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# Development of an Autonomous Remote Access Water Quality Monitoring System

**MD. Reza Ranjbar*[1], Aisha H. Abdalla[2]**
Department of Electrical and Computer Engineering, Faculty of Engineering, International Islamic University Malaysia (IIUM), Jalan Gombak, 53100 Kuala Lumpur, Malaysia
*Corresponding author, e-mail: aisha@iium.edu.my[1], eeemreza@gmail.com[2]

***Abstract***

*Due to the vast increase in global industrial output, rural to urban drift and the over-utilization of land and sea resources, the quality of water available to people has deteriorated greatly. Before the sensor based approach to water quality monitoring, water quality was tested by collecting the samples of water and experimentally analyzing it in the laboratories. However, in today, with time being a scarce resource, the traditional method of water quality testing is not efficient anymore. To tackle this issue, several electronic (microcontroller and sensor based) water quality monitoring systems were developed in the past decade. However, an in depth study of this current water quality testing technology shows that there are some limitations that should be taken into consideration. Therefore, an automatic, remote, and low cost water quality monitoring system has been developed. This system consists of a core microcontroller, multiple sensors, GSM module, LCD display screen, and an alarm subsystem. The quality of water is read from the physical world through the water quality testing sensors and sent to the microcontroller. The data is then analyzed by the microcontroller and the result is displayed on the LCD screen on the device. At the same time, another copy of the sensor readings is sent remotely to the user's mobile phone in the form of SMS. If an abnormal water quality parameter is detected by any sensor, the alarm system will turn on the respective red LED for that parameter and the buzzer will give warning sound. At the same time, the abnormality of the water parameter is reported to the user through SMS. The system is aimed to be used for wide applications and by all categories of users. It can facilitate the process of water quality monitoring autonomously and with low cost; to help people improve their quality of drinking water, household water supplies and aquaculture farms, especially in rural areas where residents do not have access to standardized water supply and suffer from different diseases caused by contaminated water.*

***Keywords***: *Water quality, remote access, sensor network, GSM, alarm system*



## 1. Introduction

Along with industrialization, environmental pollution has largely been affecting the ecological balance in our planet. Water pollution is a serious type of environmental pollution. Our lives depend on the quality of water that we consume in different ways, from juices which are produced by the industries and we consume, to the water supply in our houses. Any imbalance in the quality of water would severely affect the humans' health and, at the same time, it would affect the ecological balance among all species. Water quality refers to the chemical, physical and biological parameters of the water. The essential parameters of the water quality to be monitored can vary based on the application of water. For instance, in aquariums it is necessary to maintain the temperature, pH level, dissolved oxygen level, turbidity, and the level of the water in a certain normal range in order to ensure the safety of the fish inside the aquarium. However For the industrial and household applications, depending on the usage of the water, some parameters of water are more essential to be monitored frequently than the others [1], [2].

To ensure the safety of water quality, it should be monitored in real time. To make the process of testing the real-time quality of water simple and easy for everyone, a low cost remote access, and portable water quality monitoring system is developed. A user-friendly system which frequently tests the quality of water and sends notification and provides alarm to the user in case of any abnormality in quality of water. The main objective of this paper is to enhance the microcontroller based water quality testing method. The specific objectives are to study current water quality testing methods, analyze and evaluate the strengths and limitations of current

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methods, propose an enhanced design, and build and evaluate the proposed design. Scope of this paper includes deployment of communication technology, communication between man and machine using information transmission module and microcontroller. This work also allows a first-hand experience in application of how the different sensors work and how they can be deployed to achieve a certain objective. The design also includes a big deal of coding, it provides utilizing programming language along with a hardware system. It is important to highlight that this design is to measure the water parameters which are of concern in water pollution and does not provide a measurement of the water parameters which are rarely used by average users, such are water conductivity. Moreover, the main users of this system are assumed to be households, and aquaculture farmers-especially in rural areas.

In recent years, researchers have developed a variety of water quality monitoring technologies to contribute for different applications. In this work, different categories of water quality monitoring systems are identified, illustrated and analyzed for better understanding of the existing approaches. This paper firstly represents a detailed discussion on the strength and limitations of the existing water quality monitoring methods.

