AR-Enabled Interface for IoT Water Management Systems in Smart Cities

Vasileios Sidiropoulos[1](✉), Athanasios Sidiropoulos[2], Dimitrios Bechtsis[1], and Fotis Stergiopoulos[1]

[1] Department of Industrial Engineering and Management, School of Engineering, International Hellenic University, 57001 Thermi, Thessaloniki, Greece
billsidiropoulos27@gmail.com

[2] Department of Mechanical Engineering, Division of Industrial Management, Polytechnical School, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece

Abstract. AR technologies could provide effective and efficient solutions in challenging domains, such as Smart Cities and promote human-city interactions. Smart Cities have a complex structure with constant and real-time information exchange. In this context, the design and development of sophisticated software tools with a human-centric approach is a necessity. The Internet of Things is the cornerstone of Smart Cities and provides ubiquitous connectivity and real-time data exchange. To this end, IoT is an enabler of AR Human Computer Interactions. Critical Smart City infrastructures, such as water management systems, are of great importance as they can raise awareness among the public about environmental and social issues.

This paper demonstrates a novel system architecture that enables citizens and practitioners to interface with IoT water management systems in the Smart City context. In order to demonstrate the architecture's capabilities, a pilot system was developed. The pilot system showcases a water quality monitoring system and an AR application, featuring two types of users, citizens and administrators. The AR application provides different functionalities based on the user type. Citizens are able to get critical information regarding water quality, while administrators are also provided with insights about the hardware and the IoT infrastructure.

The proposed system aims to establish an easy-to-use infrastructure that engages citizens and practitioners in the Smart City ecosystem, with the use of innovative state-of-the-art immersive technologies. The utilization of AR as an HCI interface between end-users and IoT systems can accelerate the adoption of AR applications in the Smart City context.

Keywords: Augmented Reality · Mixed Reality · IoT · Smart City · Water quality

1 Introduction

Augmented Reality (AR) is an innovative technology that transforms the way people interact with their surroundings. It involves the overlay of digital information on the physical environment, enhancing user's perception of the real world with added value

N. A. Streitz and S. Konomi (Eds.): HCII 2023, LNCS 14037, pp. 147–155, 2023.
https://doi.org/10.1007/978-3-031-34609-5_10

content. AR provides promising applications in the realm of Smart Cities, where it can be used to improve the quality of life for citizens and increase operations efficiency [1, 2].

Smart Cities have a complex structure and are considered as a system of systems with constant and real-time information exchange. In this dynamic environment, citizens have the need to interact and exchange information using user-friendly and accessible means. In this context, the design and development of sophisticated software tools with a human-centric approach is a necessity [3]. The Internet of Things (IoT), as the cornerstone of Smart Cities, provides ubiquitous connectivity and real-time data exchange with established protocols. Thus, IoT can act as an enabler for the integration of AR applications in the Smart City context [4]. The combination of AR and IoT can create meaningful experiences in the urban realm [5].

AR technology provides added value services in human-computer and human-to-human interactions. Studies regarding AR applications indicate a high adoption rate from users and showcase the AR advantages in usability and effectiveness over web-based and mobile applications [6]. Moreover, the usability of AR applications is not limited to specific target groups indicatively young or experienced users, which designates AR as the optimal interaction means for a broad area of use cases [7].

Smart Cities improve citizens' quality of life by monitoring and controlling critical indicators, such as water quality [1]. Water quality is a critical issue in urban environments, and data streams should be collected and analyzed in real-time. IoT systems are advancing, and water quality monitoring is gaining the attention of many researchers [8, 9]. By integrating AR technologies and IoT systems, city officials and maintenance workers can access visual representations of water quality data in the field, allowing them to quickly identify and address any issues that may arise [10].

The use of AR in water quality monitoring has also the potential to significantly improve the efficiency of these systems. AR can visualize data more intuitively and interactively, making it easier for city officials and maintenance workers to understand and respond to changes in water quality. Additionally, AR provides user-friendly on-site operation support while enabling seamless remote assistance from experts [11].

