A Cost-Effective Real-Time Monitoring System for Water Quality Management Based on Internet of Things

Gonçalo Marques[1,2](✉) and Rui Pitarma[1]

[1] Polytechnic Institute of Guarda, Guarda, Portugal
goncalosantosmarques@gmail.com, rpitarma@ipg.pt
[2] Instituto de Telecomunicações, Universidade da Beira Interior, Covilhã, Portugal

Abstract. Water is a limited and essential resource to human existence. Furthermore, water management is not only relevant but also a complex task for several applications such as agriculture and industry. Consequently, the water quality must be monitored in real-time not only to detect water contamination scenarios in a useful time for enhanced public health in smart cities but also to improve agricultural productivity. Internet of Things is the pervasive presence of a variety of objects with interaction and cooperation capabilities among them to reach a common objective and can provide the interoperability to develop essential and cost-effective applications for enhanced smart cities and agricultural activities. This paper presents ***iWater***, a cost-effective solution for water quality monitoring based on Internet of Things architecture. This solution is composed of a hardware prototype for water quality analysis and support Web compatibility for data consulting. The results show that the ***iWater*** provides efficient and effective water quality monitoring using integrated communication technology, combining sensitivity, flexibility, and accuracy of measurement in real-time, allowing significant evolution of the current water quality monitoring systems.

Keywords: Agriculture · Enhanced living environments · Internet of Things · Mobile computing · Smart cities · Water quality monitoring

1 Introduction

Water is a limited and essential resource to human existence. Furthermore, ensure water quality is particularly necessary for several applications such as agriculture and industry [1].

The "smart city" concept is a strategic approach to embrace new urban production circumstances in a collaborative framework and to state the significance of Information and Communication Technologies (ICTs) to promote the competitive characterisation of a city [2]. Cities meet exciting difficulties and obstacles to reach socio-economic evolution and daily life purposes. The "smart city" concept aims to be an answer to these obstacles [3]. The smart city is straightly associated with an emerging approach

H. Santos et al. (Eds.): SmartCity 360 2019, LNICST 323, pp. 312–323, 2020.
https://doi.org/10.1007/978-3-030-51005-3_26

to moderate the difficulties created by the urban population increase and accelerated urbanisation [4]. The smart city approach will lead to several consequences at distinguished levels such as consequences on science, productivity, technology, and culture. Moreover, it will also cause ethical issues as the smart city needs to provide correct information access which is essential when before-mentioned data is accessible at a fine spatial scale where people can be recognised [5]. Natural resources such as rivers, lakes and dams are integral to cities, and as such, the context of a smart city cannot overlook the importance of water. Contamination of such water-based resources by the dumping of industrial waste is, therefore, a relevant problem for the health and well-being of citizens. Real-time monitoring of aquatic resources provides a solution to this scenario as it presents the ability to detect possible contamination on time and enables cities to provide a better quality of life to their citizens.

Internet of Things (IoT) can be defined as a ubiquitous behaviour of material things which promote communication and collaboration abilities between them to reach a shared purpose [6–8]. The IoT implementation will produce different consequences on several perspectives of daily living and will be applied in numerous forms such as home automation, enhanced living environments and medical systems [9, 10]. IoT must be considered as a meaningful approach to the design and development of real-time water quality monitoring solutions. The most relevant issue in smart cities is the interoperability of the different technologies; the IoT can provide the interoperability to build a unified urban-scale ICT platform for smart cities [11].

On several agricultural environments, the water quality supervision is essential to ensure the right water conditions for enhanced productivity and efficiency, and it is particularly essential on aquaculture, aquaponics and hydroponics. Using real-time water quality supervision is possible to store and compare the production results with the water quality data and study their direct impact on productivity and product quality. Furthermore, it is possible to detect poor water quality patterns and plan interventions to improve productivity. Regarding the smart city context, a real-time IoT water monitoring system not only can measure the water quality levels in different places and provide data to the municipal authorities to early detect water pollution and plan interventions but also offer a space-time map of water quality evolution for public safety [12]. Therefore, the water quality must be monitored in real-time for enhanced public health and safety.

