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REAL TIME MONITORING AND CONTAMINATION DETECTION IN DRINKING WATER DISTRIBUTION SYSTEMS USING SENSOR NETWORKS

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Abstract

This paper presents a low cost and holistic approach to the water quality monitoring 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 several in-pipe electrochemical and optical sensors and emphasis is given on low cost, lightweight implementation, and reliable long time operation. Such implementation is suitable for large scale deployments enabling a sensor network approach for providing spatiotemporally rich data to water consumers, water companies, and authorities. Extensive literature and market research are performed to identify low cost 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, algorithms for fusing online multisensor measurements at local level are developed to assess the water contamination risk. Experimental results indicate that this inexpensive system is capable of detecting these high impact contaminants at fairly low concentrations. The results demonstrate that this system satisfies the online, in-pipe, low deployment-operation cost, and good detection accuracy criteria of an ideal early warning system.

Keywords: Water quality monitoring, flat surface sensors, turbidity sensor, multi-sensor system, sensor networks.

1 .INTRODUCTION

Hygienic drinking water is a critical resource, important for the health and well-being of all humans. Drinking water utilities are facing new challenges in their real-time operation because of limited water resources, intensive budget requirements, growing population, ageing infrastructure, increasingly stringent regulations and increased attention towards safe-guarding water supplies from accidental or deliberate contamination. There is a need for better on-line water monitoring systems given that existing laboratory-based methods are too slow to develop operational response and do not provide a level of public health protection in real time. Rapid detection (and response) to instances of contamination is critical due to the potentially severe consequences to human health. 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: 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. Poor Spatio-temporal coverage (small number locations are sampled) It is labor intensive and has relatively high costs (labor, operation and equipment. Therefore, there is a clear need for continuous on-line water quality monitoring with efficient spatio-temporal resolution. There is a clear need for a shift in the current monitoring paradigm and this project proposes the idea of monitoring the quality of water delivered to consumers, using low cost, low power and tiny in-pipe sensors. The main contribution of this project is the design and development of a low cost system that can be used at the premises of consumers to continuously monitor qualitative water parameters and fuse multi-parametric sensor response in order to assess the water consumption risk. In particular, 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 quality monitoring, the development of event detection algorithms using fusion techniques and the experimental evaluation and validation of system performance in various concentrations of microbiologically (E.coli) and chemically (Arsenic) contaminated drinking water. Qualitative and quantitative measurements are needed from time to time to constantly monitor the quality of water from the various sources of supply. The harbor-master should then ensure appropriate water treatment within the fishery harbor complex as well as initiate remedial measures with the suppliers when water supply from outside is polluted.Water sampling and analysis should be done by ISO-certified laboratories. Wherever laboratories available locally are not ISO-certified, it is advisable to get their quality assessed by an ISO-certified laboratory by carrying out collaborative tests to ensure that variation in the accuracy of results is sufficiently small. Unreliable results exacerbate problems of pollution when corrective action cannot be taken in time. Sampling and monitoring tests should be carried out by qualified technicians.

2. LITERATURE SURVEY

In Monitoring water distribution system[11][12],the **s**ensor networks are currently being trialed by the water distribution industry for monitoring complex distribution infrastructure. Findings identify the importance of undertaking in-depth consideration of all aspects of a large sensor system with access to either expertise on every detail, or to reference manuals capable of transferring the knowledge to non-specialistsThe drawbacks are High cost and Sensors network speed is low.In GPRS based real time monitoring of water tanks and contamination detection in metropolitan cities [11][13] approach is based on the development of sensor nodes for real time monitoring and assessment of water quality on the fly.To observe the contamination factor in water, sensor setup is installed in water tank. The parameters such as temperature, turbidity, ph value of water which is very important and even water level of tank is monitored and all these data is transmitted to control room through wireless communication to alert the authorized persons.But the drawback is by using GPRS, speeding limit is low The effectiveness of large household water storage tanks for protecting the quality of drinking water [6][10][15]. After the intervention, many of the households did not change the source of their drinking water to the large storage tanks. Therefore, water quality results were first compared based on the source of the household's drinking water: store or vending machine, large tank, or collected from a public supply and transported by the household. Of the households that used the large storage tank as their drinking water supply, drinking water quality was generally of poorer quality and only used for house hold purpose.

3. SYSTEM ANALYSIS

3.1 EXISTING SYSTEM

Drinking water utilities are facing new challenges in their real-time operation because of limited water resources, intensive budget requirements, growing population, ageing infrastructure, increasingly stringent regulations and increased attention towards safeguarding water supplies from accidental or deliberate contamination. There is a need for better on-line water monitoring systems given that existing laboratory-based methods are too slow to develop operational response and do not provide a level of public health protection in real time.

DISADVANTAGES

- Using high cost
- High power and very high in-pipe sensors.

