A Smart IoT System for Water Monitoring and Analysis

João Miguel Santos[1,2](✉), Raúl Carvalho[1], João Carlos Martins[1], João Filipe Santos[1], Patrícia Palma[3,4], Dalmiro Maia[6], João Paulo Barraca[2,5], Diogo Gomes[2,5], Miguel Bergano[2,7], Domingos Barbosa[2], and José Jasnau Caeiro[1]

[1] Dep. de Engenharia, Instituto Politécnico de Beja, Beja, Portugal
{joao.santos,joao.martins,joaof.santos,j.caeiro}@ipbeja.pt, 756@stu.ipbeja.pt

[2] Instituto de Telecomunicações, Aveiro, Portugal
{jpbarraca,dgomes,jbergano,dbarbosa}@av.it.pt

[3] Dep. Technologias e Ciências Aplicadas, Instituto Politécnico de Beja, Beja, Portugal
ppalma@ipbeja.pt

[4] ICT, Instituto de Ciências da Terra, Universidade de Évora, Évora, Portugal

[5] Universidade de Aveiro, Aveiro, Portugal

[6] Faculdade de Ciências da Universidade do Porto, Porto, Portugal
dmaia@fc.up.pt

[7] Escola Superior de Tecnologia e Gestão de Águeda da Universidade de Aveiro, Agueda, Portugal

Abstract. A general architecture for collection and processing of water resources data, in terms of quality and quantity, is presented and discussed. The proposed architecture includes the sensing of physical and chemical water parameters, data communications, and high levels of information processing, namely machine learning. The architecture adopts an Internet of Things perspective and resulted from a survey of the most commonly measured water quality parameters, processing and data acquisition computing modules, and communications hardware and software protocols. It integrates state of the art technologies in the fields of long distance communications, software containers and blockchain technologies. Geographical information is associated with the sensor data. The top layer joins data analysis and machine learning of all the gathered information. Visualization of the raw data and of the results

The authors would like to thank the support from the European Union under the auspices of the Alentejo2020, Portugal2020, FEDER program with the reference ALT20-03-0145-FEDER-039494, to the Project ENGAGE SKA, Infrastructure (ENGAGE SKA), with reference POCI-01-0145-FEDER-022217, financed by Programa Operacional Competitividade e Internacionalização (COMPETE 2020), FEDER, and by the Fundação para a Ciência e Tecnologia, I.P., Portugal (FCT). This work was also funded by FCT and Ministério da Ciência, Tecnologia e Ensino Superior (MCTES) through national funds and when applicable co-funded EU funds under the project UIDB/50008/2020-UIDP/50008/2020.

I. M. Pires et al. (Eds.): GOODTECHS 2021, LNICST 401, pp. 67–79, 2021.
https://doi.org/10.1007/978-3-030-91421-9_6

of the data analysis and machine learning procedures is also part of the system. The integration of weather and remote sensing data, and offline biochemical information is presented in this architecture. The architecture is supported on common commercial of the shelf components and open source software.

Keywords: Internet of Things · Sensing · System architectures · Water resources · Water quality

1 Introduction

Advances in one area of science are eventually accompanied by new possibilities and advances in related or, sometimes, not so related technological areas. On the other way, advances in several fields can motivate and boost the progress in a particular area. As an example, radio astronomy, which moved from a single very large antenna to farms of small simple standalone antennas, disposed as an array, was made possible by the advances in the capability of computers to synchronize and process large amounts of data and fast communications links. This architecture is common to many applications, namely the deployment of sensor nodes to monitor environmental parameters scattered along a region or territory.

The Engage-SKA project[1] aims to make the bridge between radio-astronomy and social good by enabling the transfer of technology to other domains like smart agriculture, environment and water monitoring.