This paper presents ***iWater***, a cost-effective solution for water quality monitoring based on IoT architecture. This system is based on open-source technologies with several advantages compared to existing systems, such as its modularity, scalability, low-cost and easy installation. The proposed architecture is composed of a hardware prototype for water quality analysis and support Web compatibility for data consulting. This method is based on the ESP8266 with built-in Wi-Fi 2.4 GHz compatibility and incorporates a total dissolved solids (TDS) sensor. The TDS levels are calculated based on electrical conductivity (EC). Dissolved solids are the total weight of all solids that are dissolved in the water. These solids refer to any minerals, salts, metals, cations or anions dissolved in water. In general, the total dissolved solids concentration is the sum of the cations (positively charged) and anions (negatively charged) in the water. Natural processes can originate these minerals or derived from human activities such as agricultural and urban water, which can carry excess minerals, wastewater discharges, industrial wastewater and salt that used to eliminate ice on the road. In fact, according to the World Health Organization, the high concentration of dissolved solids is not associated with health symptoms [13]. However, the analysis and assessment of TDS values evaluation can be used not only to detect in useful time possible water contamination scenarios for enhanced public health and safety in smart cities but also is extremely important to increase productivity and efficiency on agricultural environments. The TDS levels variation indicates the aesthetic characteristics of drinking water and the presence of a broad array of chemical contaminants. On agricultural environments, the TDS levels assessment is particularly relevant for the selection of the fertilisers, which have a direct impact on productivity and product quality. Moreover, both in agriculture and smart city context, the TDS levels must be monitored at least to provide alerts for possible contamination scenarios. The TDS levels supervision can be used as an essential information source to alert the authorities which can behind providing quick interventions to make further validation and tests to make sure that the increase of dissolved solids is not related with contamination scenarios and to ensure water quality.

2 Related Work

Water quality assessment is an essential topic for several agricultural environments such as aquaculture, aquaponics and hydroponics. Aquaculture refers to the cultivation of both marine and freshwater species with the primary objective being to raise fish for consumption. China is not only the world's largest producer, consumer, processor, and exporter of finfish and shellfish but also produces more than one-third of the global fish supply [14]. Hydroponics is a cultivation process where nutrients are administered as mineral nutrients. This method includes numerous benefits such as pest problem mitigation and constant feeding of nutrients while contrasted to conventional cultivation practices [15, 16]. Nevertheless, that approach is high cost, taking into account the energy expenditure contrasted to conventional soil cultivation [17]. Hydroponic cultivation can deliver a higher production rate at a more economical price; however, it additionally holds numerous covered costs [18]. Aquaponics is the symbiotic cultivation of plants and aquatic animals in a recirculating environment which depend on the fish as nutrient-generators. The fish produce waste which is converted to nitrates that are used as plant food through a nitrification process [19]. Therefore, reliable water quality monitoring systems are relevant for enhanced productivity on agricultural environments, particularly on aquaculture, aquaponics and hydroponics.

Numerous monitoring methods for environmental surveillance based on IoT, which combine open-source and mobile computing features are proposed in the state of the art [20–25]. An IoT water monitoring system that includes several sensing capabilities for temperature, light and pH supervision and supports artificial intelligence methods to provide water quality management with 88% of the accuracy is introduced by [26]. A cost-effective monitoring and control system for hydroponic environments which incorporate microcontrollers and open-source technologies for remote access is proposed by [27]. A water monitoring system to support nutrient solution temperature, EC and pH supervision capabilities for non-professional production environments is proposed by [28]. An online water quality supervision system for intensive fish culture in China is proposed by [29]. This system incorporates web-server-embedded features and includes forecast methods to predict water quality data. A wireless sensor network for water quality supervision which includes low-power methods through sleeping mode functionalities was proposed by [30]. A pilot project for water quality monitoring in smart cities was conducted by [31]. The research found positive results in high-frequency data collection and real-time data access.

Smart cities aim to ensure the sustainable use of natural resources in general and water resources in particular [32]. Additionally, with the proliferation of low-cost sensors, there is significant potential to create automated and efficient solutions for environmental monitoring, particularly in the smart city context. The development and test of a specific sensor for monitoring the groundwater salinisation process to optimise water management in smart city environments is proposed by [33].

