Framework of Smart Water System

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Throughout the past years, governments, industries, and researchers have shown increasing interest in incorporating smart techniques, including sensor monitoring, real-time data transmitting, and real-time controlling into urban water systems. However, the design and construction of such a smart water system are still not quite standardized for practical applications due to the lack of consensus on the framework. The major challenge impeding the wide application of the smart water network is the unavailability of a systematic framework to guide real-world design and deployment.

A new and comprehensive smart water framework, including definition and architecture, was proposed in this article. Two conceptual metrics (smartness and cyber wellness) were defined to evaluate the performance of smart water systems. This work calls for broader collaborations in the community of researchers, engineers, and industrial and governmental sectors to promote smart water applications for addressing the increasing water quantity and quality challenges.

Keywords: Smart Water, ; Urban water management ; System Design ; Water digitalization

1. Introduction

The world's urban population has grown rapidly from 1.019 billion in 1960 to 4.117 billion in 2017 [1]. It is estimated that the population will reach 9.7 billion by 2050 [2]. The excessive population growth will cause urgent water problems like water quantity shortage and water quality degradation in urban areas. In the 21st century, the global water sector faces quality and quantity challenges, which are highly related to climate change and population growth [3]. The 2018 Global Risk Report shows that most of the high risks (high-likelihood and high-impact) issues are water-related either directly or indirectly and are currently being exacerbated by climate change [4]. Water crises have become one of the five most significant risks in terms of their societal impacts. Additionally, the breaking of economic growth and unbalanced urbanization can also contribute to water scarcity [5][6]. It is predicted that due to population and industrial growth the percentage of water shortage will increase by 50% and 18% in developing countries and developed countries, respectively, by 2025 [7]. One upcoming water scarcity event will occur in Cape Town, where it is supposed to be the first city to experience day zero but will not be the last if these threats still hold [8][9].

To date, automated control technology (ACT) and information communication technology (ICT) are applied to tackle existing problems in water distribution networks, where both technologies play critical roles in large-scale ACT and ICT applications. A number of study cases around the world consider using smart water metering to monitor water consumption and further track leakage and pipe burst issues in water distribution networks [7]. The real-time measurements can be utilized to improve the accuracy of hydraulic model calibration and forecasting. Real-time control is commonly applied in pumping, valve operation, and scheduling. The water supply efficiency significantly benefits from automatic control technology but the electricity energy efficiency needs optimization in practical applicability. If matched with appropriate and effective ICT or ACT solutions, in the form of a smart water system (SWS), city-wise water issues can be appropriately addressed and managed [10]. In SWS, progress can be made via smart metering (real-time monitoring that transmits data to the utility) and intelligent controlling (real-time feedback and action). For example, the Western Municipal Water District (WMWD) of California utilities have used the SCADA system to manage real-time alarms and automatically operate plants and networks [11]. The implementation of SCADA has been associated with 30% savings on energy use, a 20% decrease in water loss, and a 20% decline in system disruption [12]. In Brisbane City, Australia, the web-based communication and information system tools are used by governments and municipalities to deliver relevant water information to the public, as well as to provide early warnings [13]. Another SWS case is in Singapore, where a real-time monitoring system called WaterWiSe is built, utilizing wireless sensor networks and data acquisition platforms to improve the operational efficiency of the water supply system [14]. Moreover, in San Francisco, the automated real-time water meters are installed among communities for more than 98% of their 178,000 customers to transmit hourly water consumption data to the billing system via wireless sensing networks [15]. This access to frequently updated water consumption information allows engineers to detect water quality events and localize pipe leaks faster than traditional water systems that are still using existing manually-read meters [16]. Given these ACT and ICT applications in water sectors, smart water concepts therefore emerge and stimulate SWS to be widely accepted by stakeholders.

