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Air Quality Monitoring Tool using Edge Computing: A Comprehensive Study

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Abstract: As the transportation sector continues to expand rapidly, more focus has been placed on ensuring that air quality is being monitored, however existing monitoring tools are limited in their ability to provide precise data in real time at an economical cost. In this paper, we intent to provide a framework for creating an indoor air quality monitoring tool that makes use of both the Internet of Things (IoT) and edge computing. The proposed approach enables sensors to collect data on the air quality in real time and transfer it to an edge device, which then does the required processing and analysis. In the end, the IoT and edge computing combine to deliver a more rapid and efficient way of collecting data and processing. In most cases, edge computing handles real-time data processing, which helps to minimise the amount of delay and congestion in the network. Therefore, this enables a better user experience and more productivity.

Keywords: *air quality, edge computing, sensor, tool*

1. Introduction

Due to the enormous influence on human health, safety, and comfort, air quality is one of the most important metrics to monitor in real time for current urban environments [1][2]. Various systems, rules, and standards have been set up in different countries to track changes in air quality and provide warnings to people [3]. Although this information is only applicable to outside situations, the majority of the measurements are stationary and only acquire average values [4]. However, the quality of the air is variable in real time and may be affected by a variety of factors, such as the wind direction, the population density, the concentration of pollutants, and whether or not the location is an outdoor or indoor environment [5-6] [3].

In the past, air quality monitoring stations have been inconvenient in size and expensive to construct and maintain. However, the statistics concerning the air quality that are produced by these stations are quite precise. There has been an attempt to find alternatives that are both effective and economical [7] [2]. The Internet of Things (IoT) is a kind of technology that is gaining interest in both the marketplace and the academic community [8].

In this paper, we propose a framework for air quality monitoring that makes use of an edge computing approach. In this article, we take a close look at the framework, challenges, and opportunities involved in developing and implementing an integrated sensor node for monitoring indoor air quality. The purpose of this project is to build a tool for monitoring air quality that makes use of edge computing, with the goal of ensuring accurate measurements at the most affordable cost. The remainder of the paper is structured in the following manner: Section 2 provides the background information. The proposed work is outlined in Section 3. In Section 4, some challenges and open issues are addressed. The conclusion is presented in Section 5.

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2. Background

The environment is becoming more polluted as a direct result of the fast expansion of the industrial sectors and the urbanisation of society, to the point that it is interfering with the people's normal day-to-day activities. The term "environmental pollution" refers to a wide category of problems that may affect the atmosphere, waterways, and landscape [1] [9-10]. When it comes to harming human health, air pollution stands out as the most pervasive of all these factors. A significant amount of work has been put into monitoring the air in an attempt to lessen the negative effects that pollution in the air has on humans, as well as on the global environment and the worldwide economy [11-12].

Depending on the setting, air quality monitoring systems are either designed to detect and report on interior air pollution or outdoor air pollution. The term "outdoor air pollution" refers to the contamination of the atmosphere in open spaces and industrial settings. In contrast, "indoor air pollution" occurs in enclosed settings such as homes, offices, basement shopping malls, public transport, and vehicle interior compartments [12-13].

The air quality index (AQI) is a quantitative representation that serves as a benchmark for measuring the quality of the air. Fine particulate matter (PM2.5), inhalable particles (PM10), sulphur oxide (SO2), nitrogen oxide (NO2), ozone (O3), carbon dioxide (CO2) and carbon monoxide (CO) are the pollutants that can be detected The units of measurement used for PM2.5 and PM10 are micrograms per cubic metre (ug/m3), CO and CO2 is expressed in parts per million (ppm), while SO2, NO2, and O3 are expressed in parts per billion (ppb) [14-15].

Recent studies reveal a shift in the direction of a new approach for air monitoring systems, in which inexpensive sensor-based models contribute in the detection of the dispersion of air pollutants [16].

The widespread availability of wearable sensor nodes has made it possible for individuals to assess their own vulnerability to environmental hazards. According to the findings of recent research, there have been a variety of approaches that have been used for assessing the quality of the air. They are primarily divided into two kinds, either mobility based monitoring or immovable based monitoring [3] [17].

