Integrated open source air quality monitoring platform

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***Abstract* – In recent years, great importance has been paid to air quality monitoring, exhibiting a rapid development both in industrialization as well as in the transportation segment, especially in the cities and the urban area. Installation and maintenance of commercial air quality monitoring instruments are overpriced, thus making such existing air quality monitoring networks scarce, despite the significant growth in the usage of low-cost sensor technology for the monitoring of air pollution. The aim is to encourage citizens to actively contribute in such actions as monitoring air quality in the place where they live and work. Open source software seems the better way for the implementation of the low-cost constructions as it enables direct access and software customization according to implementation needs, and encourages participatory engagement between people with common concerns and common goals and actions such as air quality in their area. This work presents the implementation of an integrated open source air quality monitoring platform which includes low-cost air quality stations and an application server for the data visualization. The parts of the low cost station are the cpu wemos@arduino as well as gas [nitrogen dioxide (NO_2) and ozone ((O_3)] and particle sensors (PM2.5). The low-cost sensors present an affordable solution which covers real-time and high spatial resolution for air quality measurements with best effort performance.**

Keywords— O_3 measurements, NO_2 measurements, PM2.5 measurements Air quality IoT, Low-cost sensing systems, Open source

I. INTRODUCTION

Air quality is a major problem, especially in health, in large cities and the way to improve the quality of life of the citizens living in them is continuously being studied [1-3]. Many research studies report on the development of an air quality monitoring stations network, specifically in affordable priced stations since the cost of commercial air quality monitoring systems is overpriced [4-6]. In recent years there has been a growing tendency of citizens to participate in the gathering of air quality data in the areas that they live and work [7-8]. Such citizen initiatives benefit society as a whole as they enable the air quality data network to be enriched in a city, especially in the cities that have inadequate air quality monitoring networks. However, these days there is public awareness of being actively involved in such activities as air quality monitoring in the area where they live and work.

Another important factor for the construction of an air quality monitoring station is the overall cost. In recent years, a new generation of economical air pollution sensors have appeared [9-11]. This has resulted in the construction of low-cost air quality monitoring stations by various research teams as well as by citizen groups [5-7]. Low budget electrochemical sensors present more interest for the construction of the low-cost monitoring air quality station, according to research studies which show remarkable measurement results. Research work [12] present, according to the results, the evaluation of electrochemical sensors in a laboratory environment and in the field. On the other hand, the other devices, such as processors, transmission, etc., must meet the implementation requirements of such a system but have a low cost of acquisition. In recent years, the growth and construction of small and low-consumption microprocessors, such as Arduino [13], can be a viable solution for the construction and operation management of a low-cost air quality monitoring station. Another notable point is the software that works on these devices. Its use is intended for the general public and the best solution is an open source software application, not because it's free but because of its simple philosophy that everyone can intervene in its code to make any improvements or variants which will have better performance of its construction and then distribute it to the community. Research work presents the Open Source Building Science Sensors (OSBSS) that is based on an Arduino microprocessor for indoor environment data gathering [14]. In general, the definition of an open source software is that it is always open worldwide so that everyone can modify and share. Some reasons to use such open-source software are; Microeconomic, as it presents economic interest as an individual or as a company. Macroeconomic as it can produce high-quality software due to its functionality of combining and increasing alternative and related efforts. Open source motivations have such a strong level of moral components that are based on open-source free software. The open-source is achieved with a great degree of transparency of the process. Participatory motivations provide the possibility for participants to configure the software according to their own needs. On the other hand, the personal motivations, especially for the developers, as it could provide them personal growth within the development community as whole [15]. Although such devices give us air quality data, these are difficult for the citizens to interpret, so is the accessibility for the citizens to this data. A good solution is to visualize this data over the Internet using a server, and display these air quality monitoring stations on a map. An open source

software is the Grafana [16], which with the appropriate configuration, gives us the ability of implementation that we mentioned before.
This work presents the innovation and implementation of an integrated open-source air quality monitoring platform, which includes the structure and operation of an affordable air quality monitoring station as well as the information system for the visualization of information to the end-user. The gas sensors used are electrochemical sensors and their purchase price is half than of other corresponding sensors used in other studies [4-8]. This is the reason of the low cost of the construction. The measured values are gaseous pollutants such as nitrogen dioxide (NO_2) and ozone (O_3), and particles (PM2.5), as well as barometric parameters such as temperature (T) and humidity (RH). According to the fast growth of technology, there exist many reliable low-cost systems which respond to low power consumption and excellent processing work, like the Wemos@Arduino [17] microprocessor. These systems offer adequate local data analysis and for communication manners wireless technology (WiFi) is used. This article is organized in the following sections: II the methodology, III the experimental setup and, IV the experimental results.

