IoT based Automation of Real Time In-Pipe Contamination Detection System in Drinking Water

S. Kavi Priya, G. Shenbagalakshmi and T. Revathi

Abstract—**With the recent advancement in the communication technologies, the real time in-pipe water quality monitoring system is gaining more importance. This work describes the recent development in the field of in-pipe real time contamination detection system. In addition, a contamination detection system is developed based on the emerging Internet of Things technology. The system samples the water at regular time intervals supplied through pipelines to the consumers/public. The real time data are analyzed using fuzzy synthetic evaluation and uploaded over the internet/cloud. When contamination is detected in the water, the system sends an alarm/alert to the consumers regarding the water quality parameters and prevents the further flow of water in the contaminated region in the pipe using a solenoid valve. The other region which supplies quality water to the consumers in the water distribution network remains flowing. The results demonstrate that the developed system is capable of analyzing the water quality parameters in real time and can successfully process, transmit data to the cloud and intimate the users about the contamination in the particular region.**

***Index Terms*—Fuzzy logic, drinking water quality monitoring system, ZigBee, WiFi, Cloud, Internet of Things.**

I. Introduction

CLEAN and safe water is required to prolong life and plays a major role in the well-being of the human being [1]. The root cause of the water quality problems are exploitation of natural resources and excessive pollution caused by the individuals [2].

S.KaviPriya is with the Department of Information Technology, Mepco Schlenk Engineering College (Autonomous), Sivakasi, India.(e-mail: urskavi@mepcoeng.ac.in).

G.Shenbagalakshmi is with the Department of Information Technology, Mepco Schlenk Engineering College (Autonomous), Sivakasi, India.(e-mail: shenbagalakshmi@mepcoeng.ac.in).

T.Revathi is with the Department of Information Technology, Mepco Schlenk Engineering College (Autonomous), Sivakasi, India. (e-mail: trevathi@mepcoeng.ac.in).

The quality of the water is affected by means of both the point and non-point sources of pollution. The major sources of contamination are discharge from industries and sewage, floods and droughts etc. In most of the rural and urban areas, the water consumed by the public is however not safe for the direct consumption of water [3-4]. In [5] water quality monitoring is defined as the collection of water quality parameter data at different locations at regular intervals of time.

The traditional method on analysis of water quality parameters involves the manual collection of samples and laboratory techniques for identifying the contamination [6]. The main objective of the real time contamination detection system is to measure the microbial measurements as well as physical and chemical measurements to obtain the deviations in the measurement [7]. The Physiochemical parameters include electrical conductivity, pH, oxidation reduction potential (ORP), turbidity and temperature. The real time monitoring system also acts as an early warning and intimates the user/consumer about the quality of the water they consume. As defined by the United States Environmental Protection Agency (USEPA) [8] the contaminants in specific ways can be detected and monitored using appropriate water quality sensors. The products that are available in the market for monitoring the water quality parameters are usually bulky and quite expensive.

The sensor network technology as in [9] is still not effective in terms of cost and reliability, maintenance and data handling. In this paper the development of real time in-pipe smart contamination detection system using wireless sensor network is designed. The system measures the water quality parameters such as pH, temperature, oxidation-reduction potential, conductivity and turbidity by following the first principles. The sensed data and the contaminants observed are then processed and analyzed using fuzzy inference system and transmitted wirelessly using ZigBee to a notification node. The real time data is made available to the user, to know about the quality of water they consume and the real

978-1-5386-3521-6/18/$31.00 ©2018 IEEE

time data are uploaded to the cloud. The rest of this paper is organized as follows. Section II reviews the related works investigated relevant to this project. Section III describes the factors that were taken into consideration and necessary parameters while designing the system. Section IV discusses about the modules of the system and finally the paper concludes with Section V.