2. A Systematic Framework of SWS

A systematic architecture of SWS is comprised of various layers working synergistically to perform useful functions and applications [17]. Such a system can be represented by a set of components, with specific properties and benefits. In past years, previous studies proposed various versions of SWS to meet their particular demands. The combinations of SWS that are distinguished from traditional water management technologies are put forward herein [18]. However, the scopes and characteristics of such SWS were not identified. Referring to smart power grids, a smart system is an advanced smart grid that includes real-time information sharing through smart measurement and networking [19]. The smart components in SWG imply that a smart water network should comprise smart meters, smart valves, and smart pumps by definition [20]. These smart elements including physical electronic parts, like sensors and microcontrollers, communication protocols, and embedded systems are all folded in the concept of the Internet of Things (IoT), which is the foundation of SWS [19]. The structure of SWS, therefore, should contain three frameworks: the hierarchy framework, technical system, and function framework [21].

In the hierarchy framework and technical system, there are also numerous pieces required. An easy-to-understand architecture of SWS would be preferred. The principals of the smart water network were then explained [22]. This research can be segmented in various layers: (1) physical layer (like pipes); (2) sensing and control layer (like flow) sensors and remote control; (3) data collection and communication layer (like data transfer); (4) data management and display; (5) data fusion and analysis (like analysis tool and even detection, leakage detection, and decision making). Nonetheless, these layers still only contain physical and cyber components and a lack of improvement to the service level. It was proposed that SWS contains 5 layers: the physical layer, sensing layer, and control layer, collection, and communication layer, data management and display layer, and data fusion and analysis layer [23]. They also put forward a bottom-up framework of SWS with 5 layers: sensing layer, transport layer, processing layer, application layer, and unified portal layer, which are based on IoT and cloud computing [23]. Another SWS composed of 4 stages was established to secure the vast amounts of high-resolution assumption data and customized information [24].

The most widely accepted smart water architecture is characterized by five layers: the physical layer, sensing, and control layer, collection and communication layer, data management and display layer, and data fusion and analysis layer. Each segment covers a distinct function in the network [17]. However, all SWS introduced above are under debate since most of them are defined for one particular purpose without complete demonstration. Some of them are for smart water targets, some stress the innovation of mechanism, while others emphasize the application of ICT. Very few of in situ frameworks for understanding SWS are comprehensive and directly applicable for education, research, and public. They lack some critical elements like properties, metrics and case studies, and the ability to guide future research directions. Hence, it is necessary to build a systematic framework of SWS to further the understanding of SWS and accelerate the implementation of SWS. In this study, we adopt and integrate some of the existing architectures to propose systematic architecture. Figure 1 illustrates the authors' conceptual representation of an orderly architecture of SWS within a systematic smart water framework. There are five layers (from bottom to top: instruments layer, function layer, property layer, benefits layer, and application layer) that are proposed in order to understand how systematic architecture is implemented in the SWS framework. Although such a conceptual framework has not been tested in the field, this provides the guidance for engineers to replicate the SWS according to their purposes and application. For instance, a smart water test-bed for educational purposes can be built on the lab by following the SWS framework, while the application layer might be unnecessary in this case [25].

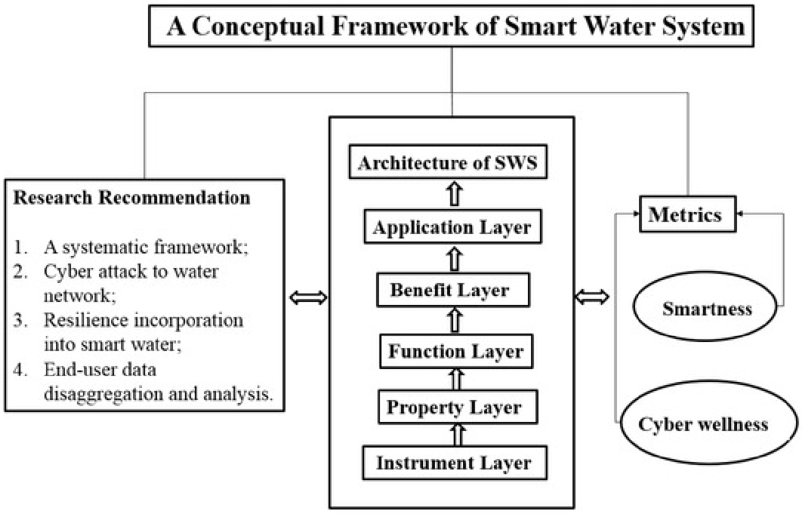

Figure 1. A New Framework of Smart Water System.

