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Real Time Assessment of Potable Water Quality in Distribution Network based on Low Cost Multi-Sensor Array

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Abstract. New concepts and techniques are replacing traditional methods of water quality parameters measurement systems. This paper proposed a new way of potable water quality assessment in distribution network using Multi Sensor Array (MSA). Extensive research suggests that following parameters i.e. pH, Dissolved Oxygen (D.O.), Conductivity, Oxygen Reduction Potential (ORP), Temperature and Salinity are most suitable to detect overall quality of potable water. Commonly MSA is not an integrated sensor array on some substrate, but rather comprises a set of individual sensors measuring simultaneously different water parameters all together. Based on research, a MSA has been developed followed by signal conditioning unit and finally, an algorithm for easy user interfacing. A dedicated part of this paper also discusses the platform design and significant results. The Objective of this proposed research is to provide simple, efficient, cost effective and socially acceptable means to detect and analyse water bodies regularly and automatically.

1. Introduction

Water quality detection is paramount requirement before consumption by all human activities ranging from potable purpose to industrial and agriculture process. Water quality can be easily monitored in treatment plants and pumping stations. Many parameters, such as pH, turbidity, total organic carbon, chlorine, conductivity and others are measured continuously to monitor the effectiveness of the treatment process. However, once the treated water enters the distribution network, detailed water quality monitoring and analysis takes lots of time and money because sampling becomes a difficult task. Therefore, two dimensional approach has been followed in this paper. Firstly, it discusses the requirements of integrated multi sensor array in water distribution network. Secondly, it presents the design and development steps of low cost autonomous Integrated Multi sensor array that can be used by companies and consumers. Proposed MSA will detect whole spectrum of water quality parameters in the distribution network. Statistics show that 20-60% of water contamination incidents are related to events in the water distribution network, for example sewage leakage, contaminated soil etc. Additionally, it is widely accepted that distribution systems are quite vulnerable to contaminations. Generally, water sensor is an electronic device that is designed to detect the presence of contamination and provide an alert in time [1]. Hall et. al demonstrated changes in water-quality parameters by measuring variations in important parameters using real-time sensors instead of targeting contamination. Empirical evidences suggested that water quality parameters, such as pH, conductivity, free chlorine and dissolved oxygen are sensitive indicators of nicotine, arsenic trioxide, and Escherichia coli [2]. Therefore, instead of direct detection of contaminants, monitoring these parameters are more feasible. Several experimental studies [3], [4] indicate the need for continuous on-line water quality monitoring with efficient data transmission. The conventional water quality methods fail to satisfy this requirement due to higher labor and operating cost. The Multi Sensor Probes shall continuously measure the water quality parameters and thereafter integrated with Arduino MEGA 2560 (a microcontroller) followed by algorithm for easy user interfacing.

Research on water quality monitoring has started in the international arena with the advent of glass electrodes in the early 1930s. However, research was based on detection of single water quality parameter, that cannot effectively judge the overall quality of water. Therefore, it was proposed to detect multiple parameters simultaneously in the last decade of the 20th century. Further research to integrate all the different parameter detection techniques in a single system is difficult due to the varying nature of water parameters. Some researchers proposed the technique for integration of six different parameters, i.e. pH, dissolved oxygen, temperature, conductivity, and water level in a single system. This approach is highly sensitive, offers broad contamination coverage with low cost [5]. However, due to a wide variety of other different water parameters, integration of the above mentioned techniques does not provide an overall solution for water quality parameters detection. O'Flyrm et al. [6] designed a multi- sensor using ZigBee standards for communication and the system accommodated six Plug-and-Play sensors that measure temperature, pH, phosphate, dissolved oxygen, con-ductility, turbidity and water levels based on Tyndall mote. Atkinson et al. (2006) developed a sensor system (YSI Sonde) to simultaneously measure conductivity, salinity, temp, depth, pH, dissolved oxygen, turbidity, chlorophyll and blue-green algae [7]. Dinh et al. used WSN for measuring salinity and underground water level. They used Fleck platform (uses Atmel processors) for sensor node deployment [8]. Chow et al. (2008) proposed Multiple parameter measurement system, applicable for wastewater and potable water that can monitor water quality online, but despite of this, color measurement of this device was not highly sensitive [9]. Real-time Monitoring of the Water Distribution System project in Singapore proposed an end-to-end integrated hardware and software system for monitoring, analysing, and modelling urban water distribution systems in real-time in collaboration with the water utility of Singapore (Public Utilities Board - PUB) [10]. Nasirudin et al. used PICl6F886 as sensor node and GSM modems for contamination detection and updating the central database respectively. Measurements included temperature, pH, turbidity and DO [11]. Similarly, Van den Broeke et al. (2005) proposed UV scanning with a single probe that can be used to measure multiple parameters, including BOD, TOC, UV-254, NO_3, NO_2, Ozone, H2S, TSS, and turbidity [12]. Earlier attempted methods are expensive and not very user friendly. Therefore, based on earlier research we target to develop low cost user friendly mechanism that can effectively detect over all water quality in distribution network.