II. METHODOLOGY

The Methodoloby is divided in three stages: the first stage presents the IoT architecture and implementation, the second stage includes the system integration and networking and the third stage is the evaluation of the system including the results. Generally an IoT system's [18] architecture consists of three sections, Perception, Network, and Application. Perception is the data received from the sensors in which the sensors belong at the architecture section. Network is the section that describes how data is being transferred from the sensors to the application. Application is the section in which all data are collected and presented in a suitable form to the users.
A. Perception section: this section consists of stations which are wireless sensor networks (WSN) that include the CPU, peripherals and the gas pollutants sensors. In our case the CPU is the Wemos@Arduino, Spec sensor's electrochemical gas sensors for ozone (O_3) and nitrogen dioxide (NO_2) and Plantower PMS5003 particle sensor.
B. Network section: this section is also presented as the transport section, with which it is achieved the connection between perception and application sections, and which is responsible for transmitting data from low-cost stations to the central station (server) that contains the application section. In this work we utilize the built-in wireless network function contained in Wemos@Arduino.
C. Application section: The final stage of the IoT system is the application section, which can provide the services to the end user. This section supports many applications for the development of IoT systems. In this work the application section includes the Grafana open source software.
The topology per sections of IoT architecture and presented at figure 1.

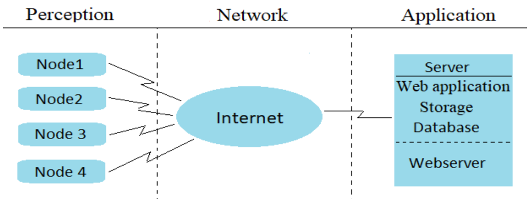

Figure 1. Topology of IoT Architecture.

III. EXPERIMENTAL SETUP

The components of an air quality monitoring station are the microprocessor, the sensors and the mini UPS in case of a power failure.
a. Wemos@Arduino
The main CPU is the Wemos@Arduino [17] that is an open-source Arduino based firmware for IoT implementations. It's an ideal module for IoT devices due to it being affordable and it having many features which presented, such as, processing capabilities with a fast time response. It can be programmed using the open-source Arduino Software (IDE) which makes it easy to write code and upload it to the board and it is also a familiar and user friendly software. This processor satisfies the need of communication with each sensor (6 I/O ports for 3 UART).The CPU data processing speed (Tensilica Xtensa Diamond 32-bit 80/160 MHz) further satisfies this implementation with low power consumption. The microprocessor integrates the data transfer communication over wireless network (Wi-Fi).

b. Sensors
For the pollutants sensors, SpecSensors' gas sensors nitrogen dioxide and ozone were used and Plantower PMS5003 sensor was used for particles. The SpecSensors' DGS-O3 968-042 [19] Ozone sensor and DGS-NO2 968-043 [20] Nitrogen dioxide sensor (Table 1), are amperometric gas sensors – which are electrochemical sensors generating a current proportional to the volumetric fraction of the gas [21]. Every sensor is supported by an expansion board which includes the potentiostat circuit, a CPU for the calculation of voltages to ppb, temperature, humidity and the transmission method, as well as a serial protocol (UART). Plantower PMS5003 [22] sensor, which is an optical technology particle sensor, uses serial communication protocol (UART).

Spec Sensors type DGS	Gas pollutant	Range	Resolution	Supply voltage
O3 968-042	Ozone	0-5 ppm	20 ppb	3.3 Volt
NO2 968-043	Nitrogen dioxide	0-5 ppm	20 ppb	3.3 Volt

Table 1. Specifications O_3 , NO_2 sensors.

c. Mini UPS
The power supply of the station is supported by commercial power pack 5V/1A DC. In case of power failure a mini UPS is provided, which includes a battery charger and a Li-ion 18650 battery. Using the mini UPS, the station can operate for up to 10 hours. The power consumption of an air pollution monitoring station is approximately 1.2W.

d. Station implementation
The implementation and construction of the open source software at a low cost air quality monitoring station have been made at the Electronic Devices and Materials laboratory (EDML) at the University of West Attica. The general

diagram of the station is depicted at figure 2 and the CPU and sensors are shown in figure 3

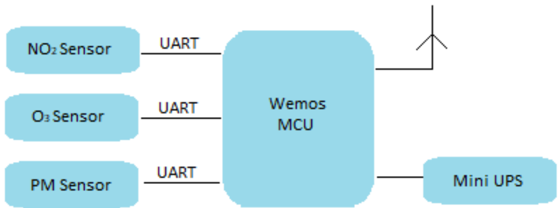

Figure 2. Station components diagram.