Some publications proposed systems consist of several sensors which are able to measure some essential parameters of the water such as temperature, pH level, conductivity, turbidity and dissolved oxygen, and the data is viewed on the internet using cloud computing. In one approach, Raspberry PI is used as core controller; its disadvantage is that it is run on LINUX kernel using keyboard and monitor. It requires the users to input a command every time they want to know the sensors reading, or the sensors' value must be read only at a set time interval [3]. In another approach, the system consists of complex wiring and requires a computer or an extra Beagle board-XM ARM processor for communication interface and operation [4]. Some methods of development of remote access water quality monitoring system are difficult to istall and uneasy to use for users. It is due to using a separate receiver section with a PC server and UART in addition to the transmitter section which contains the microcontroller, sensors, and the Ethernet shield [5].

Gurkan Tuna et al. conducted a research on water quality monitoring in drinking water reservoirs, dams and holding ponds in Turkey. They basically worked on two systems in their research which are boats to visit different points and a portable water quality monitoring system based on wireless sensor network to detect the quality of water from different points and then send it through a wireless or wired link to the utility control centre. This system is a very good solution for monitoring the quality of water in big reservoirs, dams, and holding ponds. However, it does not span a lot of other ranges of applications which the average users require [6]. A similar research was performed on monitoring the quality of water in Fiji Islands. The system could store the data on board using SD card, or send to an FTP (File Transfer Protocol) or a cloud server. This method was proposed specifically for monitoring the quality of water in Fiji Islands which has the same limitation as the former [7]. In addition, Barabde et al [8] developed a similar sensor based water quality monitoring system which is consist of data monitoring nodes, a base station and a remote station. A wireless communication link connects all these stations. The water parameters (pH, turbidity, and conductivity) are collected in the base station and sent to the remote monitoring station. The data is then displayed in visual format on a PC server using MATLAB and compared with the standard values. The undesired values of the water parameter are then automatically reported to the respective agent through SMS. this system is not compact due to several stations. Moreover, it costs high, and it uses a server PC and MATLAB to analyse the data readings of the sensors which makes it uneasy to use for common users.

In this paper, firstly the water qulity monitoring technology was reviewed and discussed in section 1. Secondly, in section 2, the proposed design is introduced and its features are elaborated. After that the design consideration, which describes the working principles of water quality detection sensors, is illustrated in section, 3 and the results and discussion is represented in section 4. Finally, the paper is ended by conclusion and the future expected work on this topic.

**2. Methodology**

In this system, a microcontroller is used together with a sensor network. Once the code is uploaded to the microcontroller, no PC system, keyboard command or monitor is required to operate the system. The system will function automatically and independently according to the code uploaded to the microcontroller. The programming to be used in this system will be C language. In this system, four sensors will be used to measure the essential water parameters. As it was studied from the previous researches, the most essential water parameters needed to be monitored by the average users are water pH level, water turbidity (cloudiness), water temperature, and the water level which is a measurement of the amount of the water in a container. Therefore, four essential water parameters which are temperature, pH level, turbidity, and water level could be measured by this device. Signal conditioning circuits are connected to the microcontroller and the probes of the turbidity, pH and temperature sensors dipped inside the water. All sensors read the water quality parameters and send the data to the microcontroller in the form of electrical signals.

The microcontroller is programmed to analyse the result and compare it with the standard ranges which will also be predetermined in the code. If any water parameter crosses the standard limit, the alarm system will turn on and the message is shown on the device's screen and sent to the user's mobile as will. The alarm system will be designed such that for every water parameter, there are one red LED (Light Emitting Diode). In case of any abnormality in a water parameter detected by the microcontroller, the respective red LED turns on to indicate that the water is not proper for use. Besides the LED indicator, there is a buzzer which creates alarm sound and informs the user about the abnormalities in the water supply system. To show the sensor readings (water parameters) on the device itself, an LCD (Liquid Crystal Display) screen is used. The LCD screen is connected to the microcontroller, and through the wired connection, sensor readings from the microcontroller is received and displayed accordingly. If the water quality is not within the desired range, the LCD screen will display a message which indicates the quality of water being out of the desired range i.e. "Water temperature is high" and it displays the value of the readings as well.