The paper presents a system for monitoring water surface quality and quantity by deploying several monitoring stations along a vast area. It will collect and centralize data in the cloud. The information will be subject to data analysis and machine learning procedures with the addition of data from other sources, namely remote sensing. Water has been considered to be among the main social resources [4], being unlike any other because it is an essential component of all forms of life. Its scarcity and value have always marked the need for its public administration and regulation. Not only the quantity but also an adequate quality is essential for the well-being and health of populations. Therefore, a careful monitoring of water quality and the judicious management of water quantity is a major concern in all countries, particularly in southern Europe, where water is becoming a precious and scarce resource. The need to monitor the water resources is becoming even more relevant in industrialized countries due to pollution and contamination and to the increasing demand of this resource, aggravated by climate change [7]. Smart environmental monitoring, in which smart water monitoring can be included, catalyzes progress in the capabilities of data collection, communication, data analysis and early warning [5].

Recent technological advances in sensors, microcontrollers and communication's technologies, with a significant drop on the energy consumption and cost,

[1] Enable Green E-Sciences for the Square Kilometer Array (Engage SKA), https://engageska-portugal.pt/.

led to the Internet of Things (IoT). For the continuous monitoring of water quality and quantity with the aim to improve efficiency in the use of water resources, IoT based systems may be adopted [11,16,20,21]. Following the study of a set of state of the art papers describing water monitoring systems, the design of the architecture of a smart surface water monitoring system is presented with the corresponding hardware and software infrastructure. The system is designed to employ cutting edge processing platforms, sensors, communications infrastructures and protocols, and cloud based software to provide a complete water quality and quantity monitoring architecture.

The state of the art of smart water monitoring using an IoT approach is the topic of Sect. 2. It presents the results of a survey on published work on this type of systems during the last few years. The latter survey substantiates Sect. 3. It starts with a layer based description of a general system for smart water monitoring and presents a general architecture of a water quality and quantity data collection and analysis IoT based system. The paper concludes with a summary of the main aspects of this work, its relevance for water as a social good and some perspectives for future research in Sect. 4.

2 Smart Water Monitoring

There is not a single method that covers all water monitoring situations and for each case the best method should be investigated to monitor water resources in that particular case [23]. However, there are a couple of architectures that can be applied to a broad range of situations [1,5,8].

Surface water monitoring implies the acquisition of data at a set of different locations along the water surface, at different depths and at regular time intervals [2,6]. The data can be used to establish the water's quality and quantity and, associated with a pattern recognition system and information from other sources, provides the possibility to preview future problems, for example in terms of biological or chemical contamination. It may also provide hints about climate change consequences.

The IoT is playing a major role in monitoring water quality and quantity in real time. An IoT system comprises both the monitoring of a single *thing* or the interconnection of millions of *things*, with the ability to deliver complex services and applications [13].

Among the reasons for the rapid increase on the quantity of IoT systems is the availability of low-cost, energy efficient and powerful hardware for sensing, acquiring, processing and transmitting data to the cloud. Ubiquitous equipment in these systems are microcontroller units (MCUs), cost-effective devices that meet the real-time needs faced by IoT applications with the lower-power constraints of this kind of systems, including data-acquisition (DAQ) and communication capabilities [3]. Also, single board computers (SBC) have become increasingly present in IoT systems. These devices, capable of running a full operating system, increase the capabilities of local nodes, namely by boosting the processing power and data storage [10].

From published reviews on the subject [5,14,18] three main subsystems stand out in a smart water monitoring system: the data collection subsystem, at the device layer; the data transmission subsystem, at the network layer; the data management, including data storage and high level processing, subsystem, at the service support, application support and application layers [9].

The data collection system includes the sensors and the DAQ and pre-processing hardware (mainly built with MCUs and SBCs). The data transmission subsystem includes the transmission hardware and communication protocols. Finally, the data management subsystem includes the data storage, the data visualization and analysis components.

A survey over published work presenting this kind of systems was carried out to collect the most common options and their evolution within these three subsystems. A synthesis of the survey results for the sensed parameters is presented in Table 1. The DAQ and pre-processing hardware is shown in Table 2 and Table 3 refers to data communications.