In conclusion, there are several state-of-the-art applications for water monitoring in the agriculture and smart city context. However, there is a lack of cost-effective and easy to install solutions for enhanced water quality monitoring. The IoT architecture can be assumed as a reliable, cost-effective, easy to install and scalable approach for water quality monitoring; hence, ***iWater*** is proposed by the authors.

3 Materials and Methods

The proposed method is a cost-effective solution that can be easily used and installed by everyone. This solution uses an ESP8266 as microcontroller and communication unit, and a TDS sensor as a sensing unit. In this section, the hardware and software used for the system development will be discussed in detail.

The proposed system aims to provide a valuable tool for water quality monitoring to promote public health and safety in smart cities and improve productivity in agricultural environments. The authors developed a Wi-Fi system using the ESP8266 module, which implements the IEEE 802.11 b/g/n networking protocol. This microcontroller with built-in Wi-Fi capabilities is used both as the processing and communication unit. In the case of agricultural fields without a Wi-Fi connection, a 3G/4G wireless router can be used to provide Wi-Fi availability. The 3G/4G wireless routers are commonly used for several applications and achieve the system communication requirement where broadband cellular network technology is available. The monitored data is stored in a Microsoft SQL Server database using Web services. For data consulting a Web portal named ***iWaterWeb*** has been developed using ASP.NET C# (Fig. 1). The ***iWaterWeb*** and the. NET Web Services are hosted at the same Windows Server instance.

The proposed solution is based on open-source technologies and is a wireless system, with several advantages compared to existing systems, such as its modularity, scalability, low-cost and easy installation. The ***iWater*** incorporates a microcontroller with native Wi-Fi support, a FireBeetle ESP8266 (*DFRobot*) and the TDS sensor module (*DFRobot*) is connected using analogue interface. Figure 2 represents the prototype developed by the authors. A short description of the components used in the development of the ***iWater*** prototype is presented below:

- **FireBeetle ESP8266:** is a wireless board with unified antenna switches, power and low noise amplifiers which is compatible with 802.11 b/g/n protocols. Additionally,

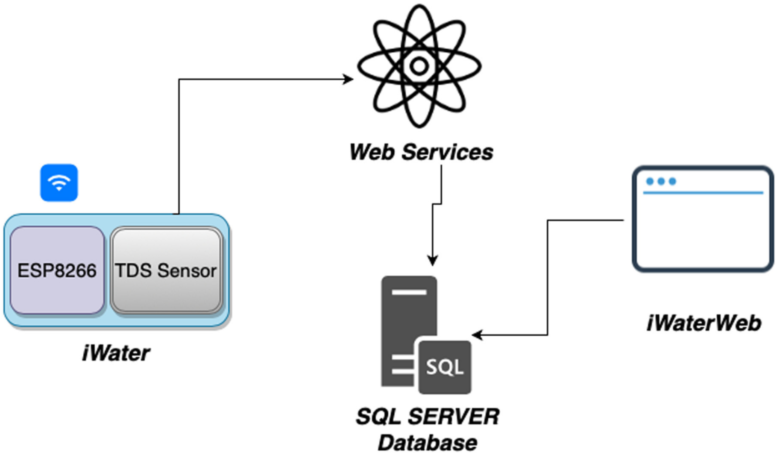

Fig. 1. ***iWater*** architecture.

this board is WPA/WPA2 compatible and includes a 32-bit MCU and 10-bit ADC. The selected board includes a 16 MB SPI flash memory.

- **DFRobot TDS module:** is a TDS sensor that provides reliable readings, supports AC excitation source to prevent the probe from polarisation effectively, and a waterproof probe. The module size is 42 × 32 mm. The operating voltage range is 3.3 V–5 V, and the analogue interface output voltage is 0–2.3 V. The TDS range us 0–1000 ppm and accuracy of ±10% FS (25 °C). The operating power consumption is 3–6 mA.