Nonetheless, in order to harness the full potential of AR technology, a holistic approach to develop robust AR HCIs for configuring IoT devices' and handling data streams is needed [12]. To this end, this paper proposes a novel system architecture that enables citizens and administrators to interface with IoT water management systems in the Smart City context. The system automatically connects to the underlying IoT infrastructure and establishes connections via IoT protocols such as Message Queuing Telemetry Transport (MQTT) and Long Range Wide Area Network (LoRaWAN). The AR application enables on-site operations, including real-time data monitoring, system monitoring and IoT device configuration. In order to evaluate the system, as the literature proposes [13], the research team developed a pilot system. The pilot system utilizes the proposed architecture and unveils its potential.

2 Architecture Overview

The proposed architecture consists of three layers, namely the communication/data layer, the hardware layer and the application layer. The communication/data layer holds the IoT Gateways and MQTT Servers as well as the Data Sources that constitute the IoT system. The hardware layer includes the microcontroller, the sensors and the equipment for the IoT infrastructure. Lastly, the application Layer entails the AR application of the proposed architecture (Fig. 1).

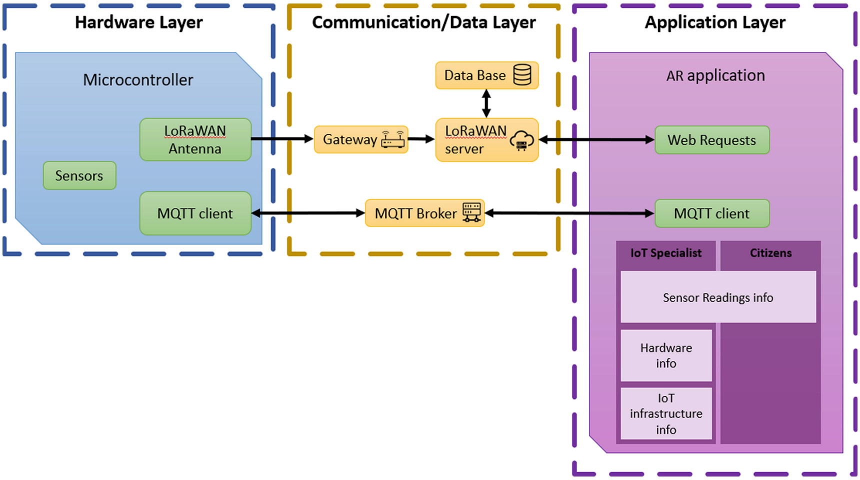

Fig. 1. Proposed system architecture

2.1 Communication/Data Layer

LoRaWAN and MQTT are two well-known IoT communication protocols. LoRaWAN is a communication protocol designed for low-power and long-range communication of IoT devices. It operates in the sub-gigahertz frequency bands, providing coverage over long distances and penetrating through building walls making it suitable for use in urban areas. LoRaWAN utilizes a star-of-stars topology in which gateways connected to the internet relay messages between the end devices and a central network server. LoRaWAN is used in Smart Cities due to its ability to support large amounts of connected devices with low-bandwidth requirements and its high scalability factor. LoRaWAN has demonstrated reliable performance in smart city applications such as waste management, environmental monitoring, and transportation [14, 15].

MQTT is a publish-subscribe lightweight messaging protocol. It is designed to be used on top of TCP/IP and has a small footprint, making it well-suited for resource-constrained devices and low-bandwidth networks. MQTT is often used in smart cities due to its ability to handle high numbers of connected devices and its efficient use of bandwidth [16].

Both LoRaWAN and MQTT are suitable communication protocols in smart cities due to their ability to support a large number of connected devices and their bandwidth management efficiency. However, they have some notable differences. LoRaWAN utilizes a spread spectrum modulation technique in the sub-gigahertz frequency bands, which allows for long-range communication and strong penetration through obstacles. In contrast, MQTT is based on TCP/IP and has a smaller footprint, making it well-suited for resource-constrained devices. As it is evident, both LoRaWAN and MQTT could be used in smart city. LoRaWAN could be used for long-range communication and MQTT could be utilized for resource-constrained devices or for direct device-to-device communication. This approach could provide a robust and flexible communication infrastructure for a smart city.

A time-series database is a specialized type of database optimized for storing and querying time-tagged data. Time-series databases are well-suited for storing data collected from IoT devices, due to the efficient querying and analysis of data. In addition, they provide fast response times regardless of the data volumes and they are used to store sensor readings, energy usage, and traffic patterns. As a last step, data analytics identify trends and patterns and is used to optimize the systems' performance and make data-driven decisions.

