Indoor Air Quality Monitoring and IoT Platform for Smart Building Management

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Abstract - Indoor air quality is rapidly becoming a global issue. On the one hand, public health experts, environmental entities, and industry experts are working to enhance the overall health, comfort, and well-being of building occupants. Smart city projects promote the use of real-time monitoring systems to acknowledge unfavorable scenarios for enhanced living environments. The primary purpose of this work is to present and describe an indoor air quality monitoring system based on the Internet of Things for smart building management purposes. This paper highlights the design aspects of the platform, including sensor types, the microcontroller, the overall architecture, and connectivity. Moreover, preliminary results are presented, considering a minimal implementation to demonstrate the feasibility and reliability of the proposed platform.

Keywords: Air Quality, Data Analytics, Internet of Things, Monitoring, and Wireless Sensor Networks

I. INTRODUCTION

The indoor air quality level is a significant concern for most developing countries as it can be correlated to building users' health, comfort, and well-being. Moreover, people generally spend around 85% of their daily time indoors, so buildings' indoor air quality directly impacts their users' overall health and workplace productivity [1]. In that sense, smart city projects nowadays promote using real-time monitoring systems to detect adverse scenarios for enhanced living conditions. While energy efficiency or thermal comfort would be paramount in the recent past, more and more emphasis is being given to monitoring variables such as CO2 or the level of volatile particles. In that sense, the technological advancements for sustainability in smart city projects nowadays promote using real-time monitoring systems to detect adverse scenarios for enhanced living conditions. While energy efficiency or thermal comfort would be paramount in the recent past, more and more emphasis is being given to monitoring variables such as CO2 or the level of volatile particles [2].

From a technological point of view, the Internet of Things (IoT) and the expansion of new low-power, miniaturized, and cheaper processors and peripherals allow for the development of new platforms. Those have increased capabilities, as further communication means such as long-range LoRa networks and Bluetooth Low Energy, but also increased computational power [3]-[5]. While low-cost sensor technology retains a significant challenge in the lack of data reliability, the increased computing power permits correction algorithms through artificial intelligence (AI) for trend analysis and prediction [6]-[8].

While platforms that rely on the features mentioned above are quite standardized, the full integration of all the components is not usual. It poses a challenge regarding its global architecture, communication protocols, software services, and middleware algorithms that may or even should support machine learning strategies [9]-[11].

To that end, the current work proposes a new software/hardware model architecture. It collects data from different sources (air quality, building occupation, etc.), processes all building data analytics, triggers actions and feedback to actuators, and supplies information to its users. One of the most pertinent novelty considered is the total distribution of the "intelligence" of the system, where the sensor nodes can also contribute to low-level AI algorithms.

II. PROPOSED SOLUTION

The architecture under development undergoes a standard distributed design, comprising sensor nodes with actuation capabilities, some communication means, and cloud services to provide the necessary information for building users and administration. Also, the required infrastructure for database storage, web support, data analytics services, and algorithm deployment are considered. Figure 1 resumes the global architecture and its components.

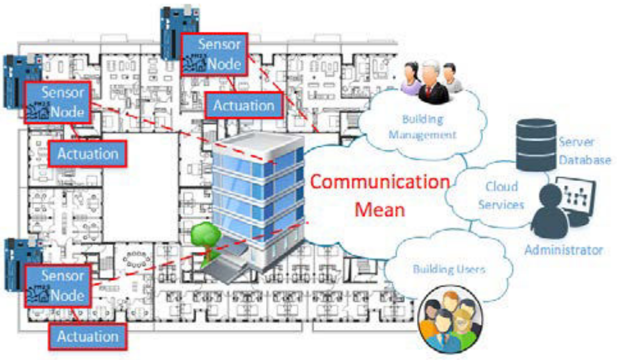

Fig. 1 - Global architecture

When considering the use cases, one can see two groups of actors: building management staff and the users of the building space. Also, the embedded sensor nodes can be seen as pseudo-actors, since they perform some actions on the overall system, and are the target of activities of the same.

The communication channel here is considered as a wireless sensor network that can exchange messages from simple sensor value packets to an extended ones, such as transferring data for or from an AI engine. Due to easy integration purposes, Wi-Fi with WPA2 Enterprise security is initially considered, although extending it to LoRa, 6LoWPAN, or ZigBee would be straightforward as updates of the IoT ecosystem. Also, MQTT through a JSON scheme is considered for data and command transmission, as a simple way to transfer simple to high complexity and length data frames.

The information gathered is stored and processed using cloud services. It is in the form of microservices that facilitates the management and availability of all distributed software implementation. Featuring a time-series database providing fast writing and reading through a web server, several tools such as administration, back-office, and AI data analytics services are available in a rich interface. From this point on, all the necessary infrastructure is available for implementing features such as air quality information, occupation maps, alerts triggering regarding fatigue, evacuation, windows opening, etc.

A. Preliminary Results

For validation purposes, a simple setup was implemented to collect initial data from a set of air quality sensors. The sensors employed are listed in table 1, with the goal of covering the most common metrics to accommodate those who are more critical for human health [12].