In order to communicate with the users, who monitor the quality of water from a far distance, a GSM (Global System for Mobile Communications) module is used. The GSM module is connected to the microcontroller and programmed so that it will receive a copy of the analysed data from the microcontroller and send it in the form of SMS (short message service) to the user's mobile. The message sent to the user's mobile includes all the data readings of the sensors as well as the condition of the water quality compared to the standard ranges. Two mobile numbers could be registered in the system in order to avoid the problems caused by any interruption in the mobile service provider networks. A flow chart of the proposed system is shown in Figure 1.

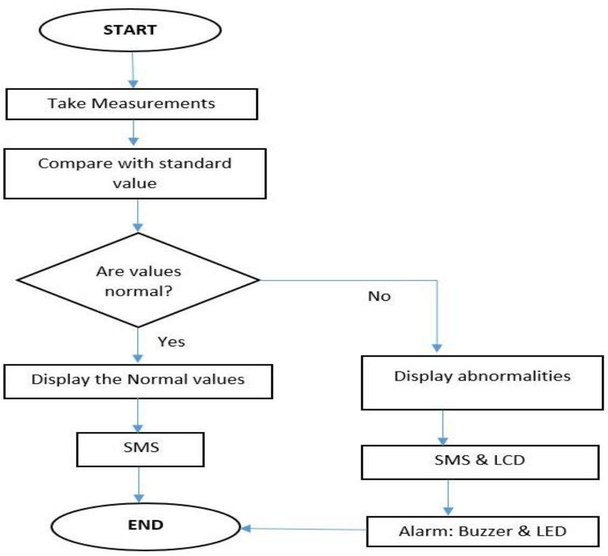


Figure 1. WQM process flow

## 3. Design Consideration
### 3.1 Temperature Sensor

Temperature is a physical parameter that describes the average kinetic energy of molecules, it is not a measure of energy itself, but it is proportional to the average kinetic energy of molecules. That means that the hotter molecules are, the more they move and the higher is the temperature. By contrast, when molecules do not move at all, i.e., their kinetic energy is zero, so the temperature is 0ºK (absolute zero, -273.15ºC).Temperature is measured by an instrument called thermometer, but it is impossible to measure the kinetic state of molecules directly. Instead, thermometers measure parameters that vary proportionally with the kinetic state of molecules, the thermometric variables; thus, there are many different ways to measure temperature depending on the thermometric variable. The most commonly used temperature sensors in oceanography are the Resistance Temperature Detectors (RTDs), Thermistors and thermocouples.[9].The principle behind RTD sensor is that pure metals change their resistivity with a change in temperature in a predictable way. RTDs are constructed with metals whose resistivity increases linearly with temperature. Metals used should have a high boiling point, be easily available in its pure form, have a good chemical stability (be resistant to corrosion) and have electrical properties that are highly reproducible. The most commonly used metal is platinum but copper and nickel are also used.Calibration is required to verify the performance of the sensor and to ensure that the sensor performs well over time. RTDs and thermistors are calibrated by producing Temperature against Resistance graphs and then comparing them with international standards [10]. The voltage reading is converted to temperature by the sensor (thermocouple) as follows.

$$\frac{V_m - V_l}{V_h - V_l} = \frac{T_m - T_l}{T_h - T_l}$$

$$T_m = T_l + \left[\frac{V_m - V_l}{V_h - V_l}\right](T_h - T_l)$$

### 3.2 Turbidity Sensor

Determination of Turbidity by Nephelometry is the United States (EPA) Environmental Protection Agency's standard [11] for turbidity meter design. This standardized criteria ensures both accuracy and comparability between compliant meters. Instruments in compliance with the EPA Method use Nephelometric Turbidity Units (NTU). Nephelometric technology is used in this method, which measures light scatter at at 90-degree angle from the initial light direction. The photodetector must be centered at that angle, and cannot extend more than 30 degrees from that center point. To minimize differences in the measurements of light scatter, the method states that the incident and scattered light cannot travel more than 10 cm from the light source to the photodetector. Additional photodetectors are permitted under this method, provided that the 90-degree angle is the primary detector.

