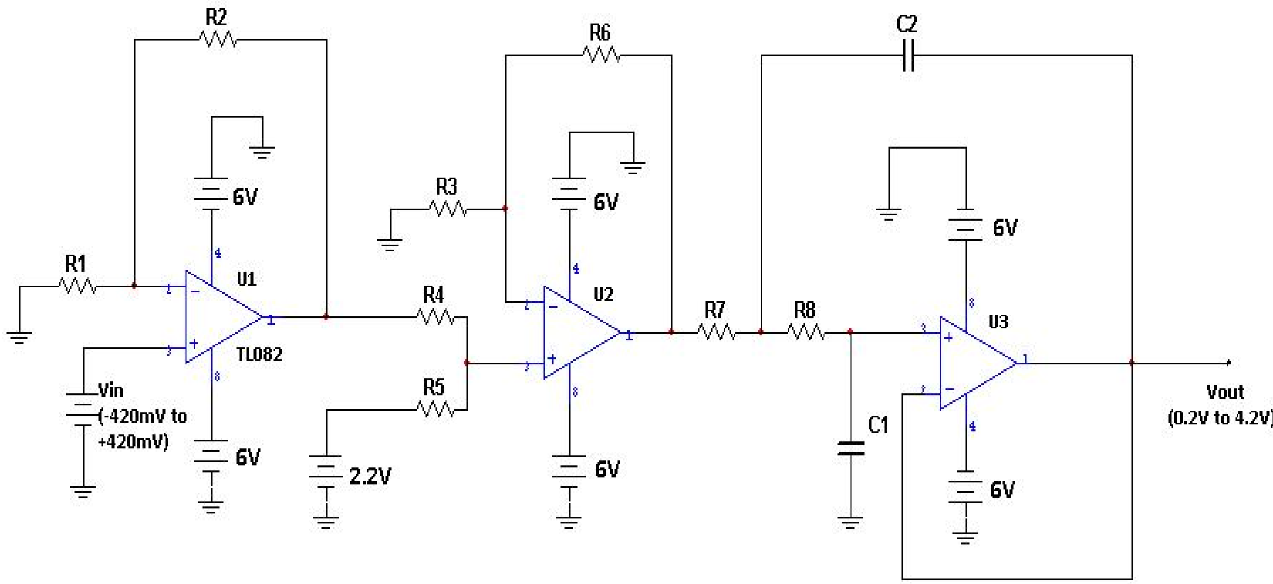

Fig. 4. Signal conditioning circuit

2) Level Shifting: In an alkaline condition, the output from the sensor can be negative. But this is unacceptable for the microcontroller, as the PIC used in this system can have positive input only. So the output from the amplifier is level shifted using an adder circuit, so that the whole output range is shifted to positive values. The offset voltage of the adder circuit was calculated to be 2.2V, since it gives a maximum output of 4.2V when added to the corresponding output (2V) from amplifier circuit. Now, the output voltage is converted to the range 0.2V to 4.2V and this is suitable for our PIC microcontroller whose input voltage is of the range 0 to 5V.

3) Filter Design: Since there is a chance that interference from other sources will get added to our input signal, it can degrade the quality of our signal and cause variations in our desired output. For the purpose of removing such interference or noise from our signal, we also adopt a suitable filter in our design. A Sallen key topology was adopted because of its simple design and unity gain. Since our signal is DC voltage, a low pass filter is used with the cut off frequency given by,

$$f_0 = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}} \tag{4}$$

B. Processing Module

The main function of this module is to process or execute the instructions relating to sensing, data transmission, etc. For the purpose of processing, the PIC microcontroller PIC16F877 is used in our system as it has low cost, compact size and low power consumption. Also it provides more programming flexibility compared to others.