Table 1. Physical and chemical parameters commonly measured in recently proposed smart water quality systems built within an IoT approach: potential of hydrogen (pH), temperature (T), turbidity (TU), electrical conductivity (EC), dissolved oxygen (DO), water level (W_L), water flow (W_{Fl}), oxidation and reduction potential (ORP), nitrates (NO_3^-), ammonia (NH_3), carbon dioxide (CO_2), nitrites (NO_2^-), total dissolved solids (TDS), ammonium (NH_4^+), sulfates (SO_4^{2-}), carbon monoxide (CO), phosphates (PO_4^{3-}), water depth (W_d), water pressure (W_p), salinity (S). [15–18]

Sensed parameters	# IoT Syst.	Freq.
pH	41	55%
T	40	54%
TU	26	35%
EC	19	26%
DO	18	24%
W_L	10	14%
W_{Fl}	7	9%
ORP	6	8%
NO_3^-	4	5%
NH_3	3	4%
CO_2	3	4%
NO_2^-	2	3%
TDS	2	3%
NH_4^+	1	1%
CO	1	1%
PO_4^{3-}	1	1%
W_d	1	1%
W_p	1	1%
S	1	1%

The most commonly measured physical and chemical water parameters are those that can be obtained from common commercial off the shelf (COTS) sensors: potential of hydrogen (pH), temperature (T), turbidity (TU), electrical conductivity (EC), dissolved oxygen (DO), water level (W_L), water flow (W_{Fl}), oxidation and reduction potential (ORP). The total dissolved solids (TDS) parameter has a very low occurrence but this may be related to the fact that it is usually obtained from the EC value. The same is true for salinity (S), a parameter often present in water quality monitoring systems within aquaculture. Less common measured water parameters are those obtained with more specific sensors, namely ion-selective electrodes: nitrates (NO_3^-), ammonia (NH_3), carbon dioxide (CO_2), nitrites (NO_2^-), ammonium (NH_4^+), sulfates (SO_4^{2-}), carbon monoxide (CO) and phosphates (PO_4^{3-}). Also water depth (W_d) and water pressure (W_p), parameters that are correlated, have a very low occurrence, though they can be measured with commonly used COTS sensors.

Table 2. Devices used for sensor control, DAQ and data pre-processing in recently proposed smart water quality systems built within an IoT approach: Microcontrolers (MCU), Single Board Computers (SBC) and Field Programmable Gate Arrays (FPGA). Though most of the MCUs are used in the form of development boards, the specific chip is listed. [17,18]

Config.	Line	MCU Model	SBC model	FPGA model	# IoT Syst.	Freq.
MCU	ATmega	ATmega8			1	47%
		ATmega16			1	
		ATmega128			1	
		ATmega328			7	
		ATmega2560			3	
		ATmega1281			3	
	ARM32	ESP8266			1	23%
		ESP32			1	
		STM32F767			1	
		STM32F103			1	
		LPC1768			1	
		LPC2138			2	
		LPC2148			1	
SBC	Galileo		GalileoGen2		1	3%
	RPi		RPi B+		1	
			RPi 3		2	
MCU+SBC	ATmega+RPi	ATmega2560	RPi 3		1	6%
		ATmega1281	RPi 3		1	
	ARM32+RPi	Kinetis K66	RPi Zero		1	
FPGA				CycloneV	1	9%
				AlteraNiosII	1	
				PSoC 5LP	1	

MCUs used in these systems usually control the sensors and the data acquisition. Sometimes they also preprocess the data, and send it to the transmission subsystem. They are generally used in the form of development boards. Some of these devices and/or development boards also feature wireless communication capabilities. Most of the systems are made with 8 bits AVR MCUs from the ATmega line. The ATmega328 series, which is the basis of the Arduino development board is the most used. More recent systems include more powerful 32 bits ARM Cortex-M MCUs from several lines, used in the form of development boards. Low-cost and low-energy MCUs from the SMT32 line and from the ESP 8266/32 line, featuring wireless communications capabilities, are used in the most recent systems.