The sensor module includes an AC signal as an excitation source. The excitation source is able to efficiently block the probe from polarisation, increase the lifetime of the module, and enhance the stability of the sensor output. The sensor probe can be covered in water for extended analysis periods. The sensor module has been selected according to the cost of the system. The main goal of the research study is to test the functional architecture of the proposed method. Nevertheless, a stable and precise sensor module has been selected and supports 10% full scale (FS) accuracy. Additional sensors modules can be combined to control different water conditions.

The proposed method provides easy network configuration procedures. The system is by a standard in client mode. Only if it remains incapable of connecting to any network, it changes the working mode to a hotspot mode. At this moment, the created hotspot can be used to introduce the credentials of the wireless network for Internet access. Figure 3 shows the network configuration method.

The firmware of the ***iWater*** is implemented using the Arduino Core that is an open-source platform that aims to enable the use of standard Arduino functions and libraries directly on the ESP8266 without an external microcontroller. The ***iWater*** is a cost-effective system for enhanced water quality monitoring, which costs an estimated 30.99 USD (Table 1).

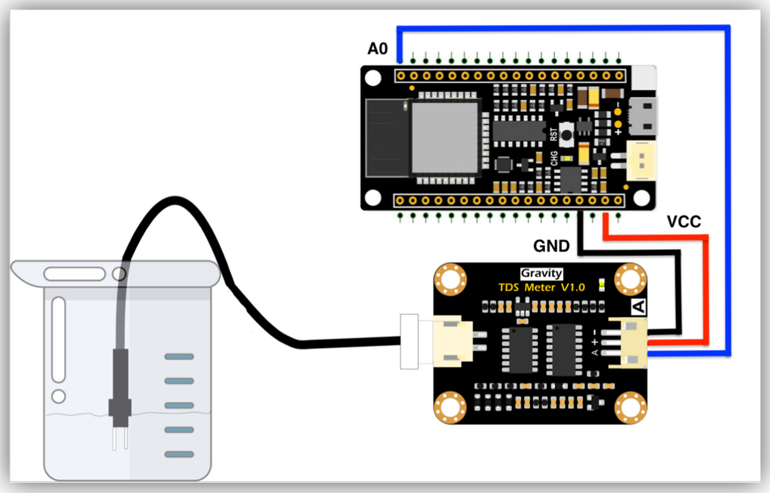

Fig. 2. ***iWater*** component diagram.

The Web application is denominated by ***iWaterWeb*** was developed with C# programming language in Visual Studio. The ***iWaterWeb*** provides real-time water quality monitoring data access using a Web browser. Figure 4 shows the ***iWaterWeb*** application.

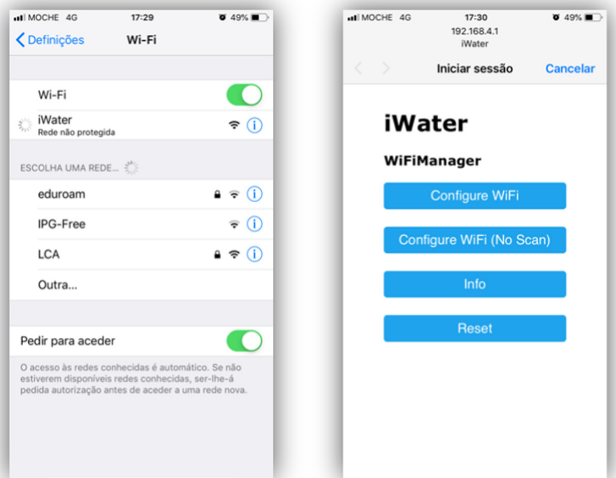

Fig. 3. ***iWater*** Wi-Fi network configuration process.

Table 1. Cost of the ***iWater*** system.

