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Review of In-line Water Quality Measurement Systems

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***Abstract*—Water is most essential in the existence of life and hence need for monitoring its purity is ever rising. With rapid urbanization, our water networks have grown steadily, which is pushing forward the need to monitor water quality from the piping network itself to ensure safety and hygiene. Systems developed for the purpose of monitoring inline water quality, check varying parameters usually with a node pipe section, having multiple sensors integrated to it. These systems are difficult to integrate into already developed piping networks and also maintenance of such systems becomes challenging which in return affects system performance over time. The purpose of this study is to have a review highlighting the advantages and limitations of existing inline monitoring systems and provide better insights to actual deployment alongside further development in the domain where existing piping infrastructure is disturbed to a minimum.**

***Index Terms*— In-line, Real-time, Internet of Things, pH, ORP.**

I. INTRODUCTION

Water being a universal solvent, is prone to several types of contamination that need to be monitored. Increasing deterioration of drinking water quality at the consumer end is a worrying trend and hence demands a better system to monitor water quality in piping networks. Piping networks may in-house a point contamination source that can be detected with variation obtained from measured parameter values of various nodes. Also, the varying types of impurities and deterioration caused to the system because of it makes it difficult for a complete system to work with expected accuracy. These systems beyond conventional requirements of accuracy, range, and resolution must also be easy to maintain and less power consuming. A significant development in this domain will make water quality monitoring in complex urban piping networks relatively efficient and simple. Here we discuss existing reviews with their arguments concerning inline measurement to establish a context; then discuss the performance of different systems and comment on the overall advantages and drawbacks for inline implementation of the system. These systems integrate sensors that function on the same principles practiced in efficient lab-based methods, in Fig. 1 techniques for monitoring are listed.

The required and/or recommended ranges for human consumption of each water parameter have already been determined by the WHO guidelines [1] are specified ranges are given in Table 1. Here a detailed discussion on existing in-line monitoring methods, followed by its analysis along with a description of measurement principle or device for discussed systems is given in a tabular format.

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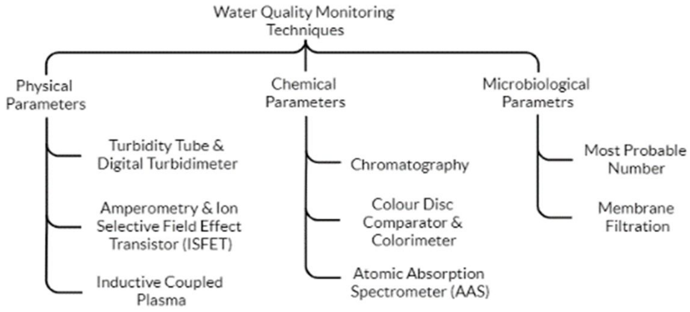

Fig. 1: Common Water Quality Monitoring Techniques for different Parameters

TABLE I. PARAMETERS FOR WATER QUALITY MEASUREMENT

	Parameter	Units	Quality Range
1	Temperature	°C	-
2	pH	pH	6.5-8.5
3	Electrical Conductivity	μS/cm	500-1000
4	ORP	mV	650-800
5	Free Residual Chlorine	mg/L	0.2-2
6	Nitrates	mg/L	< 10
7	Dissolved Oxygen	mg/L	-
8	Turbidity	NTU	0-5

II. LITERATURE REVIEW

Inline water quality measurement requires measurement of chemical, physical, and biological parameters to ensure the highest utility of the system. Novel concepts and techniques are rapidly replacing conventional techniques in water quality parameter detection, which are more user friendly and economic [2]. Many existing reviews have widely covered the advantages and drawbacks of standardized drinking water parameter testing and microwave-based in terms of physical, chemical, and microbiological parameters [3]. Separate conventional lab-based methods for small spectra of varied contamination cannot be separately deployed as it increases system cost and maintenance. Measuring parameters of three different categories is necessary as there exists interdependence among them as seen in temperature, pH, conductivity, and microbial film. Existing systems discusses real-time monitoring of parameters and centralized monitoring for wide-scale application. Due to different complex matrices and different measurement environments, an integrated water quality monitoring system remains a challenge. The Inline systems environment is predictable up to a certain degree, which opens scope for use of advanced bio-sensors, spectroscopy, and optical sensors for accurate and efficient performance. However, there are many restrictions that need to be addressed to develop a one-stop system for inline measurement. Below systems are described in detail, highlighting their peculiarities and limitations.

A. A Low-Cost Sensor Network for Real-Time Monitoring and Contamination Detection in Drinking Water Distribution Systems [4]: This system enables implementation which is less in cost, power consumption, and uses tiny in-pipe sensors. The system also includes contamination event detection algorithms that have been developed and validated to allow the sensor nodes to compare and make decisions and trigger alarms when abnormal readings are detected. Parameters monitored in this system include Turbidity, ORP, pH, Electrical Conductivity, and Temperature. The mentioned algorithm can be of very much utility as it activates no false alarm in tests with arsenic impurity and also signals the presence of lower levels of impurity. For part of microbial content, it takes into consideration only e-coli bacteria, which can be further improved. The system provides the required measurement parameters for drinking water with reliable accuracy and resolution.