Normally the output from the sensors will be an analog signal having a continuous magnitude as a function of time. So this analog signal need to be digitized for the purpose of processing and therefore, an analog-to-digital converter is required. Some sensors have integrated ADC in them; otherwise we have to incorporate an ADC module in the circuit design. In our system, since there is no integrated ADC with the pH sensor, the A/D conversion is performed by the PIC processor with a 10 bit resolution. Use of PIC16F877 for processing removes the need for an additional ADC module as this PIC has an inbuilt ADC and this in turn reduces the cost and power requirement. The 10 bit digital values from the ADC are then converted to the corresponding pH after the necessary computations. The pH value is now serially sent using the UART interface RS232 to the communication module for transmission.

C. Communication Module

The wireless transmission of the data from the sensor node to the cluster head is implemented using Zigbee technology as it is low cost, less power consuming and have long battery life. Our system adopts the MICAz mote produced by Crossbow Technology which has a ZigBee compliant RF transceiver. It uses a Chipcon CC2420 Radio Transceiver module that follows the IEEE 802.15.4 standard. It operates in the 2.4GHz ISM band offering a data rate of 250kbps using Direct Sequence Spread Spectrum (DSSS).

The data received in the MicaZ mote from the microcontroller unit is transmitted wirelessly to the mote at the base station using Zigbee communication technique. The pH value thus obtained is then processed by the receiving mote to determine the condition of water, i.e. whether it is acidic or basic and the result is outputted on the hyper terminal to be visualized on a PC.

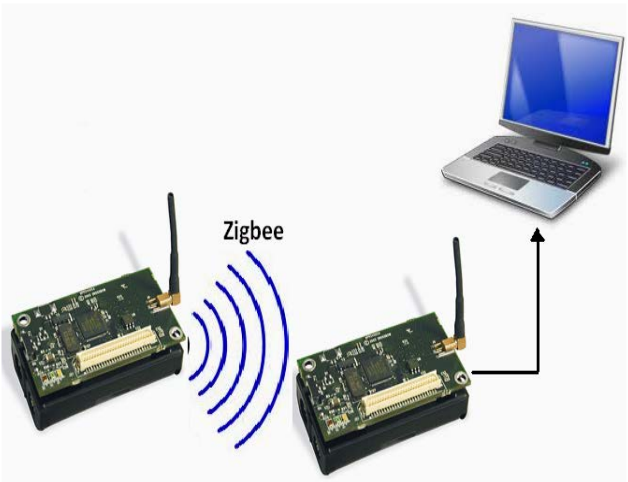

Fig. 5. Wireless transmission of data using MicaZ mote

V. Experimentation and Results

The simulation of the circuit for the pH monitoring node was performed using Proteus6.9 Simulator. Here, the DC voltage corresponding to the pH value is generated and given as the input to the signal conditioning circuit. The input voltage range for the circuit is from -420mV to +420mV. After amplification, level shifting and filtering, the resulting output voltage is fed into the PIC processor. The microcontroller was programmed using PIC C complier. The output from the PIC is then displayed using a virtual terminal/ LCD as shown in Fig. 6.

