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INDOOR AIR QUALITY MONITORING FOR DETECTING VOC GAS BASED ON IOT

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Abstract. *Many studies indicate that indoor air quality at times are not better than the outdoor air quality. The need for indoor air quality monitoring systems that can also help to avoid the risk of long exposures to bad indoor air quality has become prominent. Common elements that affect the quality of air and are very important to note are Volatile Organic Compounds (VOCs) found in building materials, such as paints, solvent agents and products that use composite wood and also from cooking, smoke, burning wood and even from reading newspaper. Existing research proved that long-term exposure to VOC could lead to chronic illness. The aim and contribution of this paper is to propose indoor air quality monitoring system that is connected to a web-based application that enables user to monitor the level of indoor air quality, especially VOC and activate mitigation devices thus they can maintain the acceptable rate of indoor air quality, thereby preventing the bad impact resulting from the VOC exposure. If the level of VOC exceeds the safe limit, and after acquiring the outdoor air condition from the Internet, system will decide which mitigation device shall be triggered remotely, such as turning on air conditioner, air purifier, exhaust fan or giving notification for user to open the window to allow air circulation.*
Keywords: Indoor air quality, Internet of Things, Volatile organic compounds, VOC

1. **Introduction.** In recent years, various scientific studies have indicated that air in homes and other buildings may be of worse quality than outdoor air, even in large cities and industrial environments. Meanwhile, there are many factors that affect indoor air quality, including temperature, humidity, circulation and outdoor air quality, or exposure to pollutants and chemicals. Other elements that are more important to note are Volatile Organic Compounds (VOC) [1]. Poor indoor air quality caused by Volatile Organic Compounds (VOCs) has adverse effect on human health.

Inhalation of low levels of VOC for a long period of time can increase the risk of health problems. Long-term inhalation of VOC can lead to chronic diseases such as cancer, liver and kidney damage and central nervous system. While the effects that are felt in the short term include eye, nose and throat irritation, headaches, nausea and vomiting, and dizziness [2]. It is difficult to detect the presence of VOC gas without adequate equipment because in general VOC cannot be seen, and some does not smell, cannot be felt and has no color. Therefore, a good solution to detect the presence of VOCs is needed.

Henceforth, this study proposes an IoT system to monitor the level of indoor air quality, specifically the presence of VOCs, and to mitigate actions that can significantly improve the indoor air quality. In the event that the VOC level in the room rises to the unacceptable level, the system will provide notification and trigger mitigation devices such as turning on air conditioner and air purifier system and exhaust fan or give notification for user to open the window if the air quality outside is better than the indoor, to allow air

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circulation. Air purifier will have beneficial impact to reduce the indoor pollution, while allowing natural air circulation, and providing quicker result.

This paper consists of the following sections. Section 2, Related Work, presents the previous works and development of IoT based indoor air quality monitoring. Section 3, Proposed Method, explains the research procedure, hardware and analysis method. Section 4, Results and Discussion, presents the result of the research and short discussion. As a closure, in Section 5, Conclusions, the writers provide the research's summary and conclusion.

2. **Related Work.** Previous researches on IoT based indoor air quality monitoring were done by [3-5], which allows real-time monitoring of airborne gas other than VOC, while several studies have focused on VOC monitoring system. [6] designed a low-power VOC monitoring sensor using ZigBee sensor network. The system was deployed with the RIVEC at the campus of Southeast University and performed favorably in practice. Priority was given to power consumption and sensing efficiency by incorporating various smart tasking and power management protocols. The monitoring of both IAQ and energy conservation can be achieved by this paper. In [7], the new portable wireless QTF sensor-based VOC-sensing device system is presented. Comparison of the VOC device to its previous version indicates that improvements to make the device smaller, lighter, and user-friendly have been accomplished. Another research [8] proposed system, *VOCkit*, which uses a paper-based fluorometric sensor combined with embedded processing and camera units. The fluorometric sensor changes its emitting color with respect to the surrounding VOC materials, and the camera takes the role of periodically capturing images of the fluorometric sensor. This image is then passed through a machine learning algorithm on the embedded platform to identify the type of VOC materials in the air. While the above researches achieved their objectives, all of them are limited to monitoring system without integrating any actuator, to mitigate action in order to reduce the VOC level, and improve the air quality. The hardware used in acquiring the parameters as compared to the previous researches is further modified by using microcontroller which enables smaller size and multitasking capabilities, thus resulting in faster response time and even more simple process.