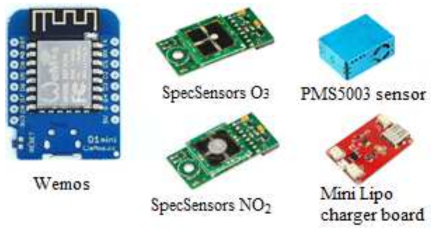

Figure 3. Components: CPU, sensors, peripherals.

For easy installation of the sensors but also for future maintenance, an expansion board was constructed on top of the Wemos@Arduino which includes the interfaces connectors for the sensors as well as passive elements such as resistors required as voltage dividers, etc (figure 4).

Figure 4. Expansion board.

Specifically for gaseous pollutants, the sensors are mounted in a tube and a fan at the end of the tube ensures a steady air flow (figure 5).This is important for the quality of the measurements [4].

Figure 5. Air flow tube.

The whole device was implemented in a waterproof box type IP66 (with dimensions of 115mm x 150mm), which is rather small. The final construction is shown at figure 6. The total cost of the construction per station is approximately 350 €. At the start-up the user, using a smartphone can select the access point (Wi-Fi) to which the station will be connected. This function (Wi-Fi Manager library) is included in the software and makes the setup procedure more comfortable. Every ten seconds a measurement is conducted and the average of five minutes values are transferred over the internet at the Application server. Data structure is in json string format. The software of the low cost monitoring station is posted on the website http://edml.uniwa.gr/

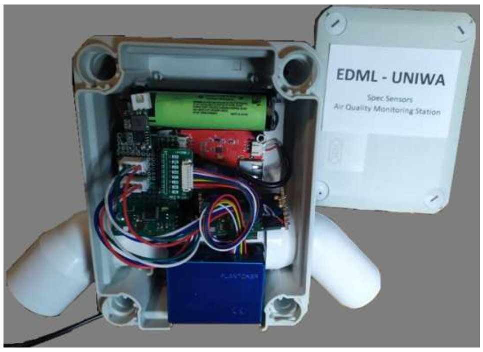

Figure 6. Open source, low cost monitoring station.

IV. EXPERIMENTAL RESULTS

The functionality and measurements of stations of our work are being presented at this section. Since October 2021, for the experimental setup two open source software low-cost air monitoring stations have been installed on the area of the east Attica in Greece and specifically at the municipalities Agia Paraskevi and Gerakas. The distance between the two stations is around 1.5Km. The results shown below are for the first week of October 2021. The measurements are displayed at the website https://iotemission.eee.uniwa.gr (figure 7), and show concentrations of particles PM2.5, nitrogen dioxide (NO_2), and ozone (O_3). The application server (Grafana software) is installed at the facilities of the University of West Attica.

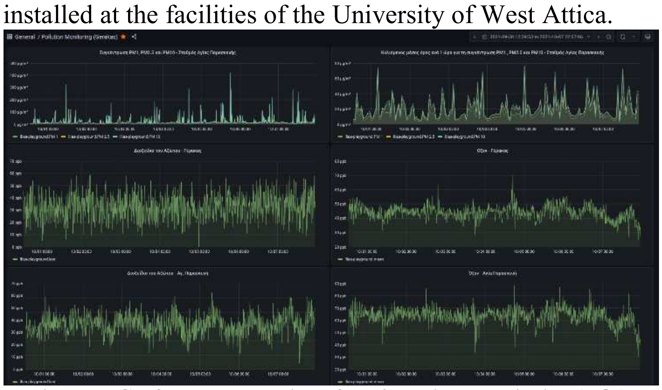

Figure 7. Grafana, concetration of PM2.5, Nitrogen dioxide (NO_2), Ozone (O_3) from two low-cost stations.

As far as the reliability of the measurement values of the low-cost air quality monitoring stations is concerned, we have compared the results of the two stations concerning the reference values obtained from the World Air Map by Plume Labs website [23]. Reference values are given in a daily report, in which the results and the correlations between low cost sensors and reference are presented for particles PM2.5 in figure 8, nitrogen dioxide (NO_2) in figure 9 and ozone (O_3) in figure 10.