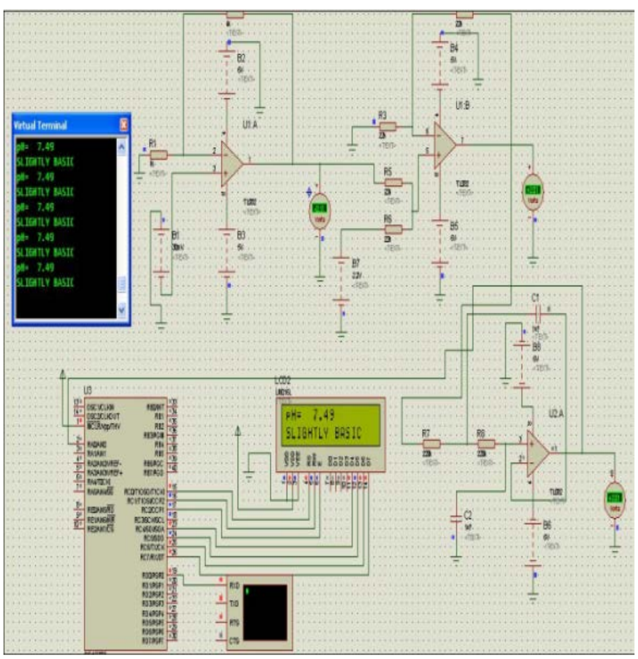

Fig. 6. Simulation of the circuit in Proteus Simulator

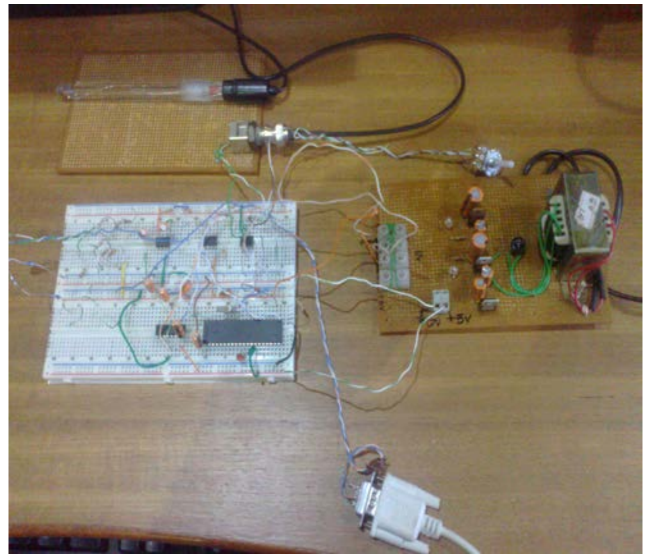

Fig. 7. Hardware implementation of the pH monitoring node

The hardware setup of the pH monitoring node was developed as shown in Fig. 7. It was tested for different conditions of pH like drinking water, rain water and lemon juice. The data in each case was simultaneously sent to the receiving mote where it was processed for evaluating the pH condition of the tested samples. The resulting information which includes the pH value along with the acidic or basic condition of the sample was displayed on the hyper terminal for each of the different cases as shown in Fig. 8, Fig. 9 and Fig. 10.