Some of previous research where [18] proposed an edge computing air quality tool by measuring data generated from PM2.5 sensors. The proposed approach incorporated the federated compressed learning (FCL) framework with compressed data obtained from edge device and aggregate the data to the server using Wi-Fi and ZigBee. Despite the proposed approach has slightly achieve lower accuracy, the author has outline to further extensive work.

Besides, [19] proposed using an edge computing system that included cloud technology in order to monitor air quality. The system is built on a Raspberry Pi that serves as an edge computing device and exchanges data with the Microsoft Azure cloud. The results of this research illustrate how useful an edge-based solution can be when intended with the responsibility of determining the degree of air pollution in a specified locality. On the other hand, the author also presented the idea of integrating LoRa communication technology for long distance transmission as a prospect to improve in future.

According [20] a low cost air quality monitoring system by measuring the concentration level of gasses with time, date, and location information was presented. The proposed system incorporates ZigBee module to transfer the data generated by sensors. The findings of the tests indicate that the proposed system is capable of performing extremely effectively in both stationary and moving environments. Nonetheless, the author emphasised that the proposed system might be further expanded to monitor with other sensors or by seasonal-based analysis (e.g. summer or winter).

On another context [21] presented an air quality monitoring tool by measuring six air pollutants (e.g. SO2, NO2, CO, O3, PM2.5 and PM10). The tool runs Kalman Filtering algorithm on Raspberry Pi as an edge device and sends the data through the Wi-Fi module. The proposed method has been successful in producing a significant prediction result. However, the author emphasises the need of taking into account the effect that the surrounding environment has on the concentration of pollutants.

According to [22], an air quality monitoring tool with the use of edge computing by measuring the data generated from several sensors (e.g. pressure, temperature, humidity, carbon dioxide) was proposed. The proposed work runs on battery powered microcontroller using Bluetooth Low Energy (BLE). Despite the proposed work has substantial power consumption, the author has highlight to look into the negative impact of the battery lifetime.

In similar context, [23] proposed an indoor air quality monitoring tool with edge computing specially for kitchen. The proposed tool incorporates Bosch BME680 sensor connected to a microcontroller where data generated was send to a local server. Despite the proposed tool has shown a strong relationship in terms of humidity and air quality correlation, the author has indicated further interest in indoor spread (e.g. air-borne viruses and pollutants).

Besides, [24] proposed an edge and cloud based air quality monitoring tool by measuring the temperature, humidity, PM2.5, and PM10. The proposed approach incorporates LoRa and MQTT technologies with container based virtualization. The experimental result show that the proposed tool has provide a substantial deployment. However, the author has outlined that the work could be explored on the power consumption model.

On a separate view, [25] designed an air quality monitoring tool with the use of sensors and image processing. The proposed approach incorporates 5G and edge testbed to perform detailed analytics. The experimental result show that the proposed approach has support scalable deployment with 5G edge testbed. However, the author has outlined to explore on calibration and real-time processing (e.g. image and video).

Besides, [26] proposed an embedded edge computing gateway device by measuring gas sensor (e.g. MQ135). This proposed approach in a wireless sensor network (WSN) which communicates with the gateway (edge) using LoRa module. The results obtained from the gateway device has shown a real time air quality data streaming. However, the author described that the proposed work can be employed for transportation and navigation application as an additional metric.

Similarly, [27] designed an IoT based air quality monitoring system by measuring PM2.5 concentration using edge device and cloud. The proposed approach employs hybrid prediction architecture using several machine learning models hosted by Nonlinear AutoRegression with eXogenous input (NARX). Despite the proposed approach has outperform existing hybrid algorithms, the author outlined that NARX model could be explored with variation exogenous order and delay.

The vast majority of the previous research that was mentioned centred on one or two key elements; if the systems assessed multiple substances, then the computational capabilities were unknown. Although researchers employed affordable sensors, the device does not include a calibration mechanism and does not address the problems associated with sensor diffusion validation. The findings of previous studies are summarised in Table 1.

