EMBEDDED BASED REAL-TIME MONITORING AND CONTAMINATION DETECTION IN DRINKING WATER DISTRIBUTION SYSTEM

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ABSTRACT

This paper presents an innovative solution for monitoring and contamination detection in drinking water distribution system. Contaminated water is a severe vexation in many developing countries with serious health effects particularly for children. Current methods for supervising waterborne microorganisms are much time taking, costly, and effortful, making them not suitable for these regions. Our access is to develop a smart real time sensor node for appraisal of water tone and drosses. The main sensor node consists of many in-pipe electrochemical, optical sensors and emphasis represents in low cost, light weight execution, and trustable long time application. The system and approach presented in this paper has the potential to be used as a useful low-cost tool for water sources monitoring.

Keywords:- Water quality monitoring, measurement system, turbidity sensor, multi-sensor system, arsenic& bacterial contamination detection.

1. INTRODUCTION

Water distribution systems are inherently sensitive to both intentional and accidental contamination. There are many points at which a contaminant may enter the dispersion system. This grade of major components such as treatment plants, pumps and tanks, to individual hydrants and consumer sites. Since it is highlight to fully protect all potential points of entry, in accession trying to depress the likely of contamination events, a major stress has been on dealing the dispersion system in case of contamination and trying to minimize the impacts of such events. Conventional methods of water tone control requires the manual collection of water samples at various locations and at different times, followed by research lab analytical techniques in order to qualify the water tone. Such attacks are no longer considered efficient. Although, the actual methodology allows a thorough analysis including chemical and biological agents, it has several drawbacks. Contaminated water sources may contain traces of metals such as copper (Cu), zinc (Zn), lead (Pb), mercury (Hg), nickel (Ni), cobalt (Co) etc. and other major ions such as nitrate (NO_3^-), phosphate (PO_4^{3-}), ammonium (NH_4^+) etc. IN this paper, the magnetic field and electric field of the sensor are reactive to the metals and other major ions. Formal methods for detecting bacterial micro-organisms are culture-based, requiring conventional laboratory settings utilizing bacterial surrogates or indicators, such as total coli form bacterium, fecal coli form bacterium or Escherichia coli. Hence there is a clear need for continuous on-line water tone supervising with efficient comprehensive resolution. US Environmental Protection Agency (USEPA) has carried out a wide experimental evaluation of water tone sensors to assess their operation on several contaminations. The independent decision was that lots of the chemical and biological contaminants used bear an impression on many water parameters monitored including Turbidity (TU), Oxidation Reduction Potential (ORP), Electrical Conductivity (EC) and pH. Therefore, it is executable to monitor and infer the water tone by observing changes in such parameters. The main part of this paper is to formulate a low cost system that can be used at the prefaces of consumers to continuously monitor qualitative water parameters and fuse multi-parametric sensor response in order to evaluate the water consumption hazard. The contributions regarding the low cost system is the design and development of low cost networked embedded systems as well as optical sensors(turbidity) for water tone monitoring, the development of event detection algorithms using fusion techniques, database evaluation and proof of system performance in various concentrations of microbiologically (E.coli) and chemically (Arsenic) contaminated drinking water.

2. RELATED WORK

The former version of this article has been presented in [1].The method reporting in this paper is based on the measurement of water drosses. This paper delivers an improved hardware platform originate a new innovative contamination event detection algorithm and provide an observational evaluation and validation of system and event detection algorithms in the presence of real microbiological and chemical contamination events. Only few number of on -line, reagent-free water supervising systems are technically available [2] (e.g. Hatch HST Guardian Blue [3], J-MAR Bio Sentry [4], etc), but these arrangements are bulky sensors are installed in flow cells situated on cabinets and remain cost prohibitory for large scale deployments cost tens of thousands of dollars per unit. Its worth mentioning that the cost is mostly attributed not to sensing probes but to instrumentation-automation controllers (analyzers) and panels. Such systems can take frequent samples of the water tone at a very fixed number of locations. Still, substantial proportion of contamination trouble is attributable to troubles within distribution systems and due to the less availability of comprehensive sampling, it is impossible for the water companies and consumers to know the tone of potable water delivered to consumer household. In addition, several water supervising Microsystems (sensor nodes) have been developed for large scale water supervising based on wireless sensor networks (WSNs) technology. In [5] a sensor node is developed for monitoring salinity in ground waters as well as the water temperature in surface waters. In [6] and [7], 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 [8] and [9].Apart from the ongoing research towards the design and development of sensors and Microsystems another parallel research direction is that of the development of software and algorithms for the detection of water tone anomalies and Contaminating events.

