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SENSOR NETWORK FOR REAL-TIME MONITORING AND DETECTION CONTAMINATION IN DRINKING WATER DISTRIBUTION SYSTEMS

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ABSTRACT
This project presents the design and development of a low cost system for real time monitoring of drinking water quality at consumer sites. The system consists of several in-pipes Electrochemical and optical sensors and emphasis is given on low cost, lightweight implementation and reliable long time operation. Such implementation is suitable for large deployments enabling a sensor network approach for providing spatiotemporally rich data to water consumers, water companies and authorities. Extensive literature and market research is performed to identify low cost, on-line sensors that can reliably monitor several parameters which can be used to infer the water quality. In this project we overcome the drawback present in existing system by monitoring water quality problem for drinking water distribution systems as well as for consumer sites.

Our approach is based on the development of low cost sensor nodes for real time and in-pipe monitoring and assessment of water quality on the fly. The main sensor node consists of electrochemical and optical sensors which can be used to monitor the water quality. From the sensor node we are sending monitored values to control room (ARM board) through RS232 serial cable.

KEYWORDS: Water quality monitoring, flat surface sensors, turbidity sensor, and multi-sensor system, and sensor networks, arsenic & bacterial contamination detection**.**

INTRODUCTION

Traditional methods of water quality control involve the manual collection of water samples at various locations and at different times, followed by laboratory analytical techniques in order to characterize the water quality. Such approaches are no longer considered efficient. Although, the current methodology allows a thorough analysis including chemical and biological agents, it has several drawbacks: a) the lack of real-time water quality information to enable critical decisions for public health protection (long time gaps between sampling and detection of contamination) b) poor spatiotemporal coverage (small number locations are sampled) c) it is labor intensive and has relatively high costs (labor, operation and equipment). This project presents the design and development of a low cost system for real time monitoring of drinking water quality at consumer sites. The system consists of several in-pipes Electrochemical and optical sensors and emphasis is given on low cost, lightweight implementation and reliable long time operation. Such implementation is suitable for large deployments enabling a sensor network approach for providing spatiotemporally rich data to water consumers, water companies and authorities. Extensive literature and market research is performed to identify low cost, on-line sensors that can reliably monitor several parameters which can be used to infer the water quality. Based on selected parameters a sensor array is developed along with several Microsystems for analog signal conditioning, processing, logging, and remote presentation of data. Finally, an algorithm for fusing on-line multi sensor measurements is developed to assess the water contamination risk.

In this project we overcome the drawback present in existing system by monitoring water quality problem for drinking water distribution systems as well as for consumer sites. Our approach is based on the development of low cost sensor

Nodes for real time and in-pipe monitoring and assessment of water quality on the fly. The main sensor node consists of electrochemical and optical sensors which can be used to monitor the water quality. From the sensor node we are sending monitored values to control room (ARM board) through RS232 serial cable. The serial cable is connected to one of UART port of ARM board. The controller transmits the data to remote PC through Ethernet by using FTP. FTP is a protocol through which users can upload files from their systems to server. Once data is placed at server we can view the data at remote PC (with internet) on web page with unique IP address. We can view continuous sensors data.

PROPOSED METHOD

A preliminary version of this article has appeared in [2]. In this article, we present an improved hardware platform, develop a new advanced contamination event detection algorithm and provide an experimental evaluation and validation of system and event detection algorithms in the presence of Real microbiological and chemical contamination events. In addition, several water monitoring micro systems (sensor nodes) have been developed for large scale water monitoring based on wireless sensor networks (WSNs) technology. In [29] a sensor node is developed for monitoring salinity in ground water as well as the water temperature in surface waters. In [33] and [38], the authors have developed a WSN and an energy harvesting system (based on a solar panel) to monitor nitrate, ammonium and chloride levels in rivers and lakes.

Energy harvesting techniques along with hibernation methods play an important role in extending the lifetime of sensor nodes. A survey on energy harvesting for WSNs is provided in

[39] and [40]. Finally, in [34] an autonomous boat equipped with water sensors is proposed to collect samples from lakes using the A∗ search algorithm. More efficient navigation algorithms for a group of boats with obstacle avoidance are presented in [35]–[37]. Apart from the ongoing research towards the design and development of sensors and micro systems another parallel Research direction is that of the development of software and algorithms for the detection of water quality anomalies and contamination events. A thorough survey on recent advances in this area is provided in [30]. A limited number of event detection software is commercially available (Hach Event Monitor [8], Blue Box [10]). A currently freely available tool is CANARY software [11] developed at Sandia National
Laboratories in collaboration with the USEPA. CANARY indicates possible contamination events by using a range of Mathematical and statistical techniques to identify the onset of anomalous water quality incidents from online raw sensor Data. Other event detection and data validation methodologies are given in [31] and references therein.