3. Metrics for Smart Water System

The technical structure of SWS has a pyramid structure with core information on the top to ensure system efficiency and security [26]. Figure 2 illustrates the features of such a technical structure. In this general structure of SWS, the configuration of components and connections can be interpreted as a network of cyber information (e.g., leak detection, discharge control, and noise recognition), data compiling (e.g., real-time modeling, real-time controlling, and real-time sampling), and physical instruments (e.g., sensors and loggers) domain. In Figure 2, nodes represent system components while the links stand for the functional relationship between nodes. For instance, the bottom nodes are connected with the intermedia nodes, which optionally means that the data from the sensor is transmitted to SCADA via links. To better assess the SWS's efficiency and security within these domains, it is necessary to develop the metrics [27].

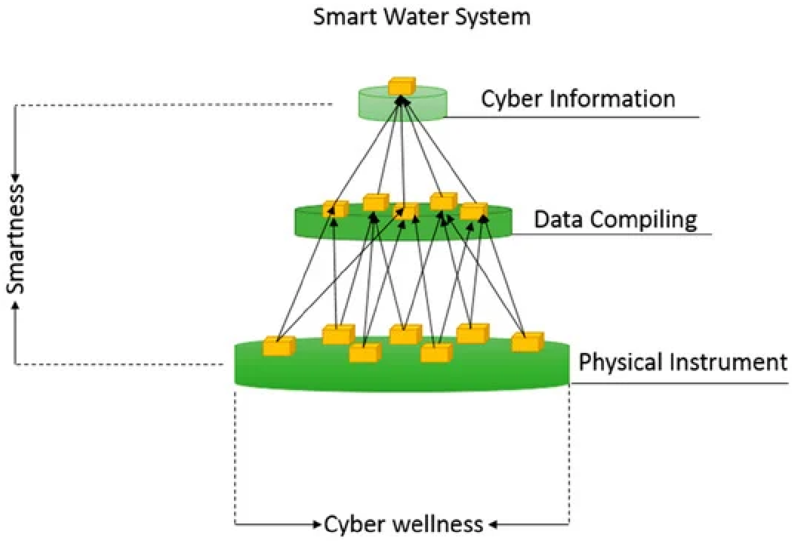

Figure 2. Illustration of a smart water system technical structure.

Before moving to the metrics discussion, the relationship between property and metrics should be clarified. While metrics are refined from properties, and both metrics and properties might be connected by functions, the application of SWS ultimately aims to assess the performance of SWS. Therefore, properties can be seen as the inherent components of SWS whilst metrics are the manual product. Additionally, properties might determine the assessment indexes on a given SWS, while metrics are those elements to achieve the terminal performance. For example, real-time modeling is a crucial property of SWS, which makes measuring the efficiency of SWS one indicator for smartness.

Furthermore, the performance of data processing in the context of resourcefulness is related to information security. However, the effects of property layers on metrics are not certain without specific analysis of a given system. In this section, the paper proposes two new conceptual metrics (Smartness and Cyber wellness) for assessing two essential properties of SWS, efficiency, and security, and discusses how to define these two metrics and how they can be objectively built to deal with threats of SWS.

4. Conclusion

Overall, we have defined what SWS is and established a systematic framework for SWS, including architecture and metrics of SWS, which also shows that SWS has great potential to maximize the benefits in water sectors over the coming decades. This study is useful for designing assessing, and rehabilitating SWS when different goals are required in practical applicability in the field or lab. Future research directions are also clarified for this cross-disciplinary work, to assist the water areas to move towards a smarter future. As smart water technologies are under development, more real-world tests will be needed to realize the full benefits of the smart water system.

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