2. Multi Sensor Array (MSA)

Water quality parameters monitoring requires on-site measurement of a wide range of different chemical and microbial compounds simultaneously. Water may contain broad, varied spectrum of inorganic as well as organic compounds, therefore the measuring equipment has to be robust, sensitive and be able to detect small changes with broad selectivity. Individual sensor can detect single parameter, but cannot detect the overall quality of water; therefore, the concept of Multi Sensor Array (MSA) arises to detect different water parameters all together [13]. The response of MSA is provided by an array of sensors detecting various parameters of water. The output data are treated subsequently with analysis techniques. Commonly MSA is not an integrated sensor array on some substrate, but rather comprises a set of individual sensors measuring simultaneously different water parameters all together [14]. MSA offers following advantages:

- Ensures timely response in the event of a crisis and enhances emergency planning.
- Lower cost, lower power consumption, and lower maintenance with higher reliability and robustness.
- This technique can provide accurate contamination detection and identification.
- MSA can be fully customised according to user requirements because contaminants of interest may vary depending on the location of source.
- Allows easy tracing of a potential waterborne disease
- Facilitates the integration with real time monitoring to support remote sensing.

Signals coming from MSA are treated using microcontrollers and pattern recognition techniques such as the principal component analysis (PCA), the K-nearest neighbour (KNN) and most popular in recent years, the artificial neural networks (ANN) [15]. In the context of this study, MSA will be associated with a microcontroller Arduino Mega 2560. The main challenge of this study is to integrate different water sensors together and develop reliable and low-cost sensing systems for accurate and continuous water quality monitoring. The system intended to be used as a part of a low cost water sensor network to provide water quality information to consumers, water companies and authorities. The data provided by such system can support complex decisions concerning the quality of potable water. Fig. 1 represents block diagram representation of proposed Multi Sensor Array.

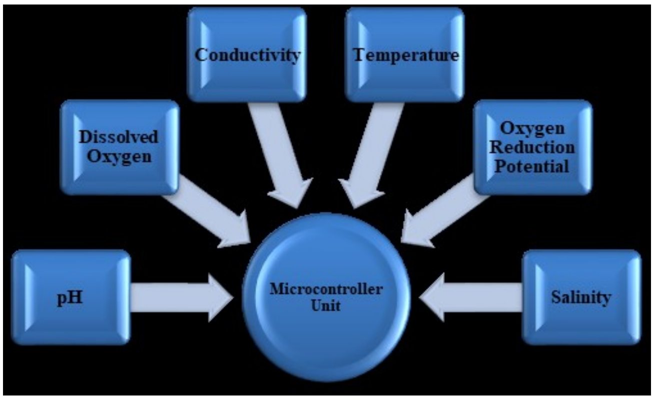


Figure 1. Multi Sensor Array Overview

3. Targeted Parameters

US Environmental Protection Agency has carried out an extensive experimental evaluation of water sensors to assess their performance on several contaminations. The main conclusion was that chemical and biological contaminants generally affect Turbidity, Oxidation Reduction Potential, Electrical Conductivity, pH and detection of variation in above mentioned parameters can significantly detect overall quality of water [16]. For example, Free Chlorine concentration (HOCl) can be approximated based on the ORP, pH and temperature measurements. Therefore, we have selected six parameters based on earlier research and Table 1presents targeted Water Quality Parameters with their acceptable ranges for potable water.