B. Design of Smart Sensors for Real-Time Water Quality Monitoring [5]: This system can display measured real-time physicochemical parameters directly to the mentioned user. The system does not monitor biological parameters but monitors flow, temperature, pH, conductivity, and the oxidation reduction potential (ORP). Simulation results of sensor performance of the system were on par with actual test results. Raw sensor values obtained after specific signal conditioning circuits were wirelessly transmitted to notification nodes via the wireless XBee modules. It provides local and remote monitoring along with a detailed description of signal conditioning for all sensors. This system provides reliable data within the mentioned range for selected parameters and enables users to monitor nodes remotely.

C. Water Quality Monitoring System Based on IOT [6]: This system enables real-time measurement of physical parameters involved in water quality measurement. A detailed description of measurement for pH, temperature, and turbidity is given along with an explanation for particular sensor selection. The system uses Arduino and ESP8266 which is an open-source for system development and provides connectivity to subsystems to App. The system also provides local monitoring via LCD which is equal to the value received by App. The system's future scope discusses the inclusion of more sensors and actuators like a relay and making connectivity more secure. This system requires a significant change in hardware and program to get enabled for multiple usages, it gives a good preliminary idea for the development of such systems from scratch.

D. Smart Pipe: A Miniaturized Sensor Platform for Real-Time Monitoring of Drinking Water Quality [7]: It is a really well-designed pipe node which has integrated sensors with low cost and high resolution for measurement along with advanced features like being self-powered and predictable maintenance. Self-diagnostics is done by impedance monitoring and then detachment of biofilm from electrodes triggered by UV activated TiO2. Parameters under consideration are pH, Conductivity, temperature, biofilm monitor. System integration for remote monitoring was done using GSM because of its ubiquitous coverage, long-range distance, and no demand for local infrastructure such as Wi-Fi, making it ideal for actual implementation to widely distributed piping networks. This node pipe can be installed prior to the installation of piping systems as later would need to make changes in existing infrastructure.

E. Design of smart sensors for real-time drinking water quality monitoring and contamination detection in water distributed mains [8]: This system is a low cost, lightweight system and also consumes less power alongside being able to log bulk data and transfer to remote locations. The system takes the following physicochemical parameters into consideration, which are Temperature, turbidity, pH, Conductivity, and ORP. The system addresses a major issue of signal attenuation at high frequencies by using separate communication links for low and high-frequency output. The system classifies water samples as contaminated or non-contaminated; based on which it is further classified as Accept, Reject, or Desirable. The SMS alert and mobile app feature ensure the safety check of drinking water, it displays all the quality parameter values and after doing analysis and using fuzzy logic, the water quality is predicted as good. This system is efficient for monitoring limited water quality parameters in piping networks where weight and power efficiency constraints are rigid.

F. Design and Implementation of a Low-Cost Real-Time In-Situ Drinking Water Quality Monitoring System Using Arduino [9]: This system developed on an open-source platform with limited parameters to measure water quality provides a reliable real-time continuous measurement with low cost of development. The system measures fewer parameters but has given a detailed description of the calibration of each sensor, and a relationship between parameters was established. This system had intensive testing for all sensors with changing conditions to measure pH, conductivity, TDS, and turbidity. It demonstrated parameter measurement in simulation and in experimentation nearing 99% accuracy. This system with further modifications can be implemented to make a more robust system that can cater to in-field challenges.

G. IoT based Automation of Real Time In-Pipe Contamination Detection System in Drinking Water [10]: This system provides a good prototyped working model monitoring several parameters along with wireless connectivity. It deploys the use of TiO based thick film pH resistive sensor which can be directly connected to the microcontroller eliminating the need for a signal conditioning circuit. The administrator uses the Zigbee module and the sensor node uses a SIM900 module to transmit sensor data. The system is ideal to be implemented in a residential water distribution network as it also provides information about respective House Identification Number (HID), where the history of records is stored in the Municipal Admin database. The inclusion of more parameters for monitoring can provide a larger scope of deployment for the system.

H. A 7-Parameter Platform for Smart and Wireless Networks Monitoring On-Line Water Quality [11]: The sensing node is a compact instrumented pipe section to be inserted in main ducts or along with derivations in the most significant spots of the network which can be identified by proper modelling. Parameters to be monitored are pH, temperature, conductivity, the thickness of micrometric deposit fouling the pipes, flow rate, and pressure where in-flow measurement is possible. Sensor pipe nodes need to be connected in series with existing infrastructure, demanding its inclusion from greenfield projects or heavy changes in brownfield projects. This system also manages to recharge its battery and harvesting energy from the velocity of water, data logging, and transmission through the LTE network. This IoT based system focuses more on quality and safety rather than just focusing on leakage detection and remote monitoring indicating higher reliability during infield implementation.