3. METHODOLOGIES

Typically the drinking water tone measures are determined according to World Health Organization (WHO) [10] guidelines for drinking-water tone as well as other pertinent systems. These systems set the standards for drinking water tone parameters and indicate which microbiological, chemical and indicator parameters must be monitored and examined regularly in order to protect the health of the consumers and to make sure the water is healthy and clean. Chief mechanism that is currently available to mitigate or reduce the effects of a contamination event in the distribution system is a contamination warning system (CWS). A contamination warning system is a combination of monitors, institutional arrangements, analysis tools, emergency protocols, and response mechanisms designed to provide early warning of contaminants in order to minimize customer exposure. USEPA (2007) describes a conceptual model for contamination warning system operation as follows.

1. Monitoring and surveillance: The basic factors of online water tone monitoring, sampling and analysis, enhanced security supervising, consumer complaint surveillance, and public health surveillance takes place on a routine basis, in near-real time until an anomaly or deviation from the baseline or base state is noticed.

2. Event detection and potential decision: Event detective work is the process or mechanism by which an anomaly or deviation from the baseline or base state is noticed.

3. Credible determination: Credibility finding procedures are performed using information from all contamination warning system elements as well as external resources when available and relevant. Whenever contamination is determined to be believable, additional confirmatory and response actions are originated.

4. Confirmed decision: In this stage of consequence management, additional information is gathered and assessed to confirm drinking water contamination. Response actions initiated during credible determination are expanded and additional response activities may be implemented.

5. Remedy and Retrievals: Once contamination has been confirmed, and the immediate crisis has been addressed through response (e.g., flushing, emergency warnings, etc.), remediation and recovery actions defined in the consequence management plan are performed to restore the system to normal operations. On-line monitors or sensors are widely considered as the primary means of detecting a potential pollution event in a distribution system. In order to reliably and efficiently notice potential contaminants, the monitors must be tender to the presence of a wide range of factors and there must be a sufficient number of appropriate monitors so that detection occurs in a timely manner. Historically, monitoring sites were taken primarily on the basis of informal selection criteria that reflected the representativeness and accessibility of the sites and the specific purpose(s) of the supervising system. The table given below shows the parameter to be measured

TABLE-1 Suggested Parameters to Be Monitored

No	Parameters	Units	Quality Range	Measure cost
1	Turbidity	NTU	0-5	Medium
2	ORP	mV	650-800	Low
3	Nitrates	mg/L	<10	High
4	Free Residual Chlorine	mg/L	0.2-2	High
5	Dissolved Oxygen	mg/L	-	Medium
6	pH	pH	6.5-8.5	Low
7	Electrical Conductivity	µS/cm	500-1000	Low

Convectional combined electrodes (for ORP and pH) have been widely used due to their good sensitivity, selectivity, stability and long lifetime. Still convectional pH glass electrodes have various disadvantages due to the intrinsic nature of the glass membrane. For exercise they have limited pressure tolerance, exhibit a slow response, require a high input impedance signal conditioning circuits and it is difficult to miniaturize based on current fabrication technologies. Consequently, a list of emerging-alternative sensor technologies in various phases of research and growth has-been existed in the literature. Nano-sensors based on nanostructures of noble alloys and their oxides (like Pt, Ru, Ir) is a recent assuring concept, yet developments so far suffer from various withdraws like temperature dependent delay reply and nondeterministic. Potential drift (electrolysis of water on oxide surfaces and irregular temperature dependence) [28].So activity of (pH,ORP)glass electrodes and solid-state sensors (TU, EC, T) are used in this work as they provide the most reliable technology. In-line water sensors instance the need for efficient and occasional probe cleaning to maintain dependable measures.