3. **Proposed Method.** As for indoor air quality, all organic chemical compounds whose compositions give them the potential to evaporate under normal atmospheric conditions are considered VOCs and should be considered in any assessment of indoor air quality impacts, the writers firstly developed a system to monitor VOC level for indoor use. In this section details of the hardware and system software will be discussed; moreover, in this section the writers provide the proposed analytic method and system architecture.

3.1. **System hardware.** The monitoring system consists of sensor, microcontroller, and wireless network, as shown in Figure 1. The writers developed the monitoring device using ESP32 microcontroller which implements the IEEE 802.11 b/g/n networking protocol. This microcontroller has built-in WiFi and Bluetooth capabilities, and can be used as the processing and communication application.

This system consists of 4 components.

a) ESP32

ESP32 is a series of low-cost, low-power system on a chip microcontroller with integrated WiFi and dual-mode Bluetooth. This microcontroller is using Xtensa dual-core (or single-core) 32-bit LX6 microprocessor, operating at 240 MHz; Memory 520 KB SRAM.

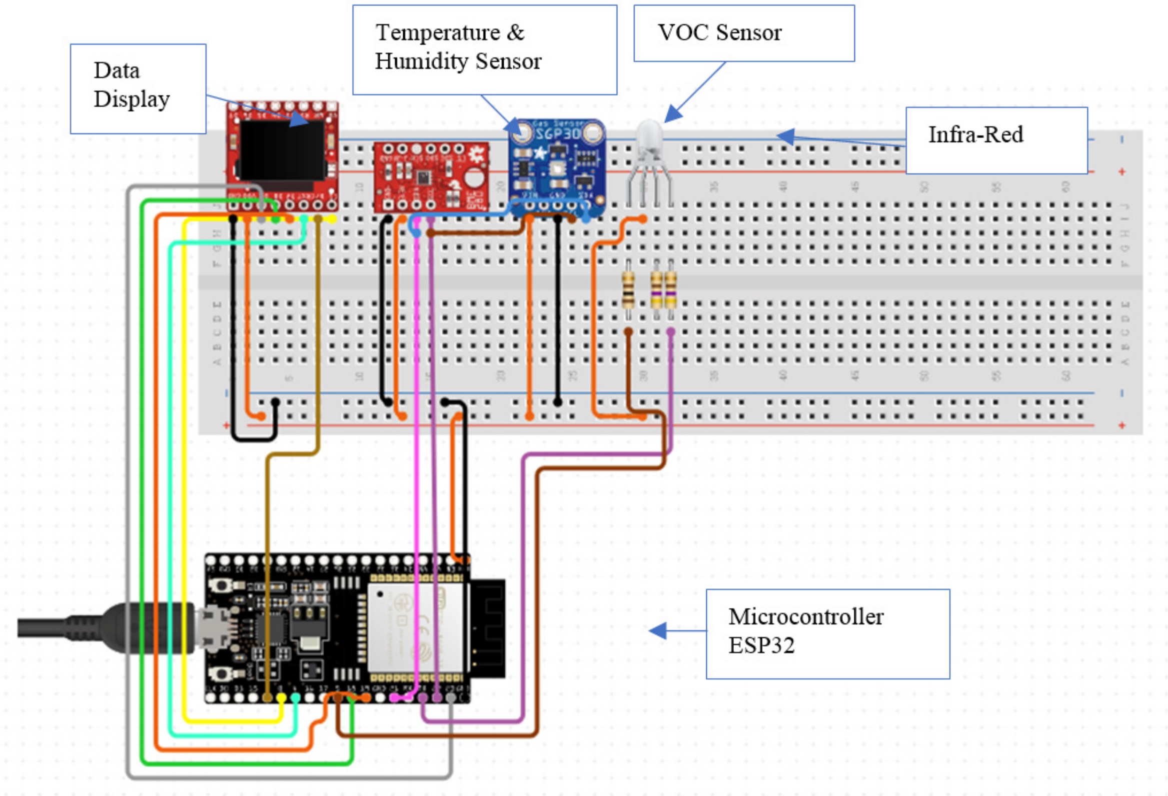

FIGURE 1. System hardware

b) SGP30 VOC Sensor
   This sensor has the capability of detecting a wide range of Volatile Organic Compounds (VOCs) and H2 and is intended for indoor air quality monitoring. Data communication with this sensor is using I2C pin.
c) BME280
   The BME280 sensor is a low-cost sensor from Bosch for measuring temperature, humidity and barometic pressure.
d) KY-005 Infra-Red
   The system uses Infra-Red to transmit signal to home appliances such as air purifier and AC system. The KY-005 Infrared transmitter consists of just a 5 mm IR LED. The IR transmitter is modulated by a carrier frequency in the 32-40 kHz range.