3.2 PROPOSED SYSTEM

In the proposed method 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 (PIC board) through RS232 serial cable. The serial cable is connected to one of UART port of PIC board. The controller transmits the data to remote PC through ZIGBEE by using MAX232. We can view continuous senor's data.

4. SYSTEM DESIGN AND IMPLEMENTATION

Drinking water quality standards are determined according to World Health Organization (WHO) [14] guidelines for drinking-water quality as well as other pertinent organizations (i.e. EU [14], USEPA [19]). These organizations set the standards for drinking water quality parameters and indicate which microbiological, chemical and indicator parameters must be monitored and tested regularly in order to protect the health of the consumers and to make sure the water is whole some and clean. For the developed system, the selection of the physicochemical parameters to be monitored was based on extensive scientific literature review [6], [16], [17], and [18] on the relation between certain physicochemical parameters and chemical or biological contaminations that present in water. it enumerates the suggested parameters to be monitored from high to low correlation significance when interpreting water contaminations (assess hazard). Also presents the measurement cost (for purchase and maintenance) associated with these parameters based on recent review [19] of measurement and instrumentation methods, compensation and calibration procedures and probe lifetime concerning these parameters. Therefore, the parameters selected to be monitored are the following:

Turbidity, Oxidation Reduction Potential (instead of Free Chlorine),Temperature,pH, Electrical Conductivity.It is noted that Free Chlorine concentration (HOCl) can be approximated based on the ORP, pH and temperature measurements. Free chlorine monitoring is expensive because it is very sensitive in the pH, temperature, flow and pressure of the sample. Therefore accurate free chlorine measurements require a flow cell with additional pH and temperature sensors for compensation. Nitrates, though considered as an important parameter for human health is not selected because measurement methods are subjected to failures (Ion-Selective electrodes) or are cost prohibitive (UV spectra photometric method). In [15], a new promising method is presented based on a PCB planar electromagnetic sensor. Finally, dissolved oxygen is not selected due to several compensations and frequent membrane replacements needed.Convectional combined electrodes (for ORP and pH) have been widely used due to their good sensitivity, selectivity, stability and long lifetime. However, convectional pH glass electrodes have several disadvantages due to the intrinsic nature of the glass membrane. For example, they have limited pressure tolerance, exhibit a sluggish response, require high input impedance signal conditioning circuits and it is difficult to miniaturize based on current manufacturing technologies.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.

(a) Measurement principle. (b) Probe board. (c) Flat surface PTFE housing. (d) Inline Tee fitting. 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 characteristics. An infrared (860nm) narrow beam LED emits light through an optical gap to the water sample and two IR photo diodes separated around 1cm from the emitter receive simultaneously the 90^o scattered and 0^otransmitted light. The photo diodes spectral sensitivity are selected to fit with that of the IR light source. The instrumentation and analog signal conditioning of the sensor is as follows: The IR emitter is pulsed at 1kHzwith 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) transimpedance amplifier with background light rejection is used to convert the each photo current to voltage output. The ac output of each transimpedance amplifier is then converted to a dc signal using a precision active peak detector. Finally the 90^oscattered 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 $V = V_{90}{}^oc.V_0{}^o$is given as the signal ratio of the scattered $V_{90}o$ to the transmitted V_0o voltage, cis calibration coefficient.The overall power consumption of the central measurement sensor node with the onboard LEDs off and the RF Xbee transceiver module sending water quality data every 5s is about 50mA at 5V operating voltage, however further improvements are planned to minimize the power consumption using hibernation schemes. 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. 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. Using Pachube scripts the user can setup various thresholds for sending notifications via sms or email.

4.1. CONTAMINATION DETECTION SYSTEM

The overall system architecture under discussion in presented in and is comprised of the following three subsystems:

4.1.1 TRANSMITTING SECTION

A central measurement node (PIC32 MCU based board) that measures the water quality measurements from sensors such as turbidity ,chlorine and also the flow rate and temperature implements the algorithm to assess water quality and transmits data to other nodes. Turbidity (or haze) is also applied to transparent solids such as glass or plastic. In plastic production haze is defined as the percentage of light that is deflected more than 2.5° from the incoming light direction.

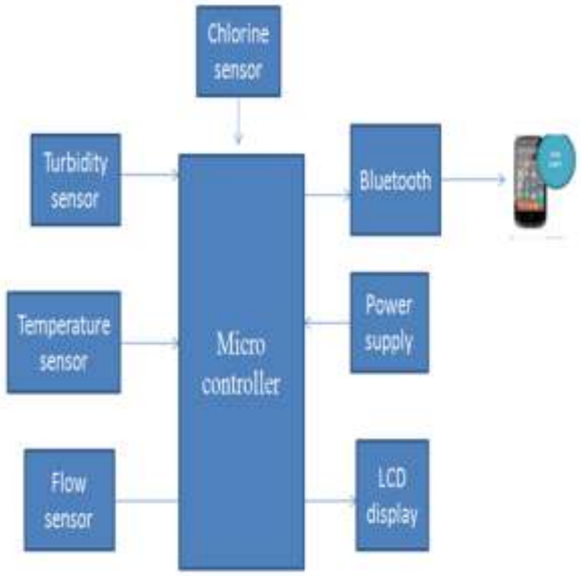

Figure 4.1 Contamination detection system.