4. DESIGN PROCESS

4.1 Water system Design and exposure

Contamination warning schemes and other methods for detecting and mitigating contamination events require active treatment in order to minimize affects. An alternative or supplemental “passive” mechanism for reducing impacts involves the re-design of distribution systems aimed specifically at improving security. In the United States and many other countries, distribution systems are designed as looped systems composed of transmission lines and interconnected local delivery pipes used to deliver water to customers. Looped systems generally result in multiple paths that water can follow from the treatment plant to customers and provide redundancy in case of outages. However, the loops also result in multiple pathways for contaminants and greater difficulties in isolating contaminants.

The diagrammatic representation of Smart real time water distribution system is given in Fig-1 and is grouped into following three groups: a central measurement node (PIC 16F877a MCU baseboard that collects water quality measurements from sensors, implements the algorithm to assess water quality and transmits data to other nodes, a control node 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 nodes (PIC MCU based board)that receives information from the central measurement node through an interconnected GSM and provideslocal near-tap notifications to the user water consumer via several interfaced peripherals LED, LCD, Buzzer.

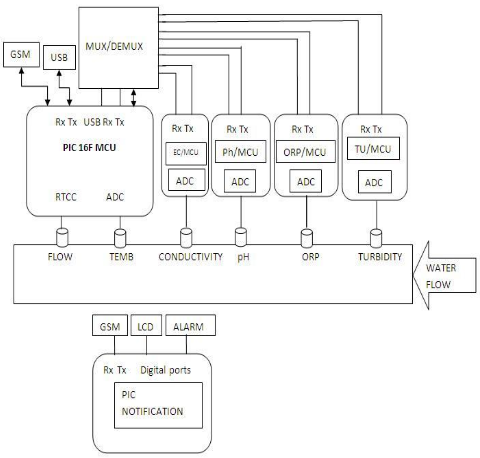

Fig.1.System architecture

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 [1] while the other sensor probes obtained from SensoreX 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 photo of the complete system with Turbidity (TU), ORP, pH, Electrical Conductivity (EC) and Temperature (T) sensors is given in Fig-2.

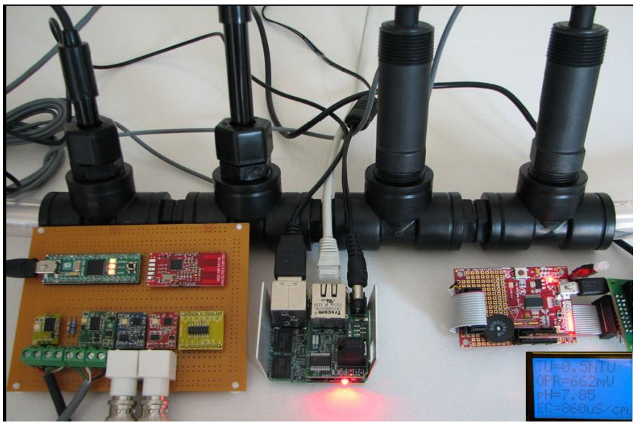

Fig.2.Photo of the complete system.