3.2. **System software.**

- IOAdaFruit. IOAdaFuit is an open IoT platform for connecting objects using web standards. Some of the services are registration, processing, and distribution of data: location-based services, many plugins, and other useful services. The first thing to do to create a new object or service is to choose the type of device (Arduino, Netduino, ioBridge, or others) and provide access data (IP, port, subnet mask, etc.). This step makes it possible to create a new channel to be used to push connected device data, show it, use it through HTTP requests, or download it in XML, JSON, or CSV format. Also, this platform offers data accessibility controls. (io.adafruit.com).
- Blynk IO. Blynk is a platform with iOS and Android applications to control Arduino, Raspberry Pi with Internet access [10]. By using the Blynk cloud server, all of the projects can be interconnected and as a live central transaction manager. At the same time, a database was also created in the Blynk application to record the level of VOC sensed by the sensor and give real-time notification to users.

3.3. **System architecture.** Figure 2 shows the system flowchart. The system consists of three parts. 1) Data acquisition: a polling mechanism is used to obtain environmental indicators such as temperature, humidity, and VOC concentration. 2) Data analysis: the collected data are being compared with the outdoor air conditions in order to choose the best options to reduce the VOC level of concentrations. 3) Data feedback: according to the analysis results, several actions may be performed. For instance, notification may be sent to mobile device, and mitigation devices such as air purifier, air conditioner or exhaust fan can be automatically controlled.