The sensor operates on the principle that when light is passed through a sample of water, the amount of light transmitted through the sample is dependent on the amount of soil in the water.An electrical conductivity meter measures the electrical conductivity in a solution.It is commonly used in hydroponics, aquaculture and freshwater systems to monitor the amount of nutrients, salts or impurities in the water. Temperature is generally measured by a thermistor within the sensor and is acquired by the meter or through LCD display.

4.1.2 RECEIVING SECTION

A control node that stores the 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 ZigBee RF transceiver and provides local near-tap notifications to the user via several interfaced peripherals such as LCD and Buzzer. The reasons being: LCDs are economical; easily programmable; have no limitation of displaying special & even (unlike in seven segment), animations and so on. Character LCDs may have a backlight, which may be LED, fluorescent, or electroluminescent. Character LCDs use a 16 contact interface, commonly using pins or card edge connections on 0.1 inch (2.54 mm) centers.

5. SENSORS

5.1 TURBIDITY SENSOR

Turbidity is the cloudiness or haziness of a fluid caused by large numbers of individual particles that are generally invisible to the naked eye, similar to smoke in air. The measurement of turbidity is a key test of water quality Fluids can contain suspended solid matter consisting of particles of many different sizes. While some suspended material will be large enough and heavy enough to settle rapidly to the bottom of the container if a liquid sample is left to stand (the settable solids), very small particles will settle only very slowly or not at all if the sample is regularly agitated or the particles are colloidal. These small solid particles cause the liquid to appear turbid. **Turbidity** (or haze) is also applied to transparent solids such as glass or plastic. In plastic

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production haze is defined as the percentage of light that is deflected more than 2.5° from the incoming light direction.

Figure 5.1.optical sensor

As the soil level increases, the amount of transmitted light decreases. The turbidity sensor measures the amount of transmitted light to determine the turbidity of the wash water. These turbidity measurements are supplied to the dishwasher controller, which makes decisions on how long to wash in all the cycles. These decisions are made based on a comparison between clean water measurements (taken at the beginning of the wash cycle) and the wash water turbidity measurement taken at the end of each wash cycle. By measuring the turbidity of the wash water, the dishwasher can conserve energy on lightly soiled loads by only washing as long as necessary. This will result in energy savings for the consumer.

5.2 CHLORINE SENSOR

Electro-Chemical Devices' series of **sensors** for chlorine analysis are designed to fit into chlorine monitoring systems in a variety of aqueous environments. The FCA-22 Free Chlorine Sensor, TCA-22 Total Chlorine Sensor and CDA-22 Chlorine Dioxide Sensor are high-accuracy aerometric sensors for fresh water applications including monitoring of industrial cooling and rinse water, **drinking water** and wastewater. The CDA-22 Chlorine Dioxide Sensor has a gold cathode and silver chloride anode and PTFE membrane. It is designed to measure chlorine dioxide in concentrations ranging from 0.05-20 ppm CIO2 and operates at 0 to 50 C (32 to 122 F). It is for applications in municipal water systems, industrial cooling and rinse water, wastewater or other fresh water samples.

Figure 5.2 Chlorine Sensor

5.3 pH SENSORS

The pH sensor components are usually combined into one device called a combination pH electrode.On the pH scale a very acidic solution has a low pH value such as 0, 1, or 2 (which corresponds to a large concentration of hydrogen ions. A neutral solution such as water has a pH of approximately 7.

Figure 5.3 pH Sensor

A pH measurement loop is made up of three components, the pH sensor, which includes a measuring electrode, a reference electrode and a temperature sensor; a preamplifier; and an analyzer or transmitter.

5.4 0_2 SENSORS

The most popular method for dissolved oxygen measurements is with a dissolved oxygen meter and sensor. While the general categories of dissolved oxygen sensors are optical and electrochemical, electrochemical sensors can be further broken down into polar graphic, pulsed polarographic and galvanic sensors. In addition to the standard analog output, several of these dissolved oxygen sensor technologies are available in a smart sensor platforms with a digital output.

As dissolved oxygen concentrations are affected by temperature, pressure and salinity, these parameters need to be accounted for 7. These compensations can be done manually or automatically with a dissolved oxygen meter or data logging software. Temperature is generally measured by a thermistor within the sensor and is acquired by the meter or data logger without.