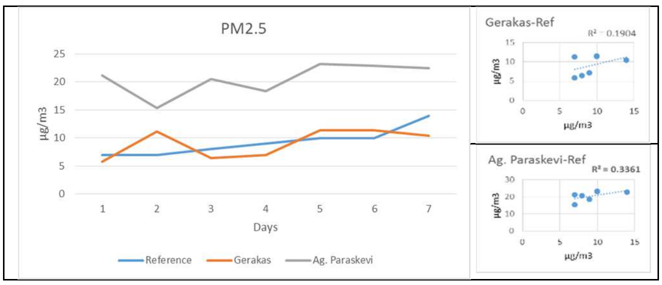

Figure 8. Particles PM2.5 – Reference, Low-cost stations.

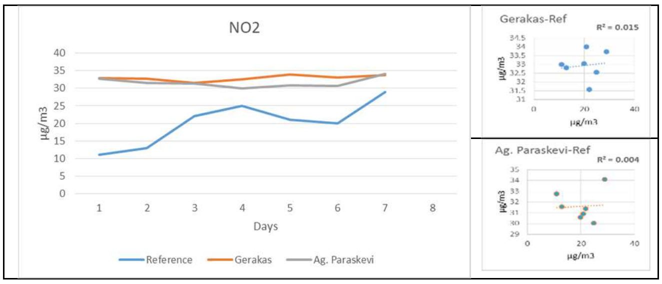

Figure 9. Nitrogen dioxide (NO_2) – Reference, Low-cost stations.

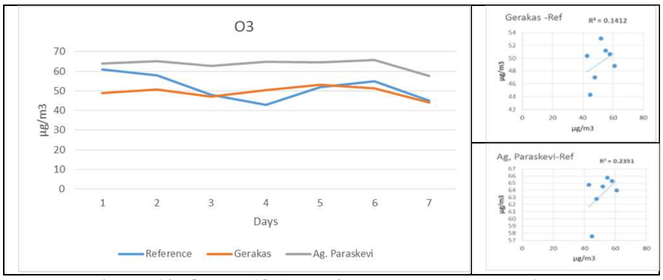

Figure 10. Ozone (O_3) – Reference, Low-cost stations.

V. CONCLUSIONS

Air pollution is a major threat to health, especially in developed cities, and the quality of life of the citizens is vastly depended on it. In this work, it is described the implementation of an integrated open source air quality monitoring platform which includes low-cost air quality stations and an application server for the data's visualization. The data transfer has been done using wireless network (Wi-Fi). The measured values are PM2.5, ozone (O_3) and nitrogen dioxide (NO_2). Low-cost stations have been operational since October 2021. This work mainly focuses on the open source software and the low-cost air quality monitoring station. Measurements have been done in the urban environment and the measurement values of each sensor are primary and without any corrections. Having observed that, it is concluded that the values of the low-cost sensors follow the trend line of the reference values for each gas severalty. The micro differences of the values between the low-cost sensors were expected, as the low-cost monitoring stations are installed at different places. The aim is to attract more and more people to actively participate in actions such as air quality which is a common good. On the other hand, we should encourage participation because using open source software, corrections, or configurations originating from other participants, will result in the improvement of such systems with better functional and efficient procedures. Finally, it's a good and affordable solution for the general public to be informed about the air quality in the place where they live and work.

REFERENCES

[1] Who.int. 2022. *Ambient (outdoor) air pollution*. [online] Available at: <https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health> [Accessed 20 April 2022].

[2] 2022. [online] Available at: <https://www.who.int/news-room/spotlight/how-air-pollution-is-destroying-our-health> [Accessed 19 April 2022].

[3] Ostro, B., Spadaro, J.V., Gumy, S., Mudu, P., Awe, Y., Forastiere, F., Peters, A., 2018. Assessingthe recent estimates of the global burden of disease for ambient air pollution: methodological changes and implications for low- and middle-income countries. Environ. Res. 166, 713–725. https://doi.org/10.1016/j.envres.2018.03.001.

[4] E. Cross et al., "Use of electrochemical sensors for measurement of air pollution: correcting interference response and validating measurements", Atmospheric Measurement Techniques, vol. 10, no. 9, pp. 3575-3588, 2017. Available: 10.5194/amt-10-3575-2017.