Table 1. Summary of Previous Studies

Reference	Device	Communication Channel	Deployment	Application
Putra et al. (2021) [18]	Raspberry Pi and Arduino Mini	Wi-Fi and ZigBee	Outdoor	Smart City
Moursi et al. (2021) [19]	Laptop, Raspberry Pi, Arduino Uno and Node MCU	Wi-Fi	Indoor	Not Applicable
Sântejudean et al. (2021) [20]	Self-Built Microcontroller	Bluetooth	Indoor	Not Applicable
Wall et al. (2021) [21]	ESP 32 MCU	Wi-Fi	Indoor	Smart Home

Su et al. (2021) [22]	Laptop and Smartphone	5G and Wi-Fi Hotspot	Outdoor	Smart Home
Kristiani et al. (2021) [23]	Raspberry Pi	LoRa	Indoor	Smart Campus
Kulshrestha and Durbha (2020) [24]	Arduino Uno	LoRa	Outdoor	Smart City
Ullah et al. (2020) [25]	Arduino Mega	ZigBee	Outdoor	Smart City
Biondi et al. (2019) [26]	Raspberry Pi	Wi-Fi	Outdoor	Smart City
Lai et al. (2019) [27]	Raspberry Pi	Wi-Fi	Outdoor	Smart Agriculture

3. Units

Edge computing are used to monitor air quality as part of the proposed work. The monitoring tool will use a tiered IoT architecture, as shown in Fig. 1. There are three tiers to this process, and they are referred to as sensing, computing, and the application, respectively. Wi-Fi and LoRa are the medium by which the tier communicates with one another; however, cellular technology of successive iterations (4G/5G) may also be used for this purpose.

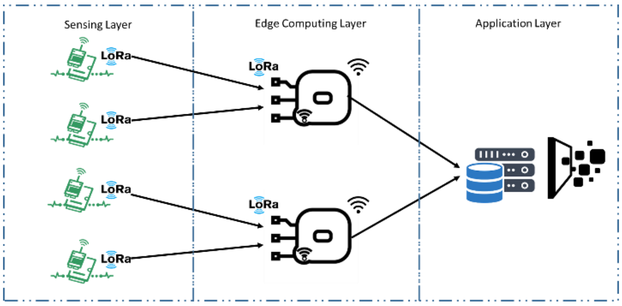

Figure 1. IoT Achitecture

3.1. Architecture

The sensing tier is the base for collecting and processing information from sensors. The sensing nodes are the primary entities that make up this tier, and they are intended to be installed aboard moving vehicles. The computing tier is composed of edge-computing devices. The primary function of these deployed devices is to communicate with the second and third tiers. The data is collected by the device from the whole of the sensing tier, and then, after any required processing, the data is sent to the application tier. The application tier is in charge of providing the end user with collaborative services and managing the data storage. It may be divided into two distinct aspects: those intended for the end user, and those intended for visualisation. Upon receiving data generated from the second tier, it saves the information in the cloud database and produces ways for visualisation the information.

3.2. Deployment

The deployment of the tool includes both the hardware and software modules; a more in-depth explanation of each is provided below.

3.2.1. Hardware

Fig. 2 depicts the primary components of the tool's hardware: the sensor module and an edge device. The sensing node is responsible for gathering data on the air quality and then transmitting it to the edge device through a communication channel. Fig. 3 shows the prototype design.

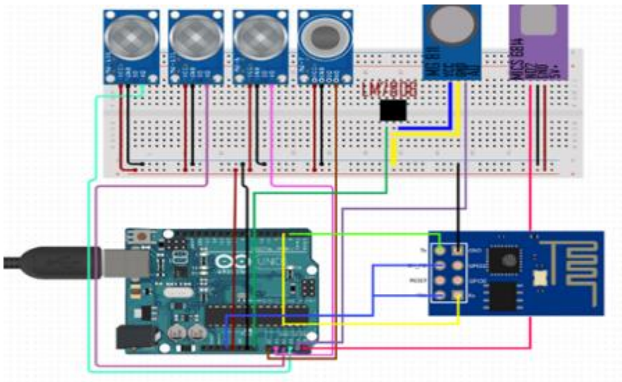

Figure 2. Breadboard Diagram

Figure 3. Prototype Design

3.2.2. Software

The software applications are the indispensable tool for both the cloud and the end-user. There are three basic categories of servers that may be found in the cloud, each with a distinct set of features and purposes. On the basis of our findings, we would like to carefully examine integrating a real-time air quality level representation. Therefore, such solutions were implemented using InfluxDB and Grafana. Fig. 4 shows a visualisation that shows the status, the events, and the data logs.