PLATFORM DESIGN

A. System and Sensors Development and Integration The overall system architecture under discussion in presented in Fig. 1 and is comprised of the following three subsystems: a central measurement node (PIC32 MCU based board) that collects water quality measurements from sensors, implements the algorithm to assess water
quality and transmits data to other nodes, a control node (ARM/Linux based platform) that stores measurement data received from the central measurement node in a local database and provides gateway to the internet, visualize data (charts), and sends email/sms alerts and finally a tiny notification node(s) (PIC MCU based board) that receives information from the central
Measurement node through an interconnected Zig-Bee RF transceiver and provides local near tap notifications to the user (water consumer) via several interfaced peripherals (LED, LCD, Buzzer). It should be noted that the central measurement node serves as the sensor node. The idea is to install these sensor nodes in many consumer sites in a spatially-distributed manner to form a WSN that will monitor the drinking water quality in the water distribution system from the source to the tap.
The central measurement node is interfaced to multi-parameter sensor array comprised of Turbidity (TU), ORP, pH, Electrical Conductivity (EC) and Temperature (T) sensors. The in-pipe Turbidity sensor is constructed from scratch based on our previous work while the other sensor probes obtained from Sensor X Corp. The pH sensor embeds an RTD sensor which is used for temperature sensing and temperature compensation of pH and EC measurements.
TU, ORP, pH and toroidal EC sensors have flat measuring surfaces for cost effective
Self - cleaning. The complete system photo, with TU, ORP, pH, EC and T sensors as well as a rotor-flow sensor mounted in a plastic pipe.

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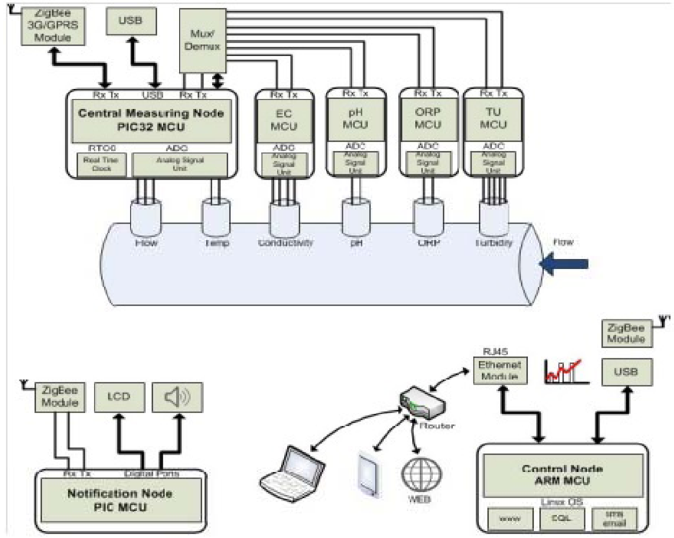

Figure 1: System Architecture

Turbidity Sensor Development:

Although there is plenty of turbidity measuring instruments available on the market at the moment, most of them are expensive and not directly compatible with in-pipe, in-line requirements as well as WSNs technology.

TABLE I
SUGGESTED PARAMETERS TO BE MONITORED

	Parameter	Units	Quality Range	Meas. Cost
1	Turbidity	NTU	0 – 5	Medium
2	Free Residual Chlorine	mg/L	0.2 – 2	High
3	ORP	mV	650 – 800	Low
4	Nitrates	mg/L	<10	High
5	Temperature	^{o}C	–	Low
6	pH	pH	6.5 – 8.5	Low
7	Electrical Conductivity	μS/cm	500 – 1000	Low
8	Dissolved Oxygen	mg/L	–	Medium

Therefore, the goal is to develop a low cost, easy to use and accurate enough turbidity sensor for continuous in pipe turbidity monitoring in water distribution systems using commercial off-the self-components. The turbidity sensor development was based on the ratio turbidimeter design (see Fig. 2) where both transmitted and scattered light intensities are measured to eliminate errors (interferences) due to IR emitter intensity drift and sample absorption characteristics.
An infrared (860nm) narrow beam LED emits light through an optical gap to the water sample and two IR photodiodes separated around 1cm from the emitter receive simultaneously the 90o scattered and 0o transmitted light.