I. A Self-Powered Wireless Water Quality Sensing Network Enabling Smart Monitoring of Biological and Chemical Stability in Supply Systems [12]: This robust system takes remote sensing a step further and makes an impactful attempt to make sensor nodes self-powered. The system measures physicochemical and biological parameters like pH, Temperature, Turbidity, Flow rate, Pressure, Conductivity, and Slime thickness measurement. The system provides wireless connectivity using GSM modules at sensor nodes, which yielded really good results in pilot system implementation. A detailed description of the current consumption of all components at various stages of operation was done to calculate the charge cycle of the attached battery. After a certain discharge, the battery can be charged using the kinetic energy of flowing water via the turbine in the system. The system also holds self-diagnostic capability, enabling it to monitor the thickness of biofilm within the piping network. This system demonstrates a ready to implement configuration equipped with calibrated sensors for potable drinking water along with advanced features of self-diagnostic and being self-powered makes it ideal for use.

J. Inline Water Quality Monitoring System (IWQMS) [13]: It describes an automated system that can measure the conductivity of water flowing downwards, by the amalgamation of electromechanical, electrical, and software subsystems. It specifically focuses on how conductivity and salt concentration can be measured without the use of conventional conductometric methods and using capacitive measurement. It measures the electrical conductivity with accuracy close to the standard device accuracy in the calibration range but is limited in the variable resistance which the user must calibrate to measure different water samples in different electrical conductivity ranges. This fact limits the system used in the varying environment but can be of an ideal use for an environment where parameter stays in calibration range. Its implementation can be made more widespread by reducing measurement duration, enable real-time connectivity, and measuring more parameters.

III. OBSERVATION

Advances in the robustness of measurement technology have yielded more accurate and efficient systems. With the Majority of In-line measurement methods requiring installation right from the planning phase of the plumbing system, to amalgamate the system into the existing pipe network changes are needed to be made into existing infrastructure. Also, the structure of the Node system requires it to be easily replaceable for the need of maintenance. The below Table II shows the measurement principle or instrument type used in monitoring parameters across various systems. With the advancement in sensor technology, we observed reduced use of signal conditioning circuits in [10] making the overall system more energy-efficient and economically viable. Using the principle of ultraviolet spectroscopy in [14] and the use of optical sensor and light scattering principle in [15] describes the further scope of development for sensors requiring no contact with water, which will reduce maintenance need and increase the durability of the system. In [16] detailed discussion over hazards of organic impurities and byproducts obtained in the treatment process, and how it can be overcome. Similarly, [17] highlights the use of luminous bacteria for safe measurement of organic impurity for inline applications. Spectroscopy-based ion detection is also an effective method for inline measurement as it involves no contact with water, but it involves complexity as a wide range of ions are needed to be measured and some methods even involve the use of dyes for spectral measurement making them unsuitable for inline monitoring. In [18] planar electromagnetic sensors are used for nitrate detection in water samples, to indicate contamination. For parameters like turbidity [19] uses optical sensors can be utilized in node pipes to make turbidity detection more efficient. Early detection and prediction-based systems will make implementation more utilitarian, in [20] ideal and relaxed conditions are taken into consideration to describe the use of early warning in distributed piping networks.

TABLE II. MECHANISM USED FOR PARAMETER WATER QUALITY MEASUREMENT

	pH	***Turbidity***	***Conductivity***	***ORP***	***Biofilm monitoring***	***Flow***	***Temperature***
A	Galvanic cell, glass electrode	Optical Scattering	Inductive cell, Conductive cell	Galvanic cell, Platinum Electrode	-	Magnetic rotor	RTD
B	Glass electrode	-	Two- or four electrode method	KCL Ag/Ag-Cl Electrode	-	Turbine flow meter	Thermistor

C	Glass electrode	Optical Scattering	-	-	-	Hall Effect sensor	DS18B20 Temperature sensor
D	Ion-selective glass membrane	-	-	-	Planar biofilm monitor	-	Thermistor
E	Glass electrode	Optical Scattering	Conductive cell	Galvanic Electrode	-	-	Thermistor
F	Glass electrode with BNC Connector	Optical Scattering	Conductive cell	-	-	-	LM35
G	Glass Electrode	Optical Scattering	-	-	-	-	Thermistor
H	Glass Electrode	Optical Scattering	Gold connector pin based Conductive cell	-	Impedimetric Deposit Sensor	Flow Meter	Thermistor
I	Glass Electrode	Optical Scattering	Gold Coated Conductive cell	-	Planar Biofilm microelectrode	Hall effect sensor	Thermistor
J	-	-	Capacitive Electrode	-	-	-	-

IV. CONCLUSIONS

Water quality monitoring in widespread distribution networks is a major challenge but with recent up-gradation in technology, real-time monitoring of multiple parameters with great accuracy and reliability has been made possible. Certain systems have also added an aspect of being predictable to predict the next maintenance cycle for each node. The majority of systems limit its use to certain parameters instead of catering to all necessary parameters. Real-time measurement with cost and energy efficiency has been implemented which allows systems to be more suitable for the real world. However, there is a substantial need for the development of systems with a modular design which provides ease in maintenance and long-term operation. Also, the development of cost-effective sensors which can measure parameters without establishing contact with water can make the entire system more durable and less expensive over time.

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