Figure 4. Grafana Platform for Data Visualization

4. Challenges and Open Issues

The deployment of air quality monitoring may require dense and massive scale of low cost sensors [28]. This presents a number of important challenges and open issues, some of which include the processing of large data quantities, real-time analysis for applications that are sensitive to delay, pervasive readiness and high-speed connectivity. In the case of mass deployment, there would be thousands of air quality sensors installed in vehicles, each of which would provide kilobytes of data on the air quality with each measurement [29] [30]. This would accumulate and generate data that can reach up to gigabytes in size. Thus, this kinds of sensors produce significant amounts of data on the quality of the air at a rapid rate, that requires artificial intelligence approach [31].

4.1. Availability

The infrastructure and services used for monitoring air quality are supported by a variety of heterogeneous and multiplatform sensing devices, which are widely detached in highly urbanized environments. In order to keep a distinct systems linked at all times, a combination of several forms of communication is required. This will certainly enable the devices to produce data, exchange it with other devices, and analyse it within an air quality sensor infrastructure [32] [33].

4.2. Connectivity

Multiple computing devices rely on high-speed connections to transport the data that AI algorithms need in order to process out real-time analysis, interpretation, and optimisation of their respective data. In the case of air quality monitoring, for instance, thermal infrared images may be processed much more quickly when a high speed connectivity is available [34] [35].

4.3. Capacity

There is a massive quantity of sensor data that are gathered from air quality monitoring devices, and these data are continually produced at high frequencies. The possibility of subsequently integrating data from different sources makes this task far more difficult. The processing of enormous data streams about air quality provides for the extraction of higher-level information, the guiding of the understanding of complicated environmental circumstances, and the enabling of real-time analysis that provides end users with insights [36] [37].

4.4. Performance

When it comes to services that are prone to delays, the ultimate objective is to produce timely insights on environmental circumstances before such services become irrelevant. Air quality monitoring would be useful in many contexts; for instance, it might help with navigation by letting end users know whether or not certain routes are appropriate for their safety, so reducing their exposure to potentially dangerous particles. When trying to keep an eye on the air quality, it is indeed important to get accurate data as quickly as possible, yet this might result in a delay in other processes [38] [39] [40].

5. Conclusion

In this paper, we proposed an IoT based edge computing framework for monitoring of indoor air quality. The prototyping was carried out utilising equipment that was both inexpensive and simple to create and put into use. The developed prototype has the capacity to analyse a variety of gases such as PM 2.5, PM 10, CO, CO_2, SO_2, NO_2 and O_3. The sensors were calibrated to ensure the accuracy of the data generation. The developed approach is built out in a form that reduces the computing load on battery-operated sensor nodes and more evenly distributes it using an edge computing device. To examine air quality data and to provide data visualisations for the end user, Influx DB and Grafana were utilised. The relationship between the trend in air quality and the deployment of edge computing has definitely resulted in the discovery of certain noteworthy realities.

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Conflicts of interest

The authors declare no conflicts of interest.

References

[1] Tran, V. V., Park, D., & Lee, Y. C. (2020). Indoor air pollution, related human diseases, and recent trends in the control and improvement of indoor air quality. International journal of environmental research and public health, 17(8), 2927.

[2] Saini, J., Dutta, M., & Marques, G. (2020). A comprehensive review on indoor air quality monitoring systems for enhanced public health. Sustainable environment research, 30(1), 1-12.

[3] Morawska, L., Thai, P. K., Liu, X., Asumadu-Sakyi, A., Ayoko, G., Bartonova, A., ... & Williams, R. (2018). Applications of low-cost sensing technologies for air quality monitoring and exposure assessment: How far have they gone?. Environment international, 116, 286-299.

[4] Lewis, A., Peltier, W. R., & von Schneidemesser, E. (2018). Low-cost sensors for the measurement of atmospheric composition: overview of topic and future applications.