EPA Method [11] also needs that the light source used in each turbidity meter to be a tungsten lamp with a color temperature between 2000 K and 3000 K. Meaning that the tungsten output is consist of many different colors, or broadband in spectrum. When the light reaches the photodetector, the spectral peak response should be between 400-600 nm. A broadband spectrum also allows the meter to be sensitive to smaller particles. This sensitivity means a tungsten lamp source will provide a more accurate response than a monochromatic light source when measuring a sample with very fine particles.

### 3.3 pH Sensor

Water pH is a representation of hydrogen ion activity in water. It is the negative logarithm of the amount of hydrogen ions (in moles) per liter of water. For instance, 10-11 moles of hydrogen ions in 1 liter of water= 11 pH.

pH=-log10[H+]

Where [H+] is the concentration of hydrogen ions in mol L-1 (mol/L or M)

[H+] = 10-pH

As the pH increases, the concentration of hydrogen ions in the solution decreases. As the pH decreases, the concentration of hydrogen ions in the solution increases.

The voltage on the outer glass surface changes proportional to changes in [H+]. The pH meter detects the change in potential and determines [H+] of the unknown by the Nernst equation [12].

$$E = E_r + \frac{2.303RT}{nF} \log \left(\frac{\text{unknown } [H^+]}{\text{internal } [H^+]}\right)$$

Where:
E = total potential difference (measured in mV)
Er = reference potential
R = gas constant
T = temperature in Kelvin
n = number of electrons
F = Faraday's constant
[H+] = hydrogen ion concentration
Since: $\frac{2.303RT}{nF}$ is a constant, we can simplify the equation.
At room temperature: $\frac{2.303RT}{nF}$ = 0.0591
Hence:

$$E = E_r + 0.0591\log\left(\frac{\text{unknown } [H^+]}{\text{internal } [H^+]}\right)$$

By definition of pH: pH = -log [H+]

$$E = E_r + 0.0591\log\left(pH_{unknown} - pH_{internal}\right)$$

$$E = \acute{E}_r + 0.0591pH_{unknown}$$

Or,

$$pH_{unkown} = \frac{E - \acute{E}_r}{0.0591}$$

The equation assumes ideal response from the glass electrode; 0.0591 value was calculated for 25°C temperature. In most cases, electrode does not behave ideally and the temperature is not exactly 25°C; therefore, slope of the electrode response is not 0.0591. To overcome these problems electrode should be calibrated before each use or series of uses [12, 13]. The basic pH scale extends from 0 (strong acid) to 7 (neutral, pure water) to 14 (strong alkali).Water pH can be measured by taking the reading of the voltage produced between two electrodes dipped in the water solution. One electrode, made of a special glass, is called the measurement electrode. It generates a small voltage proportional to pH. The other electrode (called the reference electrode) uses a porous junction between the measured water and a stable, neutral pH buffer solution (usually potassium chloride) to create a zero-voltage electrical connection to the water. This provides a continuity point for a complete circuit so that the produced voltage across the thickness of the glass in the measurement electrode can be determined by an external voltmeter. An extremely high resistance in the measurement electrode's glass membrane mandates the use of a voltmeter with extremely high internal resistance to measure the voltage. Therefore, this output voltage is proportional to pH level of water and it enables us to determine the pH of water [14].