II. Related Work

Various studies on the implementation of smart water quality monitoring systems using wireless sensor network (WSN) technology can be found in literature. The real time water quality monitoring in the water distribution mains is challenging in the management of distributed wireless sensor networks. A distributed system as in [10] for measuring water quality is designed and implemented. Temperature, conductivity, oxidation reduction potential, pH and turbidity sensors are therefore connected with field point, where the sensed data are transferred to the base station using a GSM network. The sensed data are processed using auto-associative neural networks such as Kohenen maps. In [11] developed a WSN-based water environment monitoring system that is capable of sensing and monitoring the video data and water parameters such as temperature, oxidation reduction potential, turbidity, pH, dissolved oxygen and conductivity. The sensed data is sent from the data monitoring nodes to the remote monitoring center using ZigBee and CDMA technology.

The water distribution network for monitoring the concentration of chlorine has been discussed in [12]. The water monitoring system implemented in [13] analyzes and processes water quality parameters and trigger an alarm when an event of water contamination is detected. The measured sensor data are sent to the base station via GPRS technology. The DEPLOY project monitors the environmental parameters for the river catchment as in [14]. The system measures the spatial and temporal distribution of water quality and measures parameters such as pH, temperature, depth, conductivity, turbidity and dissolved oxygen. It states that independent sensor nodes can be deployed over a wide area of network.

A microcontroller-based WSN system is proposed in [15] to measure pH, chlorine concentration and temperature in a pool where data is transmitted using GSM. In [16] a WSN system is used to measure the water quality of fresh water and uses solar daylight harvesting for optimized power management. The data thus collected from the various sensor nodes are sent to a sub-base node and from there to a monitoring station using a GSM network.

A low-cost, real-time, in-pipe sensor node with a sensor array for measuring flow, pH, conductivity, ORP and turbidity, is designed and developed in [8]. Contamination event detection algorithms are also developed to enable sensor nodes to make decisions and trigger alarms when contaminants are detected. In [17] a WSN based on ISO/IEC/IEEE 21451 standard for monitoring of surface water bodies is presented, to capture possible severe events and collect extended periods of data. It is observed from the literature study that most water quality monitoring systems have sensing nodes, perform wireless communication and process the data from the sensors [18] to achieve meaningful results.

III. Method

To design the proposed water quality monitoring system, various water quality parameters and communication technology in the wireless communication systems were investigated.

A. Water Quality Parameters

Extensive experiments are carried out by various regulatory bodies and have concluded that the biological and chemical contaminant affects the quality of the water. Therefore, the proposed work focuses on the physicochemical parameters such as pH, conductivity, ORP, temperature and turbidity to detect the contamination in the drinking water. Out of all the parameters, pH of the water plays the major role in predicting the water quality. It measures the acidic or basic properties in water. When the pH value of water is 11 or even higher, it causes irritation to the eyes and skin. The pH value of water below 4 causes irritation due to the corrosive effect. The other non-standardized water quality indicator is ORP, which is the measure of the tendency of a solution to either gain or lose electrons.

TABLE I
PARAMETERS TO BE MONITORED

S.No	Parameter	Units	Quality Range
1	Turbidity	NTU	0.5 – 1.0
2	ORP	mV	650 – 800
3	Temperature	℃	20°C – 40°C
4	pH	pH	6.5 – 8.5
5	Electrical Conductivity	µS/cm	500 – 1000
6	Dissolved Oxygen	mg/L	7 – 15

The normal tap water has the ORP value as between 200-400 mV. WHO say that the ORP of drinking water should not exceed 60 mV. The temperature of the water is analyzed as these parameters have an effect on other parameters. The recommended ranges for drinking water parameters are determined by the WHO guidelines [1]. The specific range for each parameters are listed out in Table I

B. Communication Technology

Power consumption and energy efficiency are the major constraint for IoT applications, as applications are most likely to operate on batteries. Data aggregation and data transfer consumes more power and energy. For applications such as smart water quality monitoring, data communication is between sensing unit and the controller and other is the communication between controller and application. Table II represents various communication protocols. As the power dissipation is high, WiFi is not suitable for communication. Possible protocols for communication between sensing unit and controller are ZigBee, Bluetooth and BLE. The proposed work uses ZigBee protocol for communication between sensor nodes and controller.