Component	Cost
FireBeetle ESP8266	7.50 USD
DFRobot TDS module	12.90 USD
Cables and box	10.59 USD
Total	30.99 USD

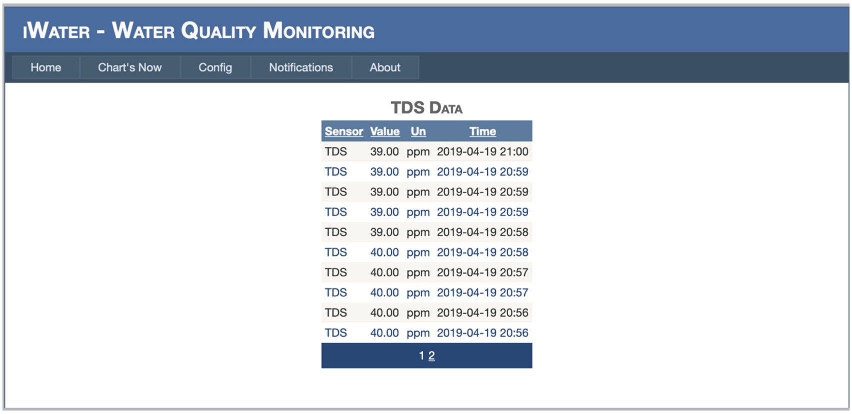

Fig. 4. ***iWaterWeb*** application.

4 Discussion and Results

For testing purposes, the ***iWater*** was mounted inside a glass laboratory volumetric flask. The system was tested with several water samples with different salt concentration. The experimental activities were conducted inside a laboratory of a Portuguese University. Figure 4 presents the water quality supervision experiments conducted by the authors. The module is powered using a 230 V–5 V AC-DC 2 A power supply. The tests show that the proposed water quality monitoring system can be used to detect poor water quality at low-cost. Furthermore, the proposed system can provide TDS monitoring for enhanced productivity in agricultural environments but also to detect possible water contamination by wastewater discharges to promote citizens health and safety.

The information is gathered every thirty seconds; however, this condition can be modified concerning the requirements of the context. The ***iWaterWeb*** offers information access as graphical or statistical methods. An example of the data obtained by the proposed method is presented in Fig. 5. It should be perceived that Fig. 5 presents the results achieved in the physical context with produced simulations. The response time and effectiveness of the proposed method have been tested with different samples of water with distinct salt concentrations. The outcomes assure the capacity to identify TDS levels changes in real-time and confirm a fast sensor response time (Fig. 6).

Fig. 5. ***iWater*** system prototype tests.

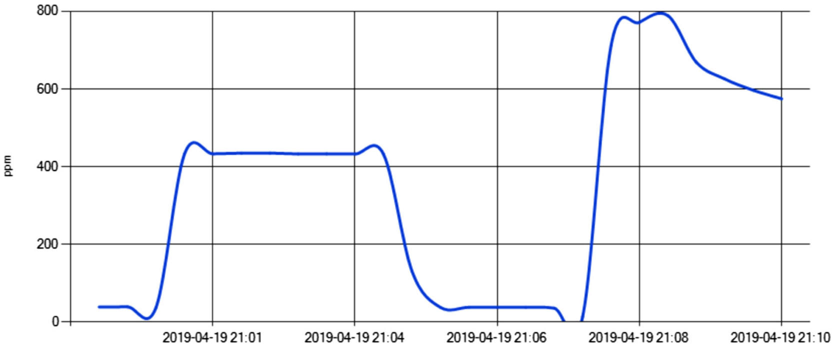

Fig. 6. TDS data collected in the tests performed.

The graphics displaying the TDS levels provide a better perception of the behaviour of the monitored parameters than the numerical format. On the one hand, the ***iWaterWeb*** provides easy and quick access to collected data and enables a more precise analysis of water quality temporal evolution. Thus, the system is a powerful tool for water supervision and to support decision making on possible interventions to increase productivity but also to detect contamination scenarios. On the other hand, the proposed IoT approach provide temporal water quality data for visualisation and analytics, which are particularly relevant to detect unproductive situations and plan interventions to promote a productive agricultural environment.