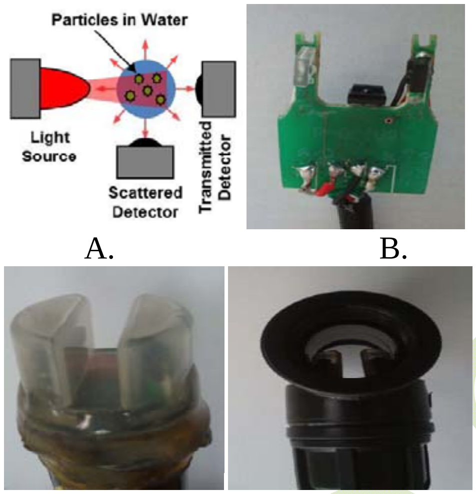

Fig.2 Turbidity sensor. (A) Measurement principle. (B) Probe board. (C) Flat surface PTFE housing. (D) Inline Tee fitting

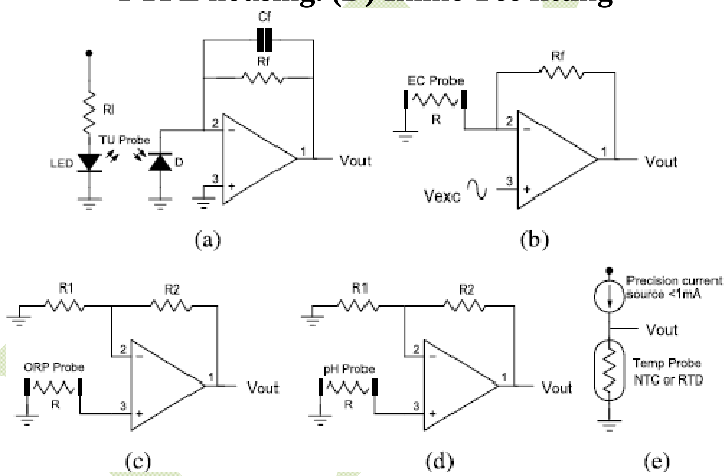

Fig. 3. The first stage of analog signal conditioning circuitry. (a) Turbidity preamplifier. (b) Conductivity preamplifier. (c) ORP preamplifier. (d) pH preamplifier. (e) Temp.

The instrumentation and analog signal conditioning of the sensor is as follows: The IR emitter is pulsed at 1 kHz with a square wave signal and the photodiodes convert the light directly into electrical current, then a high gain, low-noise CMOS (Complementary metal-oxide-semiconductor) trans impedance amplifier with background light rejection is used to convert the each photocurrent to voltage output. The ac output of each trans impedance amplifier is then converted to a dc signal using a precision active peak detector. Finally the 90*o* scattered dc signal is further conditioned by an instrumentation amplifier for 0 NTU offset nulling and additional amplification. The conditioned voltage outputs are then sampled by a 10 bit A/D converter with reference voltage of 1.1V and the sensor output voltage V = $\frac{V90°}{C.V0°}$. is given as the signal ratio of the scattered V90° to the transmitted V0° voltage, *c* is calibration coefficient.
Apart from TU sensor, analog signal conditioning circuits, calibration and compensation procedures were developed

TABLE II
SPECIFICATIONS AND ACCOMPLISHED PERFORMANCE FOR EACH MONITORED PARAMETER

Parameter	Measurement principle	Units	Range	Resolution	Accuracy	Quality Range
Turbidity	Optical/infrared scattering	NTU	0 – 100	0.1	±0.5	0 – 5
ORP	Galvanic cell, platinum electrode	mV	-2000 – 2000	2	±10	600 – 800
pH	Galvanic cell, glass electrode	pH	0 – 14	0.05	±0.1	6.5 – 8.5
Conductivity	Conductive cell	μS/cm	100 – 20000	10	5%	500 – 1000
Conductivity	Inductive cell	μS/cm	200 – 3000	10	5%	500 – 1000
Temperature	RTD resistance	^{o}C	-5 – 100	0.1	±0.1	–
Flow	Magnetic rotor, hall effect sensor	L/min	1–115	0.0015	15%	–

for pH, OPR, RTD and conductive/inductive EC sensors. Considerable attention is given to acquire linear response, reduce noise and attain high resolution and accuracy.

CONCLUSION

The design and development of a low cost s system for real time monitoring of drinking Water tone at consumer sites is presented. The proposed system consist of several in-pipe water quality sensors with flat measuring probes and unlike commercially available on-line analyzers, it is low cost, lightweight and capable of processing, logging and remote presentation of data. Such implementation is suitable for large deployments enabling a sensor network approach for providing spatiotemporally rich data to water consumers, water companies and authorities. In the future, we plan to investigate the performance of the event detection algorithms on other types of contaminants (e.g. nitrates) and install the system in several locations of the water distribution network to collect spatiotemporally rich water quality data and characterize system/sensors response in real field deployments. Moreover, additional risk assessment and anomaly detection algorithms will be investigated as well as algorithms for contaminant identification.
Finally, we plan to investigate a sensor network approach for quality monitoring of drinking water distribution systems. Towards this goal, new fusion algorithms and methodologies to assess the water quality over the entire water distribution network (network level) will be investigated.

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