4.2 Sensor development

Generally different type 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. 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 turbid meter design where both transmitted and scattered light intensities are measured to eliminate errors (interferences) due to IR emitter intensity drift and sample absorption characteristic 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. The photodiodes spectral sensitivity is selected to fit with that of the IR light source. 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 90oScattered 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 = V90oc.V0o is given as the signal ratio of the scattered V90o to the transmitted V0o voltage, c is calibration coefficient. An indirect method for the sensor calibration was employed, in order to avoid the use of the carcinogen and expensive chemical formazin solutions. Therefore, a number of samples were created and the turbidity of each sample is measured both by the turbidity sensor under calibration and by a laboratory turbid meter (Lutron TU-2016) used as reference. Then the relationship between turbidity (in NTU) and the voltage output (in mV) of the turbidity sensor is extracted and given by TU = 0.1035V − 0.292. The sensor generates an output voltage proportional to the turbidity or suspended particles and has a linear response in the range of 0-100 NTU with 0.1 NTU resolutions.

A B C D

Fig.3.A.Turbidity sensor .B. Flat surface PTFE housing. C. Inline Tee fitting. D. Probe board.

Finally, as shown in Fig. 3 the turbidity sensor probe was mounted in a flat surface PTFE (Teflon) housing and sealed in a hydraulic Tee fitting for inline installation. Apart from TU sensor, analog signal conditioning circuits, calibration and compensation procedures were developed 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. A dedicated PIC based Microsystems is developed for each parameter to accomplish this task. The first process of analog signal conditioning circuitry for each parameter is presented in Fig. 4.

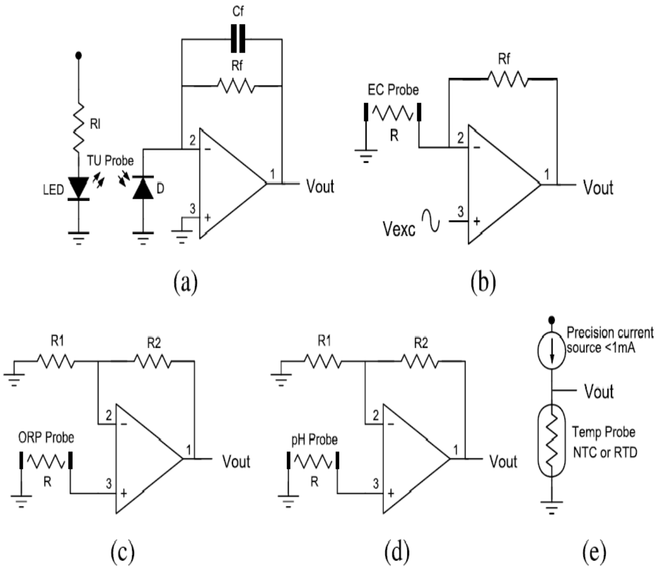

Fig. 4. The first stage of analog signal conditioning circuitry.

(a) Turbidity preamplifier. (b) Conductivity preamplifier. (c) ORP preamplifier. (d) pH preamplifier. (e) Temp.

While Table II shows the results regarding laboratory evaluation (using standard buffer solutions and reference instruments) of each parameter along with the quality range suggested byWHO guidelines and EU standards.

TABLE 2 Specifications And Accomplished Performance For Each Monitored Parameter

Parameters	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	°C	-5-100	0.1	±0.1	-
Flow	Magnetic rotor, hall effect sensor	L/min	1-115	0.0015	15%	-

The overall power consumption of the central measurement sensor node with the on board LEDs off and the RF transceiver module sending water quality data every 5s is about 50mA at 5V operating voltage. It worth mentioning that wireless communication is by far the largest consumer of the energy of the sensor node, compared to other functions such as sensing and computation.

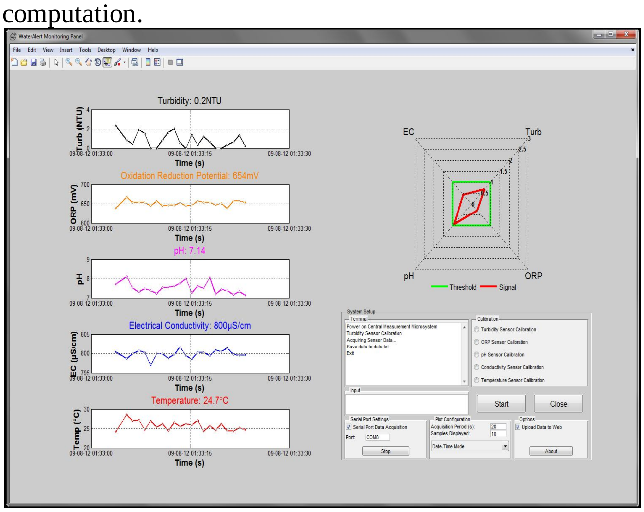

Fig. 5 Software platform.