TABLE II
COMMUNICATION PROTOCOLS

Parameter	Short distance protocols			
	ZigBee	Bluetooth	LoRa	Wi-Fi
Standard	IEEE 802.15.4	IEEE 802.15.1	LoRaWAN R1.0	IEEE 802.11 a/c/b/d/g/n
Transmission range	10–20 m	8–10 m	<30 Km	20–100 m
Energy consumption	Low	Bluetooth: Medium BLE: Very Low	Very low	High
Data Rate	40–250 Kb/s	1–24 Mb/s	0.3–50 Kb/s	1 Mb/s–6.75 Gb/s
Cost	Low	Low	High	High
Usage	Communication between sensor and controller			Communication between controller and application

C. Sensors Used

Several sensors are commercially available for water quality monitoring. Few works published in literature include fabricated sensors for ease accessibility. A fabricated type sensor node is used for parameter monitoring which includes a solar cell, Li-ion battery, a power module and transmission module. A in- house fabricated TiO based thick film pH resistive sensor output can be directly connected to the microcontroller without additional signal processing electronics. In [19], authors have presented a sea water probe for monitoring multiple parameters intended for sea water quality monitoring Table III represents the sensors used.

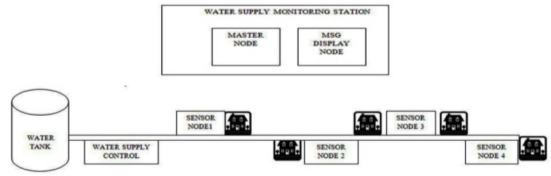

Fig. 1. Water Supply Monitoring Station

TABLE III
SENSOR NODE SPECIFICATIONS

S.No	Sensor Probes / Parameters	Temperature Sensor	pH Sensor	Electrical Conductivity Sensor	Turbidity Sensor	ORP Sensor
1	Output	4-19mA	4-19mA	4-19mA	4-19mA	4-19mA
2	Range	-50° C to + 50° C	0-14 pH	0-5000 µS	0-100% DO	-500mV to +500mV
3	Accuracy	±0.2° F or ±0.1° C	2% of full scale	1% of full scale	+/- 0.5% FS	2% of full scale
4	Operating Voltage	10-36 VDC	10-36 VDC	12 VDC (+ 5%)	10-36 VDC	10-36 VDC
5	Current Draw	Same as sensor output.	16.6 mA plus sensor output	6.5 mA plus sensor output	11.8 mA plus sensor output	13.5 mA plus sensor output
6	Warm Up Time	5 seconds minimum	3 seconds minimum	3 seconds minimum	10 seconds minimum	3 seconds minimum
7	Operating Temperature	-50°C to +100°C	-5° to +55°C	-40°C to 55°C	-40° to +55°C	0° to +55°C
8	Size of Probe	3/4" diameter x 4 1/2" long	1/4" diameter x 10" long	1" diameter x 12" long	1 ¼" diameter x 11" long	1" diameter x 10 ½" long
9	Weight	1/2 lb	1 lb.	1 lb	1 lb	1 lb

IV. SYSTEM DESIGN

A. Hardware Design

The master node controls all the sensor nodes and the entire water supply system. The message display node displays the quality of the water to the administrator of the municipal office with the specified sensor node ID and the exact location where the water is contaminated as in Fig. 1. It acts as an alert to the occurrence of the contamination. The sensor nodes are placed at regular intervals based on the topology designed in the ns-2 simulation.

B. Monitoring Station

The ZigBee module in the administrator monitoring station acts as a master node which is connected to the system that communicates with all the sensor nodes wirelessly and helps to transfer the water quality data from remote area to the system at regular intervals as in Fig.2. It sends signal and controls the solenoid valve for automatic shut off and on.