Table 1. Targeted Water Quality Parameters

Sr. number	Parameters	Unit	Range for Potable water
1	**pH**	pH	6.5-8.5
2	**Dissolved Oxygen**	mg/lit	>3 mg/lit
3	**Electrical Conductivity**	uS/cm	0-800
4	**Temperature**	^{o}C	30-35
5	**Oxygen Reduction Potetial**	mV	650-800

4. Results and Discussions

The sensor nodes collect data every second and transmit to Arduino board followed by VPython. Fig 2 presents top view of system prototype, the BNC cord of sensor array is attached to Arduino Mega 2560 board. Primarily, the system has been designed to measure sensor data over a infinity period of time for real time continuous monitoring. Experimental results are presented over X-Y scale. X axis represents time in seconds and Y axis is respective parameters for each result. The potable water sample is collected from Water Laboratory of Birla Institute of Technology and Science. The pH output is as shown if Fig. 3(a). The pH value of sample is 8.8, as confirmed by real time analysis with error of +/- 0.2 value. The dots represent time at which values are taken and for convenience, the first

50 second values have shown. Similarly, Fig. 3(b) represents Dissolved Oxygen with value 9.58 mg/lit with error of +/- 0.2 mg/lit, and Fig. 3(c) Oxygen Reduction Potential with 250 mV and response time is 95% in 1 second. Fig. 3(d) Temperature.

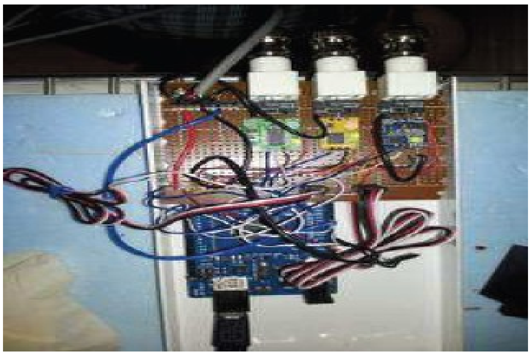
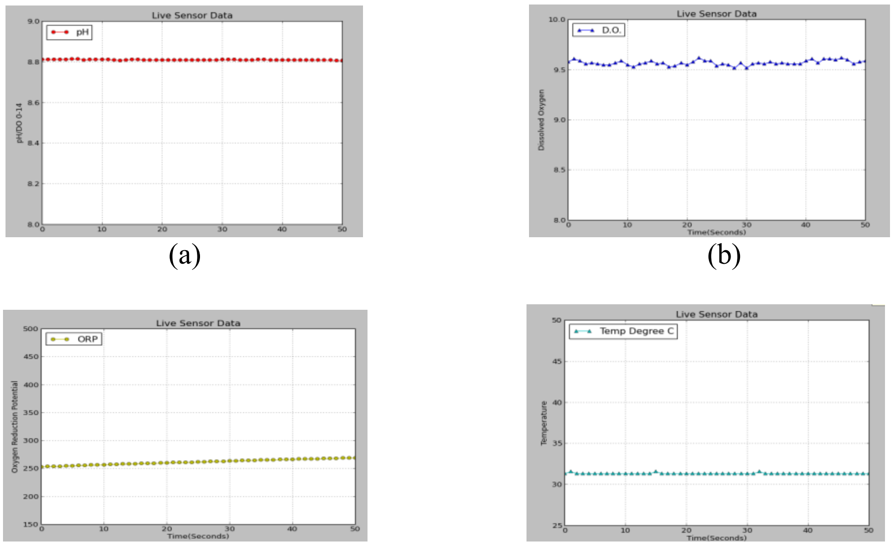


Figure 2. Top view: System Prototype



(a) (b)

(c) (d)

Figure 3. Real Time Sensor Data (a) pH (b) Dissolved Oxygen (c) Oxygen Reduction Potential (d) Temperature

5. Conclusions and Future work

This paper demonstrates effective low cost mechanism for Real Time Assessment of Potable Water Quality in Distribution Network using MSA. The prototype used Integrated Sensor Array and Arduino Mega 2560 Board with VPython. Calibration can be done by sending command from monitoring stations. This approach demonstrates the effective way to detect water quality in distribution network, environmental protection and tracking pollution sources compared to manual approaches. Moreover, from data analysis acquired from this prototype is user friendly that will assist in better understanding of water distribution network. The MSA can be deployed in user specific places and overall cost of the system is ~1000 USD. The system can be integrated with wireless tools for long distance transmission as well.

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