The software platform developed for the control node is illustrated in Fig. 5. This platform enables real time measurement charts of monitored parameters, real time assessment of water quality and sensor calibration instructions through a Graphical User Interface (GUI). It also logs sensor data in a local database and posts data to web using Pachube open source web platform.

4.3Contamination Event Detection Algorithms

Two event detection algorithms were developed to fuse on-line multi-sensor measurements in order to assess the water contamination risk when anomalies are detected. An event detection algorithm enables the system to act as an "early warning system" for possible potable water quality deterioration at the point of installation (e.g. homes). Both algorithms are based on normalized sensor outputs given by

$$N_i = \frac{Si-\mu i}{\tau i\sigma i} \quad (1)$$

where Si is the current measurement of parameter i∈{TU, ORP, pH, EC}, μi, σi are the mean and standard deviation over a moving time window w and τi is a sensor based parameter associated with measurement accuracy of each parameter i. Normalized sensor outputs Ni are used to filter baseline (i.e mean) fluctuations. The objective of the event detection algorithms is to activate an alarm when normalized sensor outputs exhibit sudden and significant changes, given that these changes are bounded within the quality ranges suggested by drinking water quality standards (see Table II, quality range). The detection of water quality changes that are outside the expected quality ranges(min/max violations) is easier and can be done by a weighted multi-parameter cost function in the form of R_0=∑_i w_0i j_i(2) Where Ji are binary variables that indicate whether parameter has been violated and w_0iare non-negative weights whichimply the significance of the violation of each parameter i. If RO = 0 no violation is assumed, however as RO >0increases the water contamination risk is also increases.

5. EXPERIMENTAL PROOF

In this section we present the results of the experimental trials performed to validate the behavior and evaluate the performance of the developed hardware and algorithm son intentional contamination events. The experimental setup consists of the sensor node (central measurement node) that takes samples every 5s from potable water flowing through a flow cell. Intentional contamination of two important contaminants (Escherichia coli bacteria and arsenic) of various concentrations was injected at discrete time intervals and the performance of the event detection algorithms is evaluated on real time. Escherichia coli bacteria and arsenic contamination in drinking water is very severe problem causing serious poisoning to large numbers of people all over the world [11].

5.1 Microbiologically (E.coli) Contaminate Drinking Water:

The first experiment considers the case of microbiologically (E.coli) contaminated drinking water. Most E. coli strains are in general harmless to humans, but some types can cause serious food and water poisoning. However, the presence of E.coli is used to indicate that other pathogenic organisms may be present (often of faecal origin). According to WHO guidelines & EU Drinking Water Directive E.coli parametric value is 0 CFU/100mL.

5.2 Chemically (Arsenic) Contaminated Drinking Water:

The second experiment considers the case of chemically (Arsenic) contaminated drinking water. Water contamination by toxic heavy metals and especially arsenic contamination is a common problem encountered in many countries due to undue deposition of mining, agricultural, industrial and urban wastes in water resources. Arsenic is known to affect negatively the mental and central nervous system function, to damage the blood composition, lungs, kidneys, liver, and other vital organs, as well as it contributes to certain neurological degenerative processes and causes skin cancer. According to WHO guidelines & EU Drinking Water Directive Arsenic parametric value is 10μg/L.

6. CONCLUSION

In this paper, 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, itis 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 fusion algorithm on intentional contamination events (biological, chemical, etc) and install the system in several locations ofthe water distribution network to collect spatiotemporally richwater tone data and characterize system/sensors response inreal field deployments.

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