2.2 Hardware Layer

The Hardware Layer of the system architecture consists of a microcontroller equipped with water-quality sensors. Additionally, a LoRaWAN antenna and a Wi-Fi module are connected to the microcontroller. The microcontroller serves as the primary processing unit for the system, utilizing the sensors for data acquisition and the LoRaWAN antenna for wireless communication with the IoT infrastructure. The Wi-Fi module allows for the establishment of a secure MQTT connection, enabling efficient data transfer, for on-site operations.

2.3 Application Layer

At the application layer an AR mobile application has been developed using the Unity game engine. Unity's ability to simulate real-world environments, along with scripting capabilities and cross-platform support make it a powerful and widely-used tool for researchers [17]. The application's functionalities are divided into two sub-categories, the AR utilities and the IoT interconnections. Additionally, the application categorizes users into two types, citizens and administrators. The provided functionalities differ based on the user type.

AR Utilities. For the AR utilities' development, the research team utilized the Vuforia SDK. The Vuforia SDK provides a powerful and versatile set of tools for creating AR applications that include image recognition and tracking which was used in this research. An image target was used for the initiation of the AR experience. As the application recognizes an image target, 3D objects and graphs regarding the hardware and the sensor readings are presented at the AR layer.

IoT Interconnection. The AR application automatically establishes a connection to the IoT infrastructure. Once identified, the image target initiates the AR experience. The image target contains the unique ID of each hardware device, which is necessary to retrieve the corresponding data from the database or to connect to the MQTT server. In addition to the image target, the application uses location data from the mobile phone to determine if the user is on-site and near the device. In that case, both MQTT and LoRaWAN connections are possible. The MQTT protocol provides a direct connection between the AR application and the microcontroller, enabling real-time data exchange. On the other hand, the LoRaWAN infrastructure provides access to the database that holds historical data.

3 Pilot System

The research team developed a pilot system in order to demonstrate the applicability of the proposed architecture. The pilot system follows the proposed system architecture and the three layers were implemented from the ground up. As mentioned above, in each mode, the application is able to connect to the IoT infrastructure with either MQTT or LoRaWAN protocols. Each protocol provides specific information to the application.

Communication

The pilot system utilizes the LoRaWAN protocol through the LoRaWAN antenna on the microcontroller, for the communication layer. LoRaWAN gateways were already available near the pilot system's installation point. For the MQTT connection, the local network was utilized. Lastly, a local time series data base was implemented in order to store the data.

Hardware

Regarding the hardware, an esp32 microcontroller and four water quality sensors namely pH, electric conductivity, ORP and temperature, were used. The microcontroller provides built-in Wi-Fi connection capabilities which are used for the MQTT protocol implementation. In addition to the sensors a LoRaWAN antenna module, the RN2483A, was connected to the microcontroller to connect to the Lora Gateway.

Application

The Augmented Reality (AR) application utilizes a user-friendly interface with self-explanatory features for user navigation. There are two modes in the application namely, citizens' mode and administrators' mode. Users can switch between modes in order to get access to different features. It is worth noting that in the pilot system, the application does not provide user profiles and allows mode switching without verification. In order to initiate the AR experience from the mobile device, the user identifies the image target of the water monitoring device. Once the image target is recognized, the application links the image target with the corresponding ID. At this stage, the application connects to the underlying LoRaWAN server and retrieves the stored location of the hardware device. The application then compares the GPS location of the mobile device to the stored location to determine if the user is near the device. If the user is on-site, the AR application will automatically connect to the MQTT server, which is hosted on the hardware device.

The citizen's mode provides access to the sensor readings. Citizens are able to see the real-time value of each critical water quality metric. In addition, a graph that shows past readings can be displayed (Fig. 2).