At present, water monitoring solutions are expensive and are based on random sampling. However, these procedures are limited by providing only information related to a specific sampling and being devoid of spatiotemporal behaviour. Most of the professional solutions available on the market are portable and compact, offering data logging on the equipment itself. However, these solutions do not support real-time data availability for city authorities or agricultural managers in order to enable rapid and efficient intervention to improve people health and productivity, respectively. For example, TDS pens are low-cost, easy to use and widely used equipment for TDS levels evaluation. However, TDS pens do not offer data transmissions and real-time monitoring for enhanced water quality supervision. One the one hand, the majority of TDS pens do not offer a history data consulting features, and the user can only be consulted in real-time values using an LCD interface on the equipment. On the other hand, the professional solutions which offer a history of data consulting are limited to the device memory and require data downloading and manipulation procedures with specific software. Additionally, a limited number of professional instruments have high accuracy and can send data to the control system, but the cost is expensive.

In this way, the development of innovative water monitoring systems based on state-of-the-art technologies that allow real-time analysis becomes essential. Thus, the ***iWater*** was developed in order to provide water quality monitoring system with integrated technology, combining sensitivity, flexibility, and accuracy of measurement in real-time, allowing significant evolution of the current water quality monitoring systems. The results are favourable as the proposed system can be used to provide a correct water monitoring assessment at low-cost. The proposed system can be used to support advanced agricultural methods but also to early detect possible contamination scenarios in smart cities. Furthermore, in the agricultural environments, the effective productivity results can be compared with the monitored data, which is particularly valuable for a correct evaluation and study of the cultivation methods used. Another significant improvement of the presented monitoring system is the scalability and modularity of the proposed method. The installation can begin applying one system, and other modules can be installed according to the necessities of the environment.

As future work, the main goal is to make technical improvements, including the development of essential alert methods such as SMS or e-mail to advise the user when TDS levels meet some parametrised values. The authors also plan to develop a mobile application for water quality analytics and notifications. Infrared thermography (IRT) technology is an appropriate method for plant disease supervision [34]. The authors plan to correlate the proposed system results in the context of the studies being carried out on the IRT technology applied to the monitoring of plants. Moreover, the results achieved will support the correlation between poor water quality effects on plants supported by IRT technology.

5 Conclusions

With the proliferation of IoT and mobile computing technologies on the smart city and agricultural context, it is relevant to develop automatic water monitoring systems. Therefore, this paper presents a cost-effective solution for water quality monitoring composed by a hardware prototype for water quality analysis and Web compatibility for data consulting. On the one hand, this solution can be used for enhanced water management at low-cost for enhanced productivity and quality in the agricultural environment context. Using ***iWater***, the collected data can be especially valued to investigate and store the temporal changes of the water quality in order to guarantee that they are established in the course of all the agricultural process. On the other hand, rivers, lakes, and dams are integral to cities. Furthermore, the contamination of these natural resources by wastewater discharges and salt that is used to eliminate ice on the road is a relevant problem for the health and well-being of citizens. The ***iWater*** provides real-time monitoring of aquatic resources in order to address a solution to this scenario as it presents the ability to detect possible contamination scenarios on time and enables cities to provide a better quality of life to their citizens.

At present, water monitoring solutions are expensive and are based on random sampling. However, these procedures are limiting by providing only information related to a specific sampling and being devoid of spatiotemporal behaviour. The results achieved are promising; the ***iWater*** indicates a significant contribution to cost-effective water quality supervision solutions based on IoT and open-source technologies. Compared to existing systems, the ***iWater*** allows the access to the history of the water quality in the graphical representation in real-time but also provides other relevant advantages such as its modularity, scalability, low-cost and easy installation.

Although the suggested method has constraints, the ***iWater*** requires additional laboratory validation procedures to increase calibration and precision. Moreover, quality assurance and quality control have also been intended to increase product quality traceability. Technological enhancements include the addition of fundamental warning techniques such as SMS or e-mail when a TDS levels reach predefined values are also projected as future work.