Table 1. List of the all sensors used and their main features

Measured Parameter	Sensor Model Manufacturer	Measuring Range	Accuracy (Repeatability)
PM$_{1/2.5}$	SEN54 [Sensirion]	0 to 100 $\mu g/m^3$	±5 $\mu g/m^3$ AND 5% m.v.
		100 to 1000 $\mu g/m^3$	± 10% m.v.
PM$_{4/10}$		0 to 100 $\mu g/m^3$	± 25 $\mu g/m3$
		100 to 1000 $\mu g/m^3$	± 25% m.v.
RHT		-10 °C-50 °C; 0% to 100%	0,1 °C; ±1%
VOC		0-1000 ppm	± 25
CO$_2$	SCD30 [Sensirion}	400-10000 ppm	± 10 ppm
RHT		-10 °C-70 °C; 0% to 95%	0,1 °C; ±0,1%
eCO$_2$	ams iAQcore [ScioSense]	450-2000 ppm	NA
eTVOC		125-600ppb	NA
CO	MQ-9 [Seeed]	20-2000 ppm	NA
NO$_2$	SEN0441 [DFRobot]	0.05-1000 ppm	NA
Barometric Pressure	BMP280 [Bosh]	300-1100 hPa	± 1 hPa
T		-40 °C-85 °C	± 1°C

The setup consists of one sensor node constituted by a Tensilica Xtensa dual-core 32 bits LX7 microprocessor featuring 240 MHz, 520 KB SRAM, and a Wi-Fi: 802.11 b/g/n transceiver. The sensor list (Table I) is connected through the I2C interface or the analog input channels. On the cloud side, there are Docker containers featuring an MQTT broker, an InfluxDB time series database, and Grafana for monitoring and analytics. Figure 2 shows the carbon dioxide level acquired by the two corresponding sensors, used here to demonstrate the feasibility and reliability of the preliminary deployed platform, and considering a person getting nearby the sensors, and thus producing the increased level.

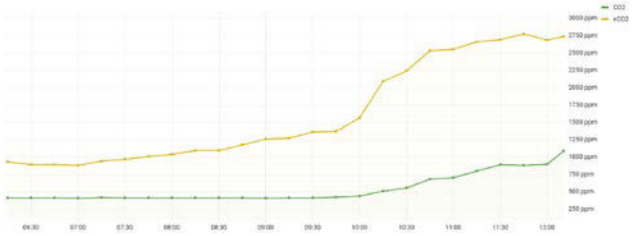

Fig. 2 Carbon dioxide in parts per million vs time

B. Conclusions

The current work describes an architecture for indoor air quality monitoring considering the possibility of acting on the environment's surroundings. This feature was possible by applying the IoT paradigm and using the most recent microcontroller design and programming advances. The preliminary results were presented to demonstrate the feasibility and reliability of the platform. Future developments will include deploying all the described features for the building users and the building administration, as well as powerful human-machine interfaces for monitoring and management. Implementing a distributed AI architecture, allowing the sensor/actuator nodes to be "intelligent" is also being considered, using a description language to transfer the AI knowledge.

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References

[1] J. Saini, M. Dutta, G. Marques, "A comprehensive review on indoor air quality monitoring systems for enhanced public health," Sustain Environ Res vol. 30, no. 6, 2020.

[2] J. Saini, M. Dutta, G. Marques, "Indoor Air Quality Monitoring Systems Based on Internet of Things: A Systematic Review", Int. J. Environ. Res. Public Health, vol. 17, no. 4942, 2020.

[3] H. Chojer, P. T. B. S. Branco, F. G. Martins, M. C. M. Alvim-Ferraz, S. I. V. Sousa, "Development of low-cost indoor air quality monitoring devices: Recent advancements," Science of The Total Environment, vol. 727, no. 138385, 2020.

[4] S. D. Correia, J. Fé, S. Tomic, M. Beko, "Development of a Test-Bench for Evaluating the Embedded Implementation of the Improved Elephant Herding Optimization Algorithm Applied to Energy-Based Acoustic Localization", Computers, vol. 9, no. 4:87, 2020.

[5] S. D. Correia, M. Beko, L. A. da Silva Cruz and S. Tomic, "Implementation and Validation of Elephant Herding Optimization Algorithm for Acoustic Localization," 2018 26th Telecommunications Forum (TELFOR), 2018, pp. 1-4.

[6] A. Daissaoui, A. Boulmakoul, L. Karim, A. Lbath, "IoT and Big Data Analytics for Smart Buildings: A Survey," Procedia Computer Science, vol. 170, pp. 161-168, 2020.

[7] S. D. Correia, S. Tomic, M. Beko, "A Feed-Forward Neural Network Approach for Energy-Based Acoustic Source Localization", J. Sens. Actuator Netw, vol. 10, no. 29, 2021.

[8] K. Alanne, S. Sierla, "An overview of machine learning applications for smart buildings," Sustainable Cities and Society, vol. 76, no. 103445, 2022.

[9] Elias M. Pinheiro, Sérgio D. Correia, "Software Model for a Low-Cost, IoT Oriented Energy Monitoring Platform" SSRG International Journal of Computer Science and Engineering vol. 5. no. 7, pp. 1-5, 2018.

[10] L. Mendoza-Pitti, H. Calderón-Gómez, M. Vargas-Lombardo, J. M. Gómez-Pulido and J. L. Castillo-Sequera, "Towards a Service-Oriented Architecture for the Energy Efficiency of Buildings: A Systematic Review," IEEE Access, vol. 9, pp. 26119-26137, 2021.

[11] A. Floris, S. Porcu, R. Girau, L. Atzori, "An IoT-Based Smart Building Solution for Indoor Environment Management and Occupants Prediction," Energies, vol. 14, no. 2959. 2021.

[12] H. Zhang, R. Srinivasan, "A Systematic Review of Air Quality Sensors, Guidelines, and Measurement Studies for Indoor Air Quality Management. Sustainability, vol. 12, no. 9045, 2020.