Fig. 8. pH value for drinking water displayed on hyper terminal

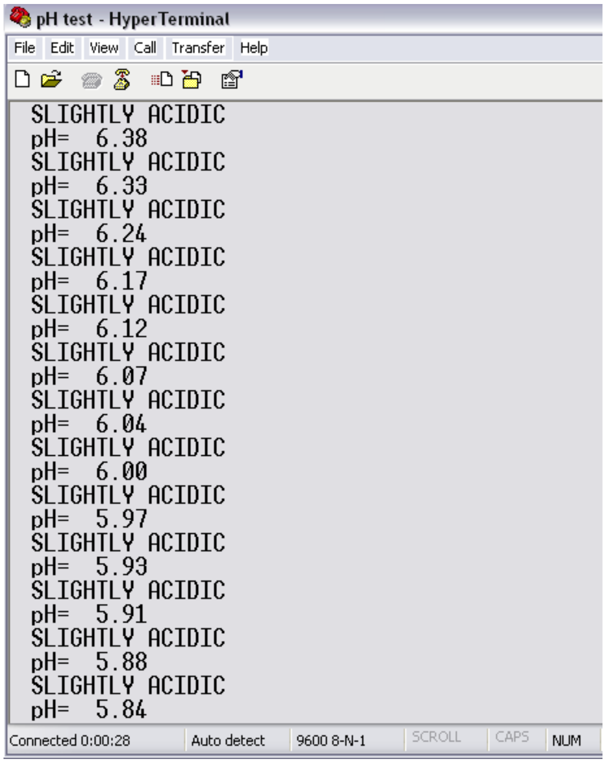

Fig. 9. pH value for rain water displayed on hyper terminal

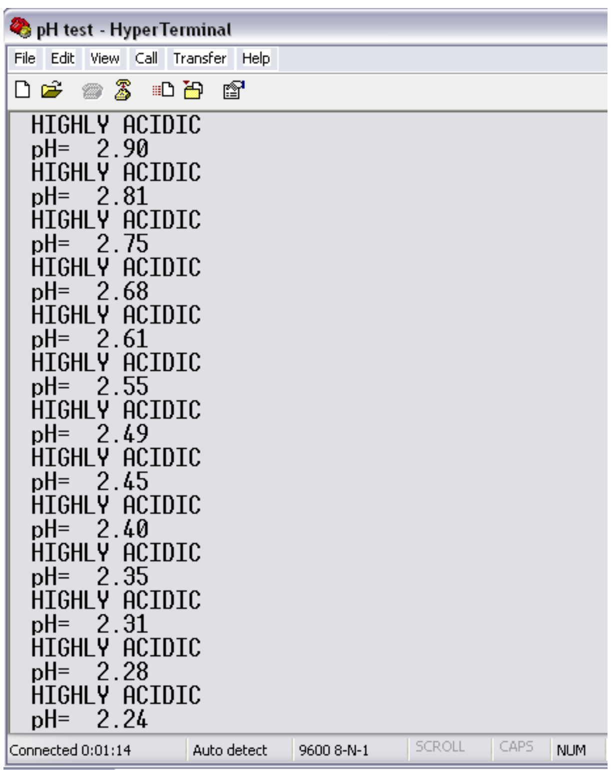

Fig. 10. pH value for lemon juice displayed on hyper terminal

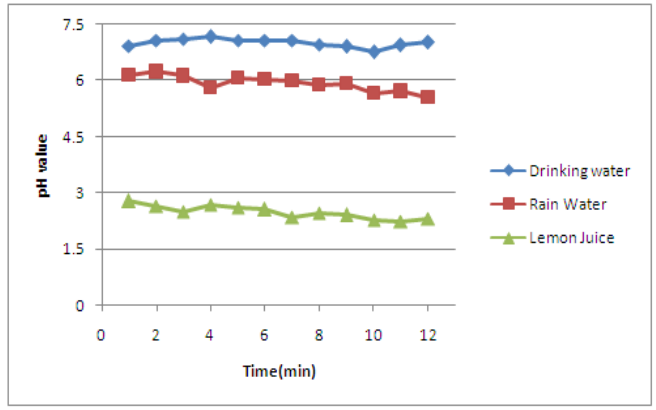

Fig. 11. Plot of pH values for Drinking water, rain water and lemon juice

From the experimental results, the pH value for drinking water was obtained in the range 6.7-7.2 which was found to be within the range prescribed by the Indian Standards Institution i.e. 6.5-8.5. The monitored values for rain water and lemon juice were found to be in the range 5.6-6.4 and 2.2-2.9 respectively. The measured pH value for each of these different sources was found in agreement with the expected values for the same. A comparison of those different pH conditions was obtained from the plot shown in Fig. 11.

VI. Conclusion and Future Work

In this paper, we present the system architecture for a Wireless sensor Network which aids in River Water Quality Monitoring. This paper also proposes a novel technique for the design of a water quality sensor node which can be used for monitoring the pH of water. The proposed design of the sensor node consists of the pH amplifier circuit, the level shifting circuit, filter design using Sallen key topology, the processing unit which is implemented using PIC microcontroller and the wireless communication module consisting of Zigbee radio. The circuit for the sensor node is designed, simulated and the hardware prototype is developed which was tested for different pH conditions with the wireless transmission of that data achieved through the use of MicaZ motes. This system provides an energy efficient and low cost sensor node platform for monitoring water quality through the use of inexpensive, low power devices for the hardware design.

When this pH sensor unit is integrated with other basic water quality sensors such as temperature, conductivity, dissolved oxygen and turbidity, etc, it can be used for monitoring the water pollution in an area as well. The next phase of this project includes integration of water conductivity, dissolved oxygen and temperature sensors with the pH sensing module. Methods to improve and optimize the system performance and reliability of the current system will also be taken up as the future work.

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