References

1. Ballance, R., Bartram, J.: Water Quality Monitoring: A Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programmes. CRC Press, Boca Raton (2002)
2. Caragliu, A., Del Bo, C., Nijkamp, P.: Smart cities in Europe. J. Urban Technol. **18**, 65–82 (2011). https://doi.org/10.1080/10630732.2011.601117
3. Schaffers, H., Komninos, N., Pallot, M., Trousse, B., Nilsson, M., Oliveira, A.: Smart cities and the future internet: towards cooperation frameworks for open innovation. In: Domingue, J., et al. (eds.) FIA 2011. LNCS, vol. 6656, pp. 431–446. Springer, Heidelberg (2011). https://doi.org/10.1007/978-3-642-20898-0_31
4. Chourabi, H., et al.: Understanding smart cities: an integrative framework. In: 2012 45th Hawaii International Conference on System Sciences, pp. 2289–2297. IEEE, Maui (2012). https://doi.org/10.1109/HICSS.2012.615
5. Batty, M., et al.: Smart cities of the future. Eur. Phys. J. Spec. Top. **214**, 481–518 (2012). https://doi.org/10.1140/epjst/e2012-01703-3
6. Giusto, D., Iera, A., Morabito, G., Atzori, L. (eds.): The Internet of Things: 20th Tyrrhenian Workshop on Digital Communications. Springer, New York (2010). https://doi.org/10.1007/978-1-4419-1674-7
7. Marques, G.: Ambient assisted living and internet of things. In: Cardoso, P.J.S., Monteiro, J., Semião, J., Rodrigues, J.M.F. (eds.) Harnessing the Internet of Everything (IoE) for Accelerated Innovation Opportunities, pp. 100–115. IGI Global, Hershey (2019). https://doi.org/10.4018/978-1-5225-7332-6.ch005
8. Marques, G., Pitarma, R., Garcia, N.M., Pombo, N.: Internet of things architectures, technologies, applications, challenges, and future directions for enhanced living environments and healthcare systems: a review. Electronics **8**, 1081 (2019). https://doi.org/10.3390/electronics8101081

9. Gubbi, J., Buyya, R., Marusic, S., Palaniswami, M.: Internet of Things (IoT): a vision, architectural elements, and future directions. Future Gener. Comput. Syst. **29**, 1645–1660 (2013). https://doi.org/10.1016/j.future.2013.01.010
10. Marques, G., Pitarma, R.: mHealth: indoor environmental quality measuring system for enhanced health and well-being based on internet of things. JSAN **8**, 43 (2019). https://doi.org/10.3390/jsan8030043
11. Zanella, A., Bui, N., Castellani, A., Vangelista, L., Zorzi, M.: Internet of things for smart cities. IEEE Internet Things J. **1**, 22–32 (2014). https://doi.org/10.1109/JIOT.2014.2306328
12. Talari, S., Shafie-khah, M., Siano, P., Loia, V., Tommasetti, A., Catalão, J.: A review of smart cities based on the internet of things concept. Energies **10**, 421 (2017). https://doi.org/10.3390/en10040421
13. World Health Organization: Total dissolved solids in Drinking-water: background document for development of WHO guidelines for drinking-water quality. World Health Organization (2003)
14. Cao, L., et al.: China's aquaculture and the world's wild fisheries. Science **347**, 133–135 (2015). https://doi.org/10.1126/science.1260149
15. Jung, D.-H., Kim, H.-J., Cho, W.-J., Park, S.H., Yang, S.-H.: Validation testing of an ion-specific sensing and control system for precision hydroponic macronutrient management. Comput. Electron. Agric. **156**, 660–668 (2019). https://doi.org/10.1016/j.compag.2018.12.025
16. Marques, G., Aleixo, D., Pitarma, R.: Enhanced hydroponic agriculture environmental monitoring: an internet of things approach. In: Rodrigues, J.M.F., et al. (eds.) ICCS 2019. LNCS, vol. 11538, pp. 658–669. Springer, Cham (2019). https://doi.org/10.1007/978-3-030-22744-9_51
17. Gomiero, T.: Food quality assessment in organic vs. conventional agricultural produce: findings and issues. Appl. Soil Ecol. **123**, 714–728 (2018). https://doi.org/10.1016/j.apsoil.2017.10.014
18. Zanella, A., et al.: Humusica 2, article 17: techno humus systems and global change − three crucial questions. Appl. Soil. Ecol. **122**, 237–253 (2018). https://doi.org/10.1016/j.apsoil.2017.10.010
19. Maucieri, C., Schmautz, Z., Borin, M., Sambo, P., Junge, R., Nicoletto, C.: Hydroponic systems and water management in aquaponics : a review (2018). https://doi.org/10.21256/zhaw-3671
20. Marques, G., Pitarma, R.: Agricultural environment monitoring system using wireless sensor networks and IoT. In: 2018 13th Iberian Conference on Information Systems and Technologies (CISTI), pp. 1–6. IEEE, Caceres (2018). https://doi.org/10.23919/CISTI.2018.8399320
21. Pitarma, R., Marques, G., Ferreira, B.R.: Monitoring indoor air quality for enhanced occupational health. J. Med. Syst. **41** (2017). https://doi.org/10.1007/s10916-016-0667-2
22. Marques, G., Ferreira, C.R., Pitarma, R.: Indoor air quality assessment using a CO_2 monitoring system based on internet of things. J. Med. Syst. **43** (2019). https://doi.org/10.1007/s10916-019-1184-x
23. Marques, G., Roque Ferreira, C., Pitarma, R.: A system based on the internet of things for real-time particle monitoring in buildings. Int. J. Environ. Res. Public Health **15**, 821 (2018). https://doi.org/10.3390/ijerph15040821
24. Marques, G., Pitarma, R.: An internet of things-based environmental quality management system to supervise the indoor laboratory conditions. Appl. Sci. **9**, 438 (2019). https://doi.org/10.3390/app9030438
25. Marques, G., Pitarma, R.: A cost-effective air quality supervision solution for enhanced living environments through the internet of things. Electronics **8**, 170 (2019). https://doi.org/10.3390/electronics8020170