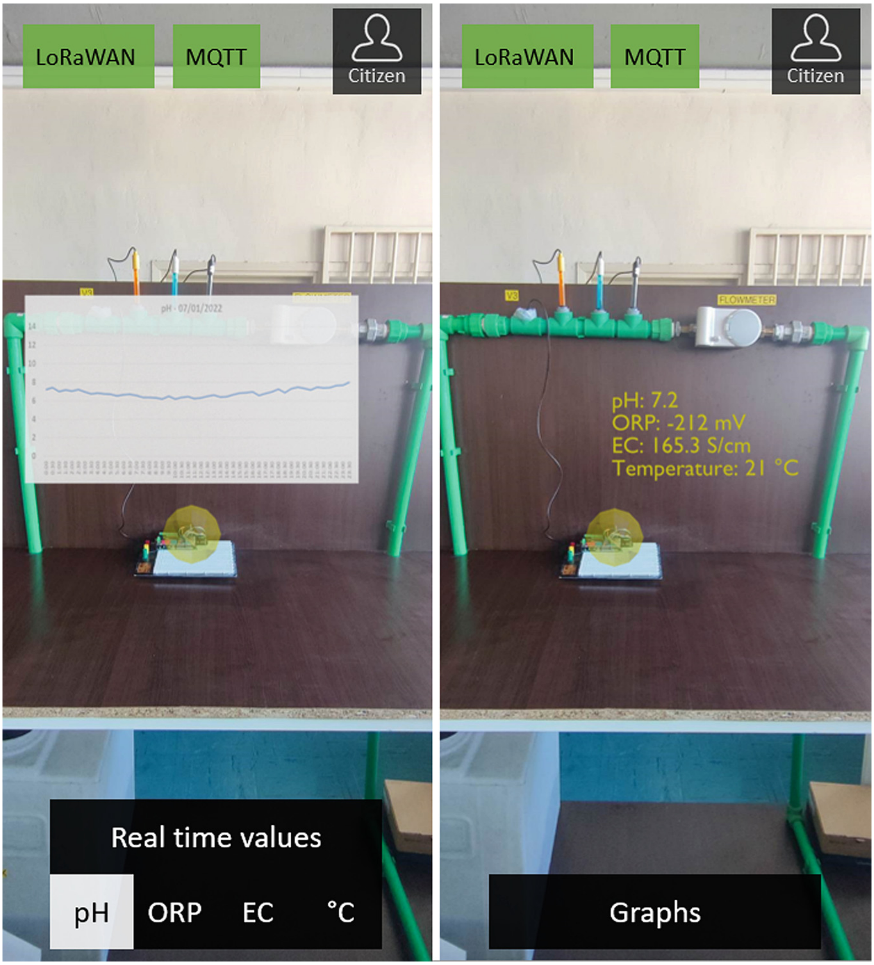

Fig. 2. AR applications for citizens

In contrast, the mode for administrators includes additional functionality for device configuration and information pertaining to the Internet of Things (IoT) infrastructure. The "Device Configuration" tab provides information about the hardware and allows for modification of sensor reading intervals and data transmission intervals while the "IoT Information" tab provides information about the IoT infrastructure (Fig. 3).