### 3.4 Ultrasonic Sensor

For transmitting the ultrasonic waves, ultrasonic sensors use a vibrating device known as a transducer to emit ultrasonic pulses that travel in a beam which looks like a cone. The range of an ultrasonic sensor is determined by the transducer’s frequency of vibration. As the frequency rises, the sound waves spread for increasingly shorter distances. On the other hand, as the frequency drops, the sound waves transmit for progressively longer distances. Therefore, long-range ultrasonic sensors work finest at lower frequencies, and short-range ultrasonic sensors work optimum at higher frequencies. When positioned in front of materials that readily reflect ultrasonic waves, such as metal, plastic, glass, and water, ultrasonic sensors work best. This allows the sensor to provide an accurate reading at a larger distance from the object in front of it. However, when the sensor is placed in front of an object that readily absorbs ultrasonic waves, such as fiber material, the sensor must move closer to the object to give an accurate reading. The angle of the object as well has an impact on the accuracy of the reading; a flat surface at a right angle to the sensor offers the longest sensing range. This accuracy declines with a change in the angle of an object relative to the sensor [15].

Ultrasonic sensor can provide a reading of distance of water surface from a fixed position. That is done by sending the waves to the surface of water and receiving the reflection back. The distance is calculated from the return time and speed of the wave. Electromagnetic waves transmitted by the ultrasonic sensor are assumed to travel at speed of light in free space.

Hence: $$d = \frac{c}{2t}$$

Therefore, as distance is found, the level of water is calculated from the size of container and the distance.

## 4. Results and Discussion

The system was tested under different conditions and with different qualities of water. The results of the system have been compared with standard instruments in Biotech Environmental Laboratory to ensure the accuracy and precision of the system. The output of the system was successful and in accordance with the research objectives. Every water parameter was tested with different water solutions several times and the results are represented in graphical forms for analysis. Figures 2a-2d show the results of the developed water quality monitoring system.

This approach offers an integration of multiple sensors together with remote access of the data in real time and with low cost. This work also contributes in reducing the size of sensor based water quality monitoring system, making it compact and portable to be installed for various applications. This paper introduces an easy to use and user-friendly system for water quality monitoring which will work without using any keyboard commands or human operator. As this work was carried out using low cost components to achieve the objectives, the system output accuracy is average and can be further improved by improvement of the components.