26. Mehra, M., Saxena, S., Sankaranarayanan, S., Tom, R.J., Veeramanikandan, M.: IoT based hydroponics system using deep neural networks. Comput. Electron. Agric. **155**, 473–486 (2018). https://doi.org/10.1016/j.compag.2018.10.015
27. Palande, V., Zaheer, A., George, K.: Fully automated hydroponic system for indoor plant growth. Procedia Comput. Sci. **129**, 482–488 (2018). https://doi.org/10.1016/j.procs.2018.03.028
28. Ruengittinun, S., Phongsamsuan, S., Sureeratanakorn, P.: Applied internet of thing for smart hydroponic farming ecosystem (HFE). In: 2017 10th International Conference on Ubi-media Computing and Workshops (Ubi-Media), pp. 1–4. IEEE, Pattaya (2017). https://doi.org/10.1109/UMEDIA.2017.8074148
29. Zhu, X., Li, D., He, D., Wang, J., Ma, D., Li, F.: A remote wireless system for water quality online monitoring in intensive fish culture. Comput. Electron. Agric. **71**, S3–S9 (2010). https://doi.org/10.1016/j.compag.2009.10.004
30. Wang, Z., Wang, Q., Hao, X.: The design of the remote water quality monitoring system based on WSN. In: 2009 5th International Conference on Wireless Communications, Networking and Mobile Computing, pp. 1–4. IEEE, Beijing (2009). https://doi.org/10.1109/WICOM.2009.5303974
31. Chen, Y., Han, D.: Water quality monitoring in smart city: a pilot project. Autom. Constr. **89**, 307–316 (2018). https://doi.org/10.1016/j.autcon.2018.02.008
32. Pellicer, S., Santa, G., Bleda, A.L., Maestre, R., Jara, A.J., Skarmeta, A.G.: A global perspective of smart cities: a survey. In: 2013 Seventh International Conference on Innovative Mobile and Internet Services in Ubiquitous Computing, pp. 439–444. IEEE, Taichung (2013). https://doi.org/10.1109/IMIS.2013.79
33. Parra, L., Sendra, S., Lloret, J., Bosch, I.: Development of a conductivity sensor for monitoring groundwater resources to optimise water management in smart city environments. Sensors **15**, 20990–21015 (2015). https://doi.org/10.3390/s150920990
34. Mahlein, A.-K., Oerke, E.-C., Steiner, U., Dehne, H.-W.: Recent advances in sensing plant diseases for precision crop protection. Eur. J. Plant Pathol. **133**, 197–209 (2012). https://doi.org/10.1007/s10658-011-9878-z