SBCs usually appear in two configurations: either replacing the MCUs for sensors control and DAQ, or working as data aggregators and/or communication gateways. In this latter configuration they receive data from MCU/SBC based sensor nodes, process it and sent the result to a remote server. The majority of these SBCs belong to the Raspberry Pi set of microcomputer boards.

A very small part of the systems use Field Programmable Gate Arrays (FPGA) or a combination of MCU and FPGA for DAQ and pre-processing. It is a solution that gives the possibility of system reconfiguration, but it typically comes at a higher implementation cost.

Table 3. Communication technologies used in recently proposed smart water quality systems built within an IoT approach: technology and range/classification. Local Area Network (LAN), Wide Area Network (WAN), Low Power (LP). [15,17,18]

Technology		# IoT Syst.	Freq.
ZigBee	Short-range/LPLAN	21	43%
WiFi	Short-range/LAN	13	27%
Cellular Networks	Long-range/WAN	14	29%
Ethernet	Short-range/LAN	12	24%
LoRa	Long-range/LPWAN	4	8%
Others	–	4	8%
IEEE 802.15.4	Short-range/LPLAN	3	6%

Communication technologies used in these systems generally include short and long range classes. Some systems use only one class, others include both of them, depending on their configuration: single station, local or remote systems, or multiple sensing nodes (sensor network) systems. All cases may include wired, wireless or both types of communication.

Wired communications are mostly over Ethernet, though there are a few cases of other types such as RS232, RS485, and SDI-12.

Most systems are based on a wireless sensor network, with low-power ZigBee (and other variants of IEEE 802.15.4) being predominant for short-range communications. LoRa technology, despite having a very small expression in the set of systems analyzed, is increasingly popular within the IoT community. It is chosen, in particular, for water monitoring systems, because of its long range and low power features.

We excluded from this description the communication at sensor components and DAQ hardware level, with different protocols like UART, I^2C or SPI.

3 IoT System Architecture for Water Monitoring

The subject of this section is the presentation and description of a general IoT based system architecture for water monitoring. The layer based diagram is discussed in Subsect. 3.1 and it shows how the data starts to be collected at the lowest levels and flows through the system up to the point where it is presented to the users. The system architecture is presented and discussed in Subsect. 3.2. It uses the results of the state of the art analysis and incorporates several diverse data input sources. Namely data collected from sensors, remote sensing and asynchronous file based inputs.

3.1 IoT Based Architectures

An IoT system's architecture may be represented using different types of diagrams [19]. A widely adopted IoT reference architecture organized on layers, where each layer groups modules offering a cohesive set of services, is the one defined by the International Telecommunication Union (ITU). It consists of four layers: devices; network; service support and application support [9].

A layer based diagram for the proposed architecture of a general IoT surface water monitoring system is represented in Fig. 1. At the lowest level, the

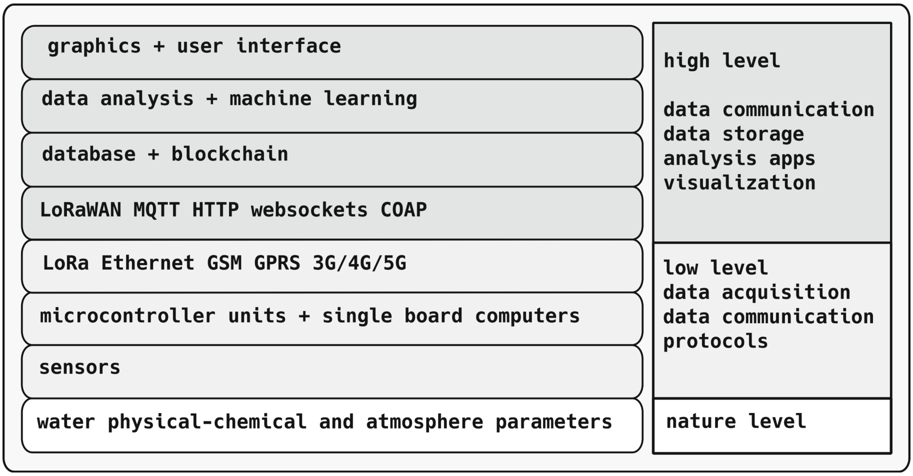

Fig. 1. A layer diagram of a general IoT water data collection system: each layer encompasses modules that offer a cohesive set of services.