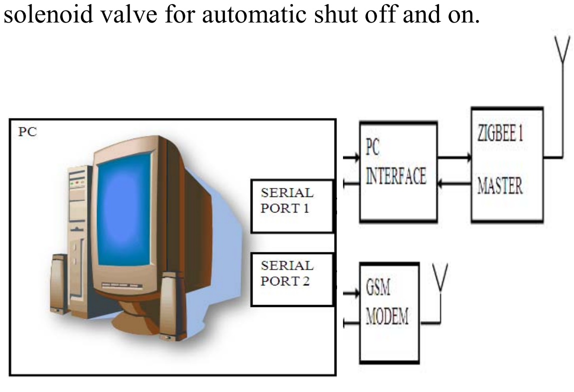

Fig. 2. Administrator Monitoring Station

C. *Design of Sensor Unit*

The zigbee module in the sensor unit acts as a slave node and works when it receives the signal from the other zigbee module in the administrator office monitoring station, which is the master node. The solenoid value is connected with the relay and driver, it stimulates the value to close automatically when it receives signal from the MCU as water is contaminated and open the value when the quality of the water is good as in Fig.3. The sensor unit has an arduino board, where the routing and event contamination detection algorithms are embedded. The control unit is connected with the solar panel from where it receives the necessary power needed. It helps us to install the sensor unit in the remote location. The circuit diagram for the sensor unit design is represented as shown in the Fig.4.

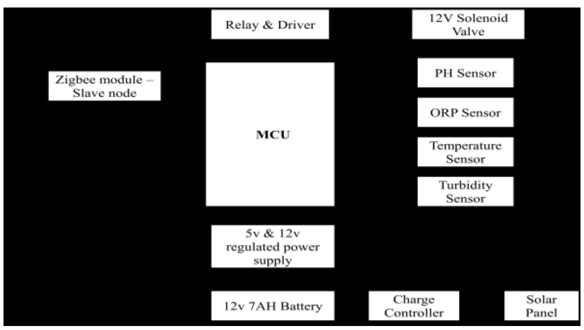

Fig. 3. Sensor Unit Design – Slave Node

The sensor unit – slave node is designed in such a way that it monitors the quality parameters of the water using a relay unit and interfacing components. The outputs of the sensor real time reading are displayed in the LCD and at the serial monitor of the arduino software. The sensor unit slave node is as designed in Fig.5. The sensed data are transmitted wirelessly to the mobile unit using the SIM900 module as shown in the Fig.6.