[5] Y. Gao et al., "Mosaic: A low-cost mobile sensing system for urban air quality monitoring", IEEE INFOCOM 2016 - The 35th Annual IEEE International Conference on Computer Communications, 2016. Available: 10.1109/infocom.2016.7524478.

[6] W. Jiao et al., "Community Air Sensor Network (CAIRSENSE) project: evaluation of low-cost sensor performance in a suburban environment in the southeastern UnitedStates", Atmospheric Measurement Techniques, vol. 9, no. 11, pp. 5281-5292, 2016. Available: 10.5194/amt-9-5281-2016.

[7] SmartCitizen Smart Citizen Documentation. Available online: https://docs.smartcitizen.me/

[8] Christakis, I., Hloupis, G., Stavrakas, I. and Tsakiridis, O., 2020. Low cost sensor implementation and evaluation for measuring NO2 and O3 pollutants. 2020 9th International Conference on Modern Circuits and Systems Technologies (MOCAST),

[9] Kumar, P., Martani, C., Morawska, L., Norford, L., Choudhary, R., Bell, M., Leach, M., 2016a. Indoor air quality and energy management through real-time sensing in commercial buildings. Energy and Buildings 111, 145–153. https://doi.org/10.1016/j.enbuild.2015.11.037.

[10] Kumar, P., Skouloudis, A.N., Bell, M., Viana, M., Carotta, M.C., Biskos, G., Morawska, L., 2016b. Real-time sensors for indoor air monitoring and challenges ahead in deploying them to urban buildings. Sci. Total Environ. 560–561, 150–159. https://doi.org/10.1016/j.scitotenv.2016.04.032.

[11] Morawska, L., Thai, P.K., Liu, X., Asumadu-Sakyi, A., Ayoko, G., Bartonova, A., Bedini, A.,Chai, F., Christensen, B., Dunbabin, M., Gao, J., Hagler, G.S.W., Jayaratne, R., Kumar, P., Lau, A.K.H., Louie, P.K.K., Mazaheri, M., Ning, Z., Motta, N., Mullins, B., Rahman, M.M., Ristovski, Z., Shafiei, M., Tjondronegoro, D., Westerdahl, D., Williams, R., 2018. Applications of low-cost sensing technologies for air qualitymonitoring and exposure assessment: how far have they gone? Environ. Int. 116, 286–299. https://doi.org/10.1016/j.envint.2018.04.018.

[12] R. Laref, E. Losson, A. Sava and M. Siadat, "Field Evaluation of Low Cost Sensors Array for Air Pollution Monitoring", 2019 10th IEEE International Conference on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications (IDAACS), 2019. Available: 10.1109/idaacs.2019.8924320

[13] Arduino.cc. 2022. Arduino - Home. [online] Available at: <https://www.arduino.cc/> [Accessed 15 January 2022].

[14] Ali, A., Zanzinger, Z., Debose, D. and Stephens, B., 2016. Open Source Building Science Sensors (OSBSS): A low-cost Arduino-based platform for long-term indoor environmental data collection. Building and Environment, 100, pp.114-126.

[15] Opensource.com. 2022. *6 motivations for consuming or publishing open source software*. [online] Available at: <https://opensource.com/life/15/12/why-open-source>

[16] 2022. [online] Available at: <https://grafana.com/>

[17] Wemos.cc. 2022. *LOLIN D1 mini — WEMOS documentation*. [online] Available at: <https://www.wemos.cc/en/latest/d1/d1_mini.html> [Accessed 19 April 2022].

[18] P. Sethi, S. R. Sarangi, "Internet of Things: Architectures, Protocols, and Applications," Journal of Electrical and Computer Engineering, vol. 2017, no. 1, pp. 1-25, Jan. 2017.

[19] Spec-sensors.com. 2022. [online] Available at: <https://www.spec-sensors.com/wp-content/uploads/2017/01/DGS-O3-968-042_9-6-17.pdf>

[20] Spec-sensors.com. 2022. [online] Available at: <https://www.spec-sensors.com/wp-content/uploads/2017/01/DGS-NO2-968-043_9-6-17.pdf>.

[21] Aqicn.org. 2022. [online] Available at: <https://aqicn.org/air/view/sensor/spec/o3.spec-3sp-o3-20.pdf>

[22] Plantower.com. 2021. PMS 5003-PM2.5-Plantower Technology. http://www.plantower.com/en/content/?108.html

[23] World Air Map by Plume Labs. Available: https://air.plumelabs.com/