nature level, we have the sources of data: surface water and the atmosphere. The parameters information is collected at the device layer, which comprises sensors, MCUs and SBCs. Sensors are at the lower level of the IOT water data collection system. They are responsible for sensing the physical and chemical parameters from the surface water and from the surrounding atmosphere, and convert them to electrical signals. At the next level, MCUs and SBCs acquire these signals, in digital or analog form, and convert them to an adequate digital format, ready to be sent through data communication hardware, to the network layer.

The network layer comprises the communication technologies and data transmission protocols. It is responsible for receiving the data from the data collection subsystem and transport it to other smart *things*, network devices and servers.

The choice of communication technologies is defined by the existing conditions at the data collection site, in particular the geographical conditions, the communications infrastructure and the power sources. As depicted in the diagram, it can be the long-range, low-energy LoRa transmission hardware or other communication technologies: GSM, GPSRS, 3G, 4G, 5G. It may even be the combination of more than one of these technologies. Data exchange protocols are responsible for communications with the service support and the application support layer. The diagram represents a series of application protocols like LoRaWAN, MQTT, HTTP, WebSockets and COAP, commonly used in IoT systems.

The service and the application support layer, represents services that enable IoT applications and services. This level comprises the treatment, analysis and storage of the collected data. The data must be stored and used intelligently for smart monitoring and actuation. In the field of database technology, there are two primary types of databases to store data: relational databases and non-relational databases. There are numerous commercial and open-source options for each form. In certain instances, having different kinds for different tasks is a better option. The use of an external blockchain technology system for data storage and sharing, offers the benefit of providing a safe, easy-to-manage and accessible mechanism to share data among multiple clients due to immutable data and decentralization [22].

To extract high-level knowledge from the collected and stored data the information quality is important. The quality of the information from each sensor depends on several factors, namely errors in measurements, precision and accuracy of the data collection, the devices' environmental noise and the digital conversion of the observation and measurements [12]. Data analysis and machine learning methodologies are nowadays common. IoT systems generate large amounts of data. This is foreseen in this general system architecture. Based on historical data, it is always possible to generate detailed perceptions into past events by using advanced machine learning techniques. The prediction of future events, namely due to climate change, is present in the architecture.

The top level includes the visualization of the collected and processed data. It includes predictions and action suggestions. The integration of geographic information system (GIS) and the usage of remote sensing tools and data provides a rich integration of information from *in-situ* with that from satellite sources.

3.2 A General Architecture for Smart Water Monitoring and Analysis

The proposed general architecture of a water quality and quantity data collection and analysis system is represented in Fig. 2. This may be divided into, *grosso modo*, the following types of data processing subsystems: data collection, data transmission and data management, which includes storage and high level processing.

The data collection subsystems are: the *water quality module*; the *water quantity module*; the *evaporation module*; the *weather station module*; the *manual data sources* input and the *GIS system*. The *water quality module* includes the acquisition of the most common physical and chemical water quality parameters, as shown in Table 1, namely: total dissolved solids (TDS); dissolved oxygen (DO); turbidity (TU); water temperature (T_W); oxidation and reduction potential (ORP); potential of hydrogen (pH); electrical conductivity (EC). The water pressure (W_p) is included to indicate at what depth the parameters are measured. The MCU, already incorporating the SMBus/I^{2}C protocol, collects data from some of the sensors, namely: pH; T; ORP; DO and EC. The remaining parameters are converted to the digital form using analog to digital converters (ADC) with I^{2}C output. The *water quantity module* acquires the data relative to water flow (W_{Fl}) and water level (W_L), either in digital form or in analogue form with proper ADC circuits. The *weather station module* collects air temperature, air humidity, precipitation, wind velocity and direction, luminosity and UV radiation data. The *evaporation module*, collects the water level variation in a class-A evaporation pan and refills the pan with water when necessary. The *manual data sources* subsystem allows the incorporation of non-periodic bio-chemical data, resulting from water samples analyzed in the laboratory, in the *DBMS data storage*. The *data analysis system* uses this data for more complex machine learning procedures.