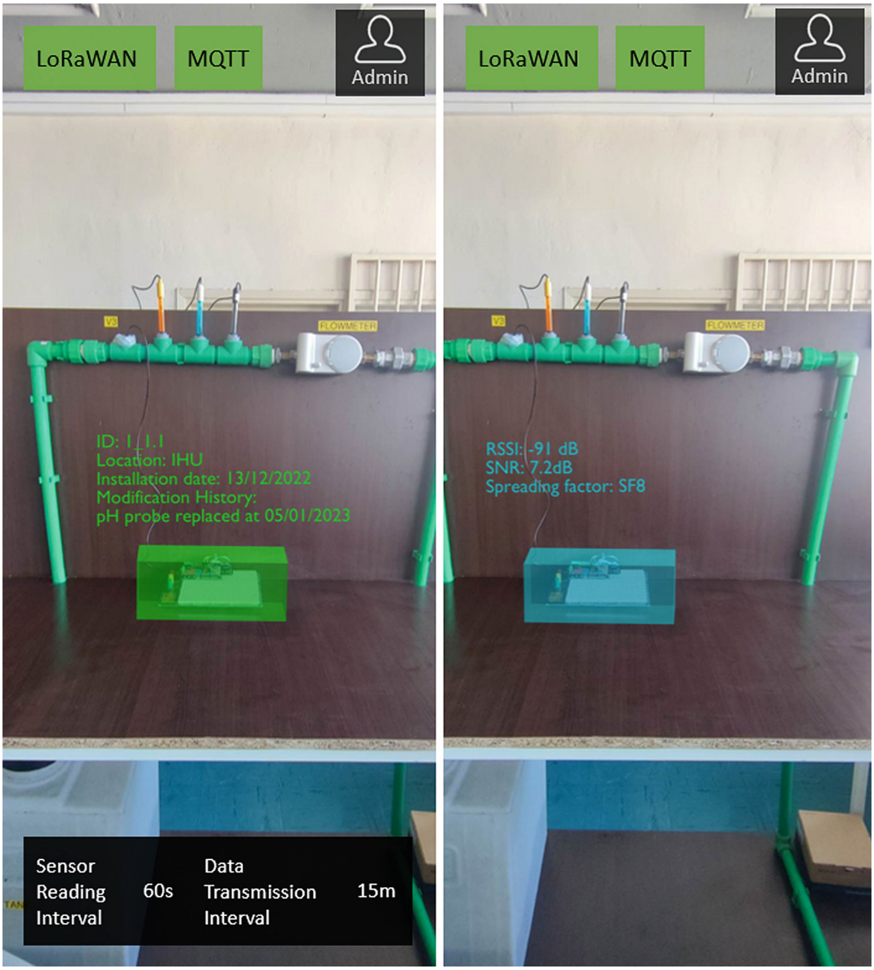

Fig. 3. AR application for Administrators

4 Conclusion

This paper has proposed a novel system architecture for an AR-enabled interface for IoT water management systems in Smart Cities. The proposed architecture utilizes the strengths of both AR and IoT technologies to improve the quality of life for citizens and increase the efficiency of city operations. Moreover, the system is designed with a human-centric approach, which is crucial in Smart Cities, making the system user-friendly and intuitive. This is an important aspect of the proposed architecture as it allows citizens to have access to information about the water quality in a convenient way and allows administrators to access the information about the hardware and the IoT infrastructure in a more efficient way.

The proposed system architecture is composed of three layers: communication/data, hardware and application. The communication/data layer includes IoT Gateways, MQTT Servers, and Databases that constitute the IoT system. The hardware layer incorporates the microcontroller, sensors, and communication hardware. The application layer includes the AR application. The proposed architecture enables citizens and practitioners to interface with IoT water quality monitor systems in a user-friendly way. The system automatically connects to the underlying IoT devices and establishes connections via the respective IoT protocol. The AR application enables on-site or remote operations, including real-time data monitoring, system monitoring, and IoT device configuration.

According to the literature, AR is a useful technology in the Smart City ecosystem [18], nonetheless, a system architecture for the integration of AR and IoT technologies for water management systems in Smart Cities is missing. The proposed system architecture has the potential to significantly improve the efficiency and effectiveness of IoT water management systems in Smart Cities. Lastly, the architecture can be used as a blueprint for other Smart City applications and will pave the way for future research in this field. It has the potential to improve the transparency of Smart Cities and enable citizens to have a more active role in the management of their city's resources.

With that being said, the system architecture is in a preliminary phase and there are some key technological limitations as well as some research gaps that need further examination from the research community. First of all, safety and privacy issues are not in consideration at the current stage. If the system would be used in Smart Cities both issues should be solved prior to wide adoption. Additionally, the pilot system was created in order to evaluate the system, but in the current stage, only the technical limitations were examined. Future research regarding the usability and the scalability of the system will provide insight into the potential of the proposed architecture, in real-world scenarios.

Acknowledgement. This research was carried out as part of the project "iWet: Intelligent IoT System for Quantitative and Qualitative Measurements for water distribution networks" (Project code: KMP6-0072250) under the framework of the Action "Investment Plans of Innovation" of the Operational Program "Central Macedonia 2014 - 2020", that is co-funded by the European Regional Development Fund and Greece.