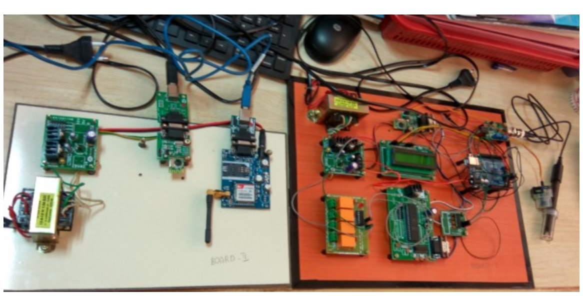

Fig. 6. Transferring sensed data to mobile unit

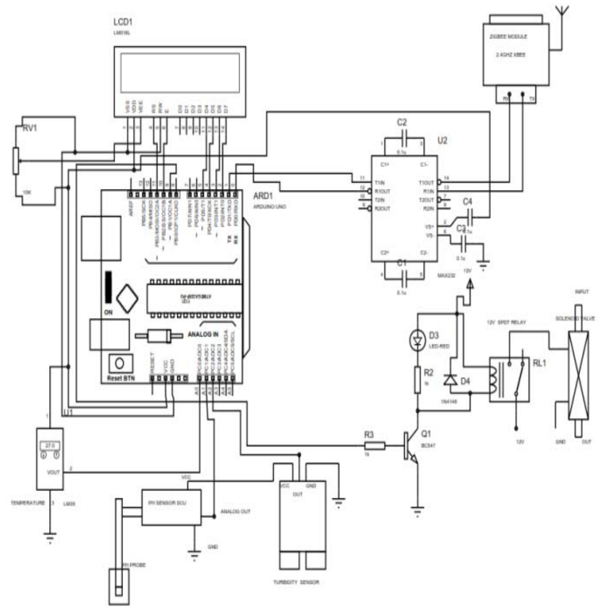

Fig. 4. Circuit diagram of the sensor unit design - Slave Node

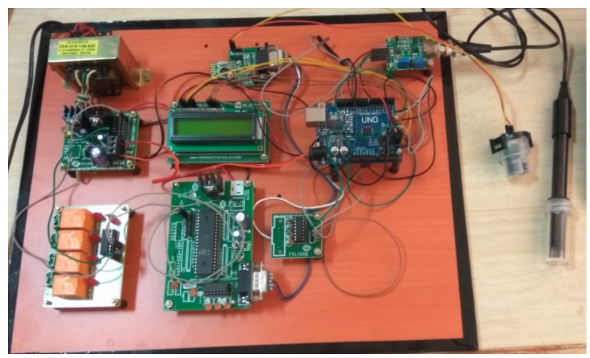

Fig. 5. Sensor unit module – slave node

Finally, a notification message is sent to the consumer/public as shown in Fig.7. It displays all the water quality parameters and quality of water is predicted as accepted, desirable and rejected. The Fig.8. displays the real time sensing from the sensors with the respective House Identification Number (HID), where the history of records are stored in the Municipal Admin database.

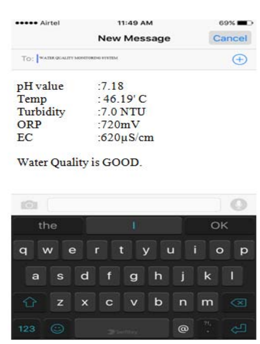

Fig. 7. SMS to consumers regarding water quality

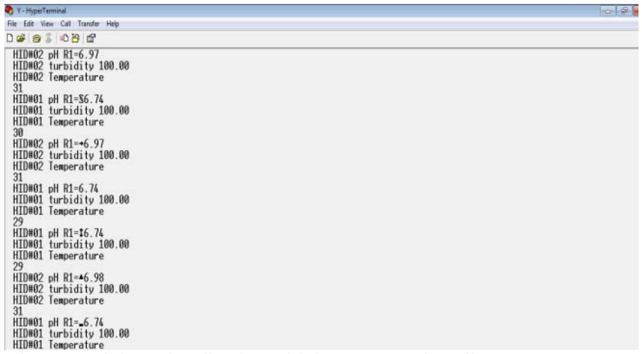

Fig. 8. Real time visualization with house ID and quality parameter values

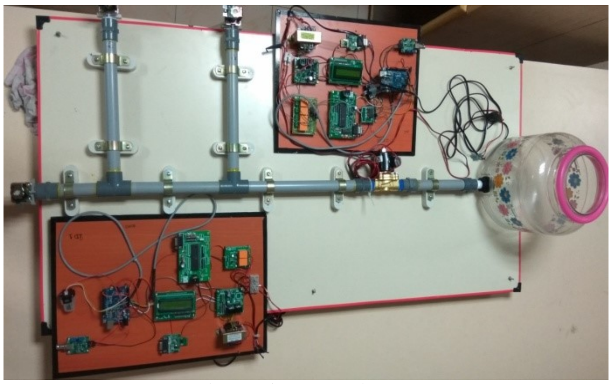

Fig. 9. The system layout

Hence, the proposed water quality monitoring system as in Fig.9. has improved energy efficiency, detects the water contamination with better accuracy as of fuzzy rules are applied, maximizes water quality monitoring level and overall the network lifetime is maximized.

V. Conclusion And Future Work

The paper describes the recent development in the field of in-pipe real time contamination detection system. Also, a low cost, less complex water quality monitoring system is proposed. The implementation enables sensor to provide online data to consumers. The experimental setup can be improved by incorporating algorithms for anomaly detections in water quality. The real time data are analysed using fuzzy logic and uploaded over the internet. When contamination is detected in the water, the system sends an alarm/alert to the consumers regarding the water quality parameters and prevents the further flow of water in the contaminated region in the pipe using a solenoid valve. The results demonstrate that the developed system is capable of analyzing the water quality parameters in real time and can successfully process, transmit data to the cloud and intimate the users about the contamination.

Acknowledgements

This work is jointly supported by Department of Science and Technology, Government of India under Water Technology Initiative (WTI) scheme with [Grant Number: DST/TM/WTI/2K14/216].

References

[1] WHO. (2011). *Guidelines for Drinking-Water Quality*, accessed on May 31, 2016. [Online]. Available:http://www.who.int/water_sanitation_health/publications/dwq-guidelines-4/en/.

[2] Central Ground Water Board (2017) Ministry of Water Resources, River Development and Ganga Rejuvenation, Government of India. http://cgwb.gov.in/. Accessed 24 July 2017.