[5] Shum, C., Alipouri, Y., & Zhong, L. (2022). Examination of human interaction on indoor environmental quality variables: a case study of libraries at the University of Alberta. Building and Environment, 207, 108476.

[6] Nair, A. N., Anand, P., George, A., & Mondal, N. (2022). A review of strategies and their effectiveness in reducing indoor airborne transmission and improving indoor air quality. Environmental Research, 213, 113579.

[7] Idrees, Z., & Zheng, L. (2020). Low cost air pollution monitoring systems: A review of protocols and enabling technologies. Journal of Industrial Information Integration, 17, 100123.

[8] Tsiatsis, V., Karnouskos, S., Holler, J., Boyle, D., & Mulligan, C.

(2018). Internet of Things: technologies and applications for a new age of intelligence. Academic Press.

[9] Ukaogo, P. O., Ewuzie, U., & Onwuka, C. V. (2020). Environmental pollution: causes, effects, and the remedies. In Microorganisms for sustainable environment and health (pp. 419-429). Elsevier.

[10] Ćurić, M., Zafirovski, O., & Spiridonov, V. (2022). Air Quality and Health. In Essentials of Medical Meteorology (pp. 143-182). Springer, Cham.

[11] Zeng, Y., Cao, Y., Qiao, X., Seyler, B. C., & Tang, Y. (2019). Air pollution reduction in China: Recent success but great challenge for the future. Science of the Total Environment, 663, 329-337.

[12] Majd, E., McCormack, M., Davis, M., Curriero, F., Berman, J., Connolly, F., ... & Koehler, K. (2019). Indoor air quality in inner-city schools and its associations with building characteristics and environmental factors. Environmental research, 170, 83-91.

[13] Kodali, R. K., Pathuri, S., & Rajnarayanan, S. C. (2020, January). Smart indoor air pollution monitoring station. In 2020 International Conference on Computer Communication and Informatics (ICCCI) (pp. 1-5). IEEE.

[14] Paleologos, K. E., Selim, M. Y., & Mohamed, A. M. O. (2021). Indoor air quality: pollutants, health effects, and regulations. In Pollution Assessment for Sustainable Practices in Applied Sciences and Engineering (pp. 405-489). Butterworth-Heinemann.

[15] World Health Organization. (2021). WHO global air quality guidelines: particulate matter (PM2. 5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. World Health Organization.

[16] Gulia, S., Khanna, I., Shukla, K., & Khare, M. (2020). Ambient air pollutant monitoring and analysis protocol for low and middle income countries: An element of comprehensive urban air quality management framework. Atmospheric Environment, 222, 117120.

[17] Van Fan, Y., Perry, S., Klemeš, J. J., & Lee, C. T. (2018). A review on air emissions assessment: Transportation. Journal of cleaner production, 194, 673-684.

[18] Putra, K. T., Chen, H. C., Ogiela, M. R., Chou, C. L., Weng, C. E., & Shae, Z. Y. (2021). Federated compressed learning edge computing framework with ensuring data privacy for PM2. 5 prediction in smart city sensing applications. Sensors, 21(13), 4586.

[19] Biondi, K., Al-Masri, E., Baiocchi, O., Jeyaraman, S., Pospisil, E., Boyer, G., & de Souza, C. P. (2019, July). Air pollution detection system using edge computing. In 2019 International Conference in Engineering Applications (ICEA) (pp. 1-6). IEEE.

[20] Ullah, N., Khan, F., Khan, A. A., Khan, S., Tareen, A. W., Saeed, M., & Khan, A. (2020). Optimal Real-time Static and Dynamic Air Quality Monitoring System. vol, 13, 91-102.

[21] Lai, X., Yang, T., Wang, Z., & Chen, P. (2019). IoT implementation of Kalman Filter to improve accuracy of air quality monitoring and prediction. Applied Sciences, 9(9), 1831.

[22] Sântejudean, T. V., Mois, G. D., Sanislav, T., & Folea, S. C. (2022, June). Edge Computing in Wireless Sensing Applications. In 2022 11th Mediterranean Conference on Embedded Computing (MECO) (pp. 1-4). IEEE.