5.5 Conductivity sensor

An electrical conductivity meter (EC meter) measures the electrical conductivity in a solution. It is commonly used in hydroponics, aquaculture and freshwater systems to monitor the amount of nutrients, salts or impurities in the water.

Industrial conductivity probes often employ an inductive method, which has the advantage that the fluid does not wet the electrical parts of the sensor. Here, two inductively-coupled coils are used. One is the driving coil producing a magnetic field and it is supplied with accurately-known voltage. The other forms a secondary coil of a transformer. The liquid passing through a channel in the sensor forms one turn in the secondary winding of the transformer. The induced current is the output of the sensor.

salt	$NaCl \rightarrow Na^+ + Cl^-$
acid	$HCl \rightarrow H^+ + Cl^-$
base	$NaOH \rightarrow Na^+ + OH^-$
water	$H_2O \rightleftarrows H^+ + OH^-$

The analyzer measures the current and uses Ohm's law to calculate the resistance of the solution (resistance = voltage/current). The conductance of the solution is the reciprocal of the resistance. The ionic current depends on the total concentration of ions in solution and on the length and area of the solution through which the current flows. The current path is defined by the sensor geometry, or cell constant, which has units of 1/cm (length/area). Multiplying the conductance by the cell constant corrects for the effect of sensor geometry on the measurement. The result is the conductivity, which depends only on the concentration of ions.

Figure 5.4 Conductivity Sensor

6.HARDWARE DESCRIPTION

The Atmega328 is a very popular microcontroller chip produced by Atmel. It is an 8-bit microcontroller that has 32K of flash memory, 1K of EEPROM, and 2K of internal SRAM. AT mega328 has 28 pins. It has 14 digital I/O pins, of which 6 can be used as PWM outputs and 6 analog input pins. These I/O pins account for 20 of the pins.

Hardware circuit of Contamination detection

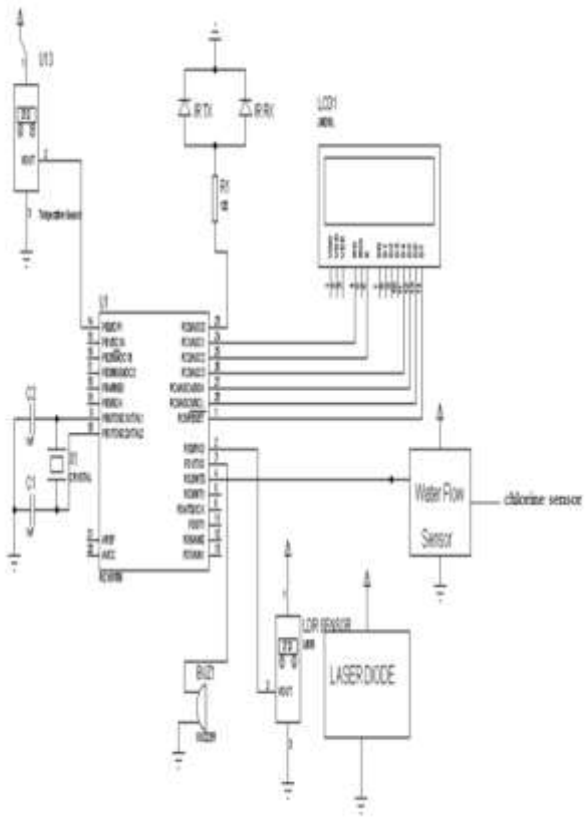

Figure 6.1 Pin diagram of contamination detection system

7. SOFTWARE DESCRIPTION

C51 C Compiler

The Keil C51 C compiler for the 8051 microcontroller is the most popular 8051C compiler in the world. It provides more features than any other 8051 C compiler available today.Bluetooth operates at frequencies between 2402 and 2480 MHz, or 2400 and 2483.5 MHz including guard bands 2 MHz wide at the bottom end and 3.5 MHz wide at the top. Each channel has a bandwidth of 1 MHz. It usually performs 800 hops per second, with Adaptive Frequency-Hopping (AFH) enabled.[14] Bluetooth low energy uses 2 MHz spacing, which accommodates 40 channels.

CONCLUSION

In this article, the design and development of a low cost sensor node for real time monitoring of drinking water quality at consumer sites is presented. The proposed sensor node consists of several in-pipe water quality sensors with flat measuring probes. Unlike commercially available analyzers, the developed system is low cost, low power lightweight and capable to process, log, and remotely present data. Moreover, contamination event detection algorithms have been developed and validated to enable these sensor nodes to make decisions and trigger alarms when anomalies are detected. 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 characterize system/sensors response and wireless communication performance in real field deployments. Finally, we plan to investigate networkwide fusion/correlation algorithms to assess water quality over the entire water distribution system.

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