[3] M. Goldblatt, ``Realising the right to sufficient water in South Africa's cities," *Urban Forum*, vol. 8, no. 2, pp. 255-276, 1997.

[4] S. Heleba, ``The right of access to sufficient water in South Africa: How far have we come?" *Law, Democracy Develop.*, vol. 15, no. 1, pp. 10-13, 2011.

[5] D. V. Chapman, *Water Quality Assessments: A Guide to the Use of Biota, Sediments, and Water in Environmental Monitoring*, 2nd ed. London, U.K.: F and FN Spon, 1996.

[6] O. Korostynska, A. Mason, and A. Al-Shamma'a, ``Monitoring pollutants in wastewater: Traditional lab based versus modern real-time approaches," in *Smart Sensors for Real-Time Water Quality Monitoring*, vol. 4. The Netherlands: Springer, 2013.

[7] A. Dufour, M. Snozzi, W. Koster, J. Bartram, E. Ronchi, and L. Fewtrell, *Assesing Microbial Safety of Drinking Water: Improving Approaches and Methods*. London, U.K.: IWA Publishing, 2003.

[8] J. Hall *et al.*, ``On-line water quality parameters as indicators of distribution system contamination," *J. Amer. Water Works Assoc.*, vol. 99, no. 1, pp. 66-77, 2007.

[9] M. V. Storey, B. vander Gaag, and B. P. Burns, ``Advances in on-line drinking water quality monitoring and early warning systems," *Water Res.*, vol. 45, no. 2, pp. 741-747, 2011.

[10] O. Postolache, P. S. Girao, J. M. D. Pereira, and H. Ramos, ``Wireless water quality monitoring system based on field point technology and Kohonen maps," in *Proc. IEEE Can. Conf. Elect. Comput. Eng. (CCECE)*, vol. 3. Montreal, QC, Canada, May 2003, pp. 1873-1876.

[11] K. Yifan and J. Peng, ``Development of data video base station in water environment monitoring oriented wireless sensor networks," in *Proc. Int. Conf. Embedded Softw. Syst. Symp.*, Sichuan, China, Jul. 2008, pp. 281-286.

[12] Eliades D, Lambrou T, Panayiotou C, Polycarpou M (2014) Contamination Event Detection in Water Distribution Systems using a Model-Based Approach. In: 16th Conference on Water Distribution System Analysis. 14–17 July 2014.

[13] P. Jiang, H. Xia, Z. He, and Z. Wang, ``Design of a water environment monitoring system based on wireless sensor networks," *Sensors*, vol. 9, no. 8, pp. 6411-6434, 2009.

[14] B. O'Flynn, F. Regan, A. Lawlor, J. Wallace, J. Torres, and C. O'Mathuna, ``Experiences and recommendations in deploying a real-time, water quality monitoring system," *Meas. Sci. Technol.*, vol. 21, no. 12, pp. 4004-4014, 2010.

[15] W.-Y. Chung, C.-L. Chen, and J.-B. Chen, ``Design and implementation of low power wireless sensor system for water quality monitoring," in *Proc. 5th Int. Conf. Bioinform. Biomed. Eng. (ICBBE)*, Wuhan, China, May 2011, pp. 1_4.

[16] M. Nasirudin, U. N. Za'bah, and O. Sidek, ``Fresh water real-time monitoring system based on wireless sensor network and GSM," in *Proc. IEEE Conf. Open Syst. (ICOS)*, Langkawi, Malaysia, May 2011, pp. 354_357.

[17] F. Adamo, F. Attivissimo, C. G. C. Carducci, and A. M. L. Lanzolla, ``A smart sensor network for sea water quality monitoring," *IEEE Sensors J.*, vol. 15, no. 5, pp. 2514_2522, May 2015.

[18] X. Jin, J. Shao, X. Zhang, W. An, and R. Malekian, ``Modeling of nonlinear system based on deep learning framework," *Nonlinear Dyn.*, vol. 84, no. 3, pp. 1327_1340, 2016.

[19] Francesco A, Filippo A, Carlo GC, Anna ML (2015) "A Smart Sensor Network for Sea Water Quality Monitoring". IEEE Sensors J 15(5):2514–2522.