There are two types of data communications present in the system. The first type is short distance wireless communication between local system's components. An example is the weather station. The sensors are placed some meters away from the microcomputer unit. The sensors data is captured and decoded with a software defined radio package installed at the microcomputer and afterwards sent to the LoRaWAN gateway. The second type is a long distance wireless communication based on the LoRa hardware and LoRaWAN software protocol architecture. The water quantity, water quality and weather station modules are each considered and registered as devices in the LoRaWAN network/application server. The data sent by these modules is therefore ciphered and uniquely identified in the system. The data is sent through a LoRa gateway registered at the LoRaWAN application server. The LoRa gateway receives the information from the devices that can be placed at distances ranging from some tens of meters to some kilometers away. The LoRa transmission frequency is in the 868MHz band. The LoRa gateway forwards the data through the 3G/4G network using an MQTT broker to publish the data and exchange control data with the LoRaWAN network/application server.

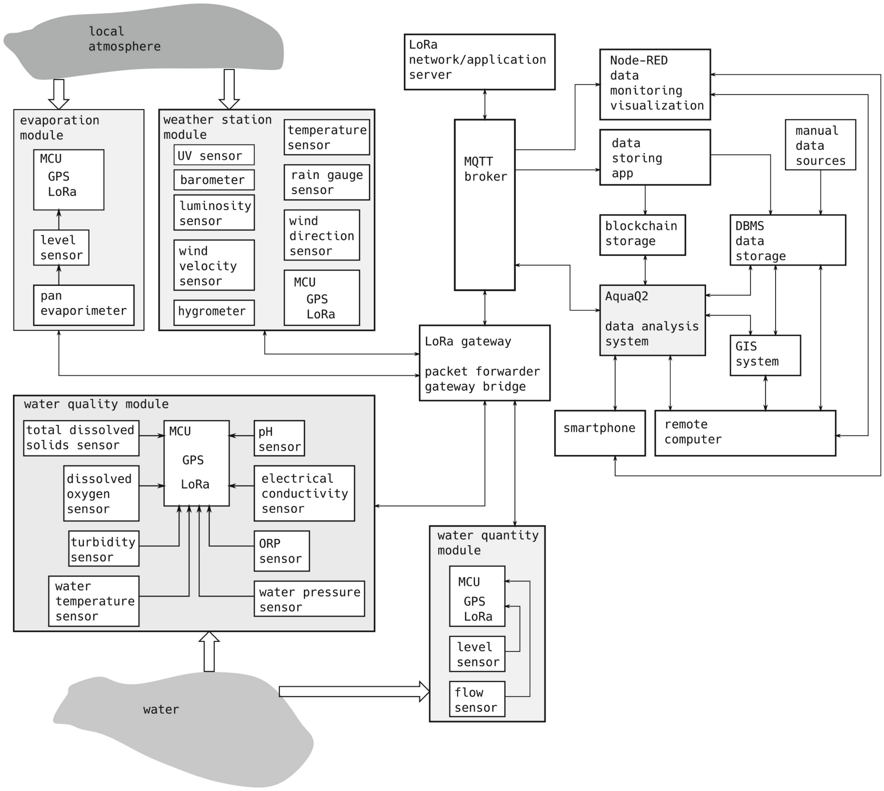

Fig. 2. The architecture of a water quality and quantity system based on the most common elements of an IoT approach.

The servers are launched using a Docker container based infrastructure. Namely the *LoRa network/application* server; the *Node-RED data monitoring and visualization* subsystem; the *data storing app*; the *blockchain storage*; the *DBMS data storage* and the *data analysis* system. The Docker container services are run in a Linux system.