[23] Wall, D., McCullagh, P., Cleland, I., & Bond, R. (2021). Development of an Internet of Things solution to monitor and analyse indoor air quality. Internet of Things, 14, 100392.

[24] Kristiani, E., Yang, C. T., Huang, C. Y., Wang, Y. T., & Ko, P. C. (2021). The implementation of a cloud-edge computing architecture using OpenStack and Kubernetes for air quality monitoring application. Mobile Networks and Applications, 26(3), 1070-1092.

[25] Su, X., Liu, X., Motlagh, N. H., Cao, J., Su, P., Pellikka, P., ... & Tarkoma, S. (2021). Intelligent and scalable air quality monitoring with 5G edge. IEEE Internet Computing, 25(2), 35-44.

[26] Moursi, A. S., El-Fishawy, N., Djahel, S., & Shouman, M. A. (2021). An IoT enabled system for enhanced air quality monitoring and prediction on the edge. Complex & Intelligent Systems, 7(6), 2923-2947.

[27] Kulshrestha, U., & Durbha, S. (2020, September). Edge Analytics and Complex Event Processing for Real Time Air Pollution Monitoring and Control. In IGARSS 2020-2020 IEEE International Geoscience and Remote Sensing Symposium (pp. 893-896). IEEE.

[28] Motlagh, N. H., Lagerspetz, E., Nurmi, P., Li, X., Varjonen, S., Mineraud, J., ... & Tarkoma, S. (2020). Toward massive scale air quality monitoring. IEEE Communications Magazine, 58(2), 54-59.

[29] Shah, J. L., Bhat, H. F., & Khan, A. I. (2021). Integration of Cloud and IoT for smart e-healthcare. In Healthcare Paradigms in the Internet of Things Ecosystem (pp. 101-136). Academic Press.

[30] Vitabile, S., Marks, M., Stojanovic, D., Pllana, S., Molina, J. M., Krzyszton, M., ... & Salomie, I. (2019). Medical data processing and analysis for remote health and activities monitoring. In High-performance modelling and simulation for big data applications (pp. 186-220). Springer, Cham.

[31] Zhang, W., Wu, Y., & Calautit, J. K. (2022). A review on occupancy prediction through machine learning for enhancing energy efficiency, air quality and thermal comfort in the built environment. Renewable and Sustainable Energy Reviews, 167, 112704.

[32] Katsiri, E. (2021). Developing reliable air quality monitoring devices with low cost sensors: Method and lessons learned. International Journal of Environmental Science, 6.

[33] Kiani, F. (2018). A survey on management frameworks and open challenges in IoT. Wireless Communications and Mobile Computing, 2018.

[34] Lăzăroiu, G., & Harrison, A. (2021). Internet of Things sensing infrastructures and data-driven planning technologies in smart sustainable city governance and management. Geopolitics, History, and International Relations, 13(2), 23-36.

[35] Wan, J., Li, X., Dai, H. N., Kusiak, A., Martínez-García, M., & Li, D. (2020). Artificial-intelligence-driven customized manufacturing factory: key technologies, applications, and challenges. Proceedings of the IEEE, 109(4), 377-398.

[36] Bibri, S. E., & Krogstie, J. (2020). Environmentally data-driven smart sustainable cities: Applied innovative solutions for energy efficiency, pollution reduction, and urban metabolism. Energy Informatics, 3(1), 1-59.

[37] Firouzi, F., Farahani, B., Weinberger, M., DePace, G., & Aliee, F. S. (2020). Iot fundamentals: Definitions, architectures, challenges, and promises. In Intelligent internet of things (pp. 3-50). Springer, Cham.

[38] Xing, L. (2020). Reliability in Internet of Things: Current status and future perspectives. IEEE Internet of Things Journal, 7(8), 6704-6721.

[39] Gupta, B. B., & Quamara, M. (2020). An overview of Internet of Things (IoT): Architectural aspects, challenges, and protocols. Concurrency and Computation: Practice and Experience, 32(21), e4946.

[40] Zhao, Z., Liu, L., Zhang, F., & Yang, G. (2022). Does air pollution prompt corporations to implement green management? Evidence from China. Environmental Science and Pollution Research, 29(6), 8933-8946.