References

1. Salah-ddine, K., Badouch, A., Mustapha, K., Karimi, K.: Augmented reality services implemented within smart cities, based on an internet of things infrastructure, concepts and challenges: an overview. 7 (2018)
2. Bohloul, M.: Smart cities: a survey on new developments, trends, and opportunities. J. Ind. Integr. Manag. **05**, 311–326 (2020). https://doi.org/10.1142/S2424862220500128
3. Tsampoulatidis, I., Komninos, N., Syrmos, E., Bechtsis, D.: Universality and interoperability across smart city ecosystems. In: Streitz, N.A., Konomi, S. (eds.) Distributed, Ambient and Pervasive Interactions. Smart Environments, Ecosystems, and Cities. Lecture Notes in Computer Science, vol. 13325, pp. 218–230. Springer, Cham (2022). https://doi.org/10.1007/978-3-031-05463-1_16

4. Shinde, G.R., Dhotre, P.S., Mahalle, P.N., Dey, N.: Augmented Reality and IoT. In: Shinde, G.R., Dhotre, P.S., Mahalle, P.N., Dey, N. (eds.) Internet of Things Integrated Augmented Reality. Springer Briefs in Applied Sciences and Technology, pp. 55–71. Springer, Heidelberg (2021). https://doi.org/10.1007/978-981-15-6374-4_4
5. Sanaeipoor, S., Emami, K.H.: Smart city: exploring the role of augmented reality in placemaking. In: 2020 4th International Conference on Smart City, Internet of Things and Applications (SCIOT) [Preprint] (2020). https://doi.org/10.1109/sciot50840.2020.9250204
6. Yagol, P., et al.: New trends in using augmented reality apps for smart city contexts. ISPRS Int. J. Geo-Inf. **7**(12), 478 (2018). https://doi.org/10.3390/ijgi7120478
7. Pokric, B., et al.: Engaging citizen communities in smart cities using IOT, serious gaming and fast markerless augmented reality. In: 2015 International Conference on Recent Advances in Internet of Things (RIoT) [Preprint] (2015). https://doi.org/10.1109/riot.2015.7104905
8. Syrmos, E., et al.: An intelligent modular water monitoring IOT system for real-time quantitative and qualitative measurements. Sustainability **15**(3), 2127 (2023). https://doi.org/10.3390/su15032127
9. Deploying full water metering at the household/final user level (no date). https://greenbestpractice.jrc.ec.europa.eu/print/pdf/node/586. 6 Feb 2023
10. Davis, K., Smith, J.E.: City probe finds 'human error' responsible for spiking hundreds of water bills, Tribune. San Diego Union-Tribune (2018). https://www.sandiegouniontribune.com/news/environment/sd-me-water-bills-20180208-story.html. Accessed 6 Feb 2023
11. Palmarini, R., et al.: A systematic review of augmented reality applications in maintenance. Robot. Comput.-Integr. Manuf. **49**, 215–228 (2018). https://doi.org/10.1016/j.rcim.2017.06.002
12. Jo, D., Kim, G.J.: AR enabled IOT for a smart and interactive environment: a survey and future directions. Sensors **19**(19), 4330–4347 (2019). https://doi.org/10.3390/s19194330
13. Kaji, S., Kolivand, H., Madani, R., Salehinia, M., Shafaie, M.: Augmented reality in smart cities: a multimedia approach (2018). http://researchonline.ljmu.ac.uk/
14. Augustin, A., et al.: A study of lora: long range & low power networks for the internet of things. Sensors **16**(9), 1466 (2016). https://doi.org/10.3390/s16091466
15. Georgiou, O., Raza, U.: Low power wide area network analysis: can lora scale? IEEE Wirel. Commun. Lett. **6**(2), 162–165 (2017). https://doi.org/10.1109/lwc.2016.2647247
16. Rubí, J.N., Gondim, P.R.: IOT-based platform for environment data sharing in smart cities. Int. J. Commun. Syst. **34**(2), e4515 (2020). https://doi.org/10.1002/dac.4515
17. Lambrecht, J., et al.: Towards commissioning, resilience and added value of augmented reality in robotics: overcoming technical obstacles to industrial applicability. Robot. Comput.-Integr. Manuf. **71**, 102178 (2021). https://doi.org/10.1016/j.rcim.2021.102178
18. Fernandez, F., et al.: The augmented space of a smart city. In: 2020 International Conference on Systems, Signals and Image Processing (IWSSIP) [Preprint] (2020). https://doi.org/10.1109/iwssip48289.2020.9145247