The *Node-RED data monitoring and visualization* system provides a real time view of the status of the sensors using the Node-RED dashboard user interface.

The data storing app subscribes the *MQTT broker* for all the topics from the sensors and stores the information using the *DBMS data storage* server. The latter is a traditional relational model based server with geographical data representation extensions.

The *GIS system* uses the data from the sensors and geographical information data, like maps and remote sensing information, to enhance the data analysis capabilities. A non corruptible data image is maintained using *blockchain storage*. Critical data is kept by this subsystem.

The most complex subsystem in the architecture is the *data analysis system*. A large set of tasks are assigned to this system centralized around a Python based web framework. The system takes the data made available by the *DBMS data storage* server and using machine learning methods, provided by common Python packages, provides high level analysis to the users. This system also incorporates geographical data analysis with a Python based API for the *GIS system*.

4 Conclusions

Water resources have always had primacy among social goods, particularly with regard to water quantity and quality. With the accelerated pace of climate changes, its judicious use becomes more and more pressing and it is crucial to have immediate access to data that reliably characterizes it in order to better manage such a precious resource. The IoT revolution has made possible the collection of vast amounts of data from the physical world, in particular from the environment. IoT-based water and resource quality sensing systems using commercial off-the-shelf (COTS) components provide a fast and scalable way to deploy real-time in *situ* monitoring and data collection solutions. From the analysis of systems that comply with these characteristics a general IoT based architecture is proposed that generalizes the applicability to water resources, not only with a comprehensive set of water quality parameters, but also with water quantity data from in *situ* continuous monitoring. The architecture goes further, adding to the data collected continuously also in *situ* data from other sources: manually collected; remote sensing originated and from GIS, and a modern data analysis system.

The use of modern pattern recognition systems, machine learning and artificial intelligence software, together with techniques to guarantee the reliability of the information, will provide a dynamic, easy-to-follow, insight into the evolution of water quality and water quantity and the consequences of climate change and other human-related activities, such as pollution sources. The concrete implementation of cost-effective devices under the framework of this general architecture is underway in order to build a complete prototype of the proposed Smart IoT System for Water Monitoring and Analysis. Future work includes the testing of the prototype on location to begin the initial deployment of the whole system.

References

1. Andres, L., Boateng, K., Borja-Vega, C., Thomas, E.: A review of in-situ and remote sensing technologies to monitor water and sanitation interventions. Water **10**(6), 756 (2018). https://doi.org/10.3390/w10060756
2. Chapman, D.V., World Health Organization, UNESCO U.N.E.Programme: Water Quality Assessments: A Guide to the Use of Biota, Sediments and Water in Environmental Monitoring, 2nd edn. E & FN Spon, London (1996)