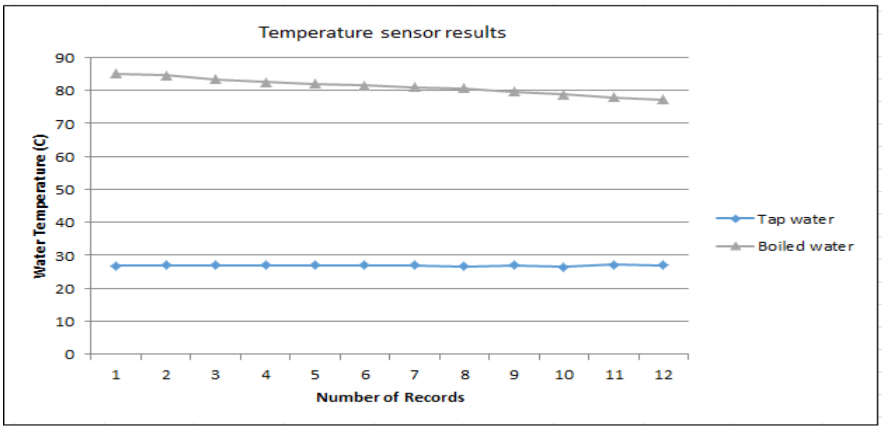


Figure 2a. Water Temperature

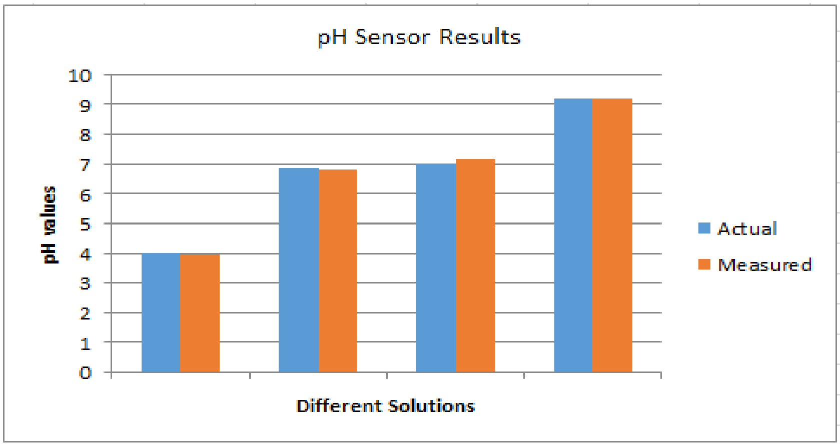


Figure 2b. Water pH

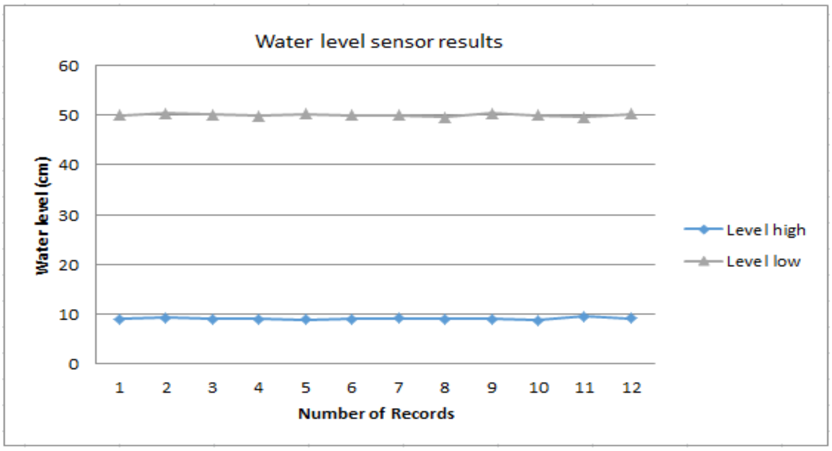


Figure 2c. Water turbidity

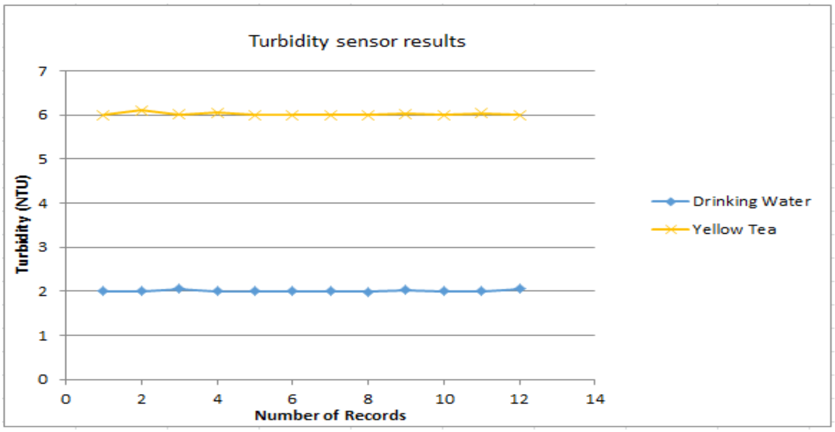


Figure 2d. Water level in the container

## 5. Conclusion and Future Work

In this paper, the development of a remote, automatic, and real time water quality monitoring system has been presented. In this system, low cost components i.e. microcontroller, GSM, LCD screen and other non-main components are used to achieve the objectives of the proposed design with acceptable accuracy. Compared to the previous proposed approaches, the cost of this device prototype is remarkably low. The developed system was tested under different conditions, with solutions of water with different impurities, and in different periods of time. The results of the test for all times have been successful. The system was tested with standard sample solutions of water and the results were compared with standard instruments from Biotech Laboratory. It is concluded that the objectives of this paper have been achieved.

To test more parameters of the water quality for specific applications, other sensors can be included in the system. The system is best used when synchronized with a water quality control system; in fact, a water quality control system can be developed in parallel with this design. That could be applied to i.e. open and close a water supply valve or mix a particular liquid or gas based on a predetermined condition (sensor reading) as necessary. Furthermore, the accuracy and precision can be further improved by using better quality sensors or modifying the applied units. The system has wide application and it is usable and affordable by all categories of users.

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