Smart Water Applications in Drinking Water Distribution Systems: A Review

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Abstract. As the basic substance in our bodies, drinking water is facing an intensive environment ever due to complicated reasons like climate change, urbanization, and epidemic diseases. Frequent water scarcity, contamination, and leakage urgently demand a deeper understanding and better management of drinking water distribution systems. Smart water technologies are able to guarantee both drinking water quantity and quality in the form of data collection, data transmission, and data analysis. This review exhibits the current common smart water applications in drinking water distribution systems along with limitations and future scope. A conclusion is shown that smart water applications would definitely have positive effects on better management and decision-making in a long term.

Keywords: Smart Water · Drinking Water Distribution System · Security · Efficiency

1 Introduction

Water is of great significance worldwide as it is involved in almost all aspects of our lives. Conventional drinking water distribution system (DWDS) management is difficult to handle with the increasing water problems, for instance, water scarcity and quality deterioration. To guarantee water security and improve its efficiency, smart water has been introduced to the system in recent years.

Smart water is regarded as a revolution in the water industry to enable governments, enterprises, and organizations to integrate a suite of emerging smart techniques. It provides stakeholders a platform for data collection, data transmission, and data analysis to have a better grasp of drinking water distribution systems. Although smart water in drinking water field has been studied a lot, most of which are reviewed mainly from one single angle such as irrigation. Little attention has been paid to reviewing how these advanced techniques could be applied to drinking water distribution systems systematically. Therefore, this study presents a brief and common framework of the DWDS. On the basis of this, it describes the current widely used smart water applications on DWDSs and related limitations. A general smart water design idea is conceived then, and future scope is given in the last part.

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2 Literature Review

2.1 Drinking Water Distribution System

According to the United States Environmental Protection Agency, DWDS connects raw water sources to end users through a series of components, and the keys of which include pipe networks, storage infrastructures, and appurtenances. Generally, the aim of drinking water distribution system construction is divided into two steps. The basic step is to allocate adequate portable drinking water to customers with sufficient pressure and the second step is to provide them with stable water and higher quality. To achieve these goals, great efforts such as scientific investigations and huge capital investments have been devoted worldwide.

2.2 Water Security

Guarantee access to safe and portable drinking water is crucial to public health and social stabilization. As mentioned by the World Bank [1] in its annual report 2021, over 2 billion people are in shortage of safely managed drinking water. Further, at least 2 billion people drink contaminated water with feces, posing a great threat to drinking water safety. With the help of smart water technology applications, more integrated and comprehensive solutions are able to be provided in both quantity and quality guarantees.

2.3 Quantity Guarantee

Determine the amount of drinking water is the basic step for a drinking water distribution system while water demands are not static in real life. It is affected by dynamic natures, such as precipitation, atmosphere, and humidity. Accurate forecasts with the help of smart techniques, especially for domestic use, enable water utilities to design, manage, and optimize with more reasonable costs and higher efficiency.

Smart water techniques involve drinking water demand simulation mainly in three parts: data collection, model setup, and prediction. Ultrasonic sensors and smart water meters are preferred in continuous and real-time consumption data collection for the dataset generation [4]. Chandrashekar et al. [2] conducted research on domestic water usage with multiple linear regression for small-scale household consumption. 12 Random Forest Models are applied by Xenochristou et al. [3] to show that the weather becomes valuable when predicting water demand under hot temperature.

In spite of geographical limitations, natural events such as seawater intrusion, drought, and contamination result in insufficient drinking water resources to meet national daily demands. In addition, pipe bursts and leakage problems in drinking water supply systems are increasing to unexpected high levels [4].

The Smart Water Gird based on ICT (information and communication technology) is developed to enable a reliable resource risk management by integrating all water infrastructure, including alternative resources like desalinated water. The South East Queensland (SEQ) Water Grid from Australia and Water Supply Network Department in Singapore have successfully applied this new approach [5]. In this grid, water can be controlled and moved to the needed place by using bi-directional water pipelines, and multiple alternative resources can be introduced to solve the water scarcity problem.

2.4 Quality Guarantee

Conventional monitoring and measurements of water quality are often discontinuous and non-instant. In contrast, smart water quality is monitored remotely by means of real-time data acquisition, transmission, and processing, based on which evaluation, prediction and risk management can also be conducted.

Optical eventLab, a probe developed by Optiqua Technologies, provides a real-time online monitoring solution to continuously measure color, organics, and turbidity. This sensor with the risk assessment approach is used in the European Project 'SmartWater4Europe' to detect early water contamination, providing clues in identifying priorities of contaminants. An automated Internet of Things (IoT) based water quality monitoring system is able to detect various water bodies remotely in real-time by using Arduino to integrate multiple sensors and GSM module [6].

2.5 Water Efficiency

In drinking water distribution networks, water efficiency commonly refers to the water loss reduction during collection and transportation. Losses caused by pressure, water consumption, pipe materials, distance, aging, low maintenance, and other reasons has aroused great trouble around the world. As main sources of non-revenue water losses, leaks can lead to precious resource waste, potential health risks, and safety dangers. Traditional methods like acoustic detection are proved to be greatly affected by outside factors [7]. Smart water applications could be ascribed to three parts: assessment, detection, and control. Hydraulic parameters like water flow and pressure are measured and monitored by a set of sensors continuously. Extensive platforms are used for data processing, integration, analysis, and decision making.

A workflow based on KNIME platform combining water balance and minimum night flow approach was developed [8] to access leakage automatically at a large-scale campus. According to Merzi & Özkan [9], SCADA program with the continuity equation is able to determine the weakest pressure zones where most possible leaks occur in water distribution networks in Ankara. Computational modeling is more feasible when it distinguishes leakage and non-leakage situations in realistic distribution networks. EPANET software is used to model the distribution networks in CEERI and simulate leak events. With the help of Support Vector Machine, this smart system is able to detect and localize leakages more accurately.

2.6 Constraints

By now, most smart water technologies are merely applied to DWDSs on a laboratory scale while few in large district metered areas. One of the most obvious reasons is that the high investment and costs will not be recovered overnight. Sensors, monitors, meters, and hardware are basic needs, followed by technical support like programming, database setup, operation, and maintenance. As a complicated system, positive adoption is also expected while smart water applications often lack leadership support due to understanding absence [10] in reality, especially for cities with small populations [11]. Data security is an emerging risk restricting households to use smart water applications as privacy leaking and cyber attacks that often occur. Recorded users' personal information and living habits might be used illegally, which requires strong protection strategies.

3 Conclusion

There is no doubt that smart water applications could lead to a better understanding of DWDSs and then well-organized management. This review summarizes smart water applications from the perspective of water security and water efficiency, aiming to help researchers sort out general process when it comes to smart requirements on DWDSs. The whole intelligent process is basically divided into data collection, data transmission, and data analysis. Not only real-time data is available, but also warnings and predictions could be generated by ensuring both drinking water quantity and quality combined with instant leakage detection and remediation. Although limitations of smart water applications are apparent, we could still be confident in their long-term robustness and flexibility. The next step is to make applications cost-efficient. Besides, all application solutions contain a standardized network core that guarantees standard data communication and also complies with safety and cybersecurity requirements [12].

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