3. Cheour, R., Khriji, S., Abid, M., Kanoun, O.: Microcontrollers for IoT: optimizations, computing paradigms, and future directions. In: 2020 IEEE 6th World Forum on Internet of Things, WF-IoT 2020 - Symposium Proceedings, pp. 1–7 (2020). https://doi.org/10.1109/WF-IoT48130.2020.9221219
4. Day, D.: Water as a social good. Aust. J. Environ. Manag. **3**(1), 26–41 (1996). https://doi.org/10.1080/14486563.1996.10648341
5. Dong, J., Wang, G., Yan, H., Xu, J., Zhang, X.: A survey of smart water quality monitoring system. Environ. Sci. Pollut. Res. **22**(7), 4893–4906 (2015). https://doi.org/10.1007/s11356-014-4026-x
6. EPA (ed.): Parameters of Water Quality: Interpretation and Standards. Environmental Protection Agency, Ireland (2001)
7. Gaaloul, N., Eslamian, S., Katlane, R.: Impacts of climate change and water resources management in the Southern Mediterranean countries. Water Prod. J. **1**(1), 51–72 (2020). https://doi.org/10.22034/wpj.2020.119476
8. Huang, C., Chen, Y., Zhang, S., Wu, J.: Detecting, extracting, and monitoring surface water from space using optical sensors: a review. Rev. Geophys. **56**(2), 333–360 (2018). https://doi.org/10.1029/2018RG000598
9. Telecommunication Standardization Sector of ITU: ITU-T Recommendation Y.4000/Y.2060 : Global Information Infrastructure, Internet Protocol Aspects and Next-Generation Networks, Next Generation Networks-Frameworks and Functional Architecture Models, Overview of the Internet of Things. ITU (2012). https://www.itu.int/rec/T-REC-Y.2060-201206-I
10. Johnston, S.J., Apetroaie-Cristea, M., Scott, M., Cox, S.J.: Applicability of commodity, low cost, single board computers for Internet of Things devices. In: 2016 IEEE 3rd World Forum on Internet of Things (WF-IoT), pp. 141–146 (2016). https://doi.org/10.1109/WF-IoT.2016.7845414
11. Li, D., Liu, S. (eds.): Water Quality Monitoring and Management. Elsevier, Amsterdam (2019)
12. Mahdavinejad, M.S., Rezvan, M., Barekatain, M., Adibi, P., Barnaghi, P., Sheth, A.P.: Machine learning for internet of things data analysis: a survey. Digit. Commun. Netw. **4**(3), 161–175 (2018). https://doi.org/10.1016/j.dcan.2017.10.002
13. Minerva, R., Biru, A., Rotondi, D.: Towards a definition of the internet of things (IoT). Technical report. IEEE (2015)
14. Olatinwo, S.O., Joubert, T.H.: Enabling communication networks for water quality monitoring applications: a survey. IEEE Access **7**, 100332–100362 (2019). https://doi.org/10.1109/ACCESS.2019.2904945
15. Olatinwo, S.O., Joubert, T.H.: Energy efficient solutions in wireless sensor systems for water quality monitoring: a review. IEEE Sens. J. **19**(5), 1596–1625 (2019). https://doi.org/10.1109/JSEN.2018.2882424
16. Park, J., Kim, K.T., Lee, W.H.: Recent advances in information and communications technology (ICT) and sensor technology for monitoring water quality. Water **12**(2), 510 (2020). https://doi.org/10.3390/w12020510
17. Pule, M., Yahya, A., Chuma, J.: Wireless sensor networks: a survey on monitoring water quality. J. Appl. Res. Technol. **15**(6), 562–570 (2017). https://doi.org/10.1016/j.jart.2017.07.004
18. Santos, J.M., Caeiro, J.J., Martins, J.C., Santos, F., Palma, P.: Physical and chemical water quality parameters sensing IoT systems for improving water productivity. Water Prod. J. **1**(2), 33–46 (2020)
19. Serpanos, D., Wolf, M.: Internet-of-Things (IoT) Systems: Architectures, Algorithms, Methodologies. Springer, Heidelberg (2018). https://doi.org/10.1007/978-3-319-69715-4

20. Tiyasha, Tung, T.M., Yaseen, Z.M.: A survey on river water quality modelling using artificial intelligence models: 2000–2020. J. Hydrol. **585**, 124670 (2020). https://doi.org/10.1016/j.jhydrol.2020.124670
21. Topp, S.N., Pavelsky, T.M., Jensen, D., Simard, M., Ross, M.R.V.: Research trends in the use of remote sensing for inland water quality science: moving towards multidisciplinary applications. Water **12**(1), 169 (2020). https://doi.org/10.3390/w12010169
22. Tseng, L., Yao, X., Otoum, S., Aloqaily, M., Jararweh, Y.: Blockchain-based database in an IoT environment: challenges, opportunities, and analysis. Clust. Comput. **23**(3), 2151–2165 (2020). https://doi.org/10.1007/s10586-020-03138-7
23. World Meteorological Organization (ed.): Planning of Water-Quality Monitoring Systems. No. 3 in Technical Report Series, World Meteorological Organization (2013)