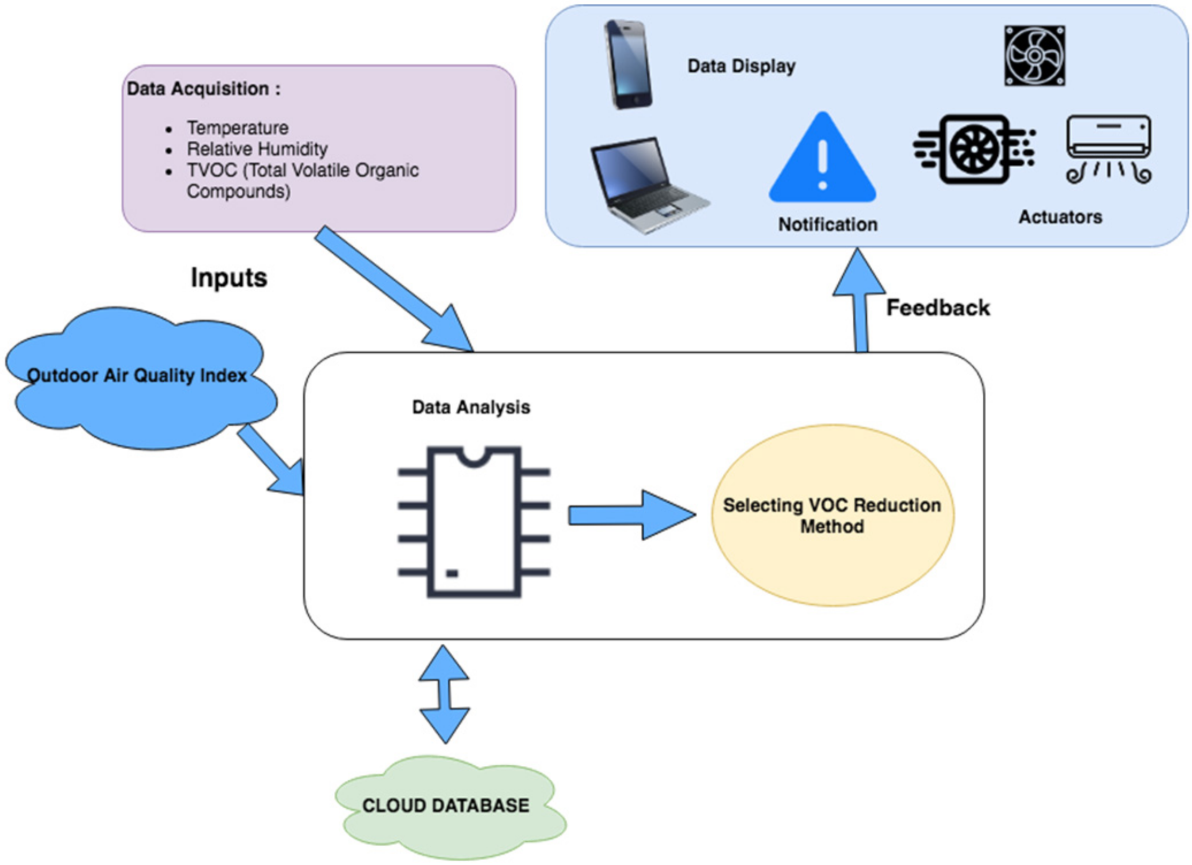

FIGURE 2. System flowchart

The TVOC covers a large range of different organic gases that may be chemically similar and difficult to differentiate. Hence the combination of standards for indoor air quality level from two health agencies are combined and furthermore convert to the units that the sensor uses in the system [9]. The parameter of air quality level that the writers use in this paper is shown in Table 1.

This parameter is stored in flash memory (ESP32-microcontroller). When the sensor detects the TVOC reaching level 2, the system needs to compare the outdoor air quality on AIQ API, if the outdoor air quality is in a better level, then what is sensed indoor, the system will suggest (give notification) to open ventilation. On the other hand, if the outdoor air quality is worse, the system will activate other actuators, i.e., air purifier, air conditioner or exhaust fan to reduce the VOC level, as shown in Figure 2, the data analysis used in the system is simple compared to the parameter, and more details of the mitigation process can be seen in Figure 3.

To provide the air quality signals, SGP30 uses a dynamic baseline compensation algorithm and on-chip calibration parameters. Based on the sensor signals a Total VOC signal (TVOC) and a CO2 equivalent signal (CO2eq) are calculated. Sending an "sgp30_iaq_init" command starts the air quality measurement. Afterwards, "sgp30_measure_iaq" command

TABLE 1. Air quality parameter

IAQ rating	Reference level	Air information	Action	TVOC range			Air quality
				Mg/m^3	ppm	ppb	
<= 1.99	Level 1	Clean hygienic air (Target value)	No action required	< 0.3	< 0.15	< 150	Very good
2.00-2.99	Level 2	Good air quality (If no threshold value exceeded)	Ventilation recommended	0.3-1	0.15-0.5	150-500	Good
3.00-3.99	Level 3	Noticeable comfort concerns (Not recommended for exposure > 12 months)	Ventilation required. Identify sources	1-3	0.5-1.5	500-1500	Medium
4.00-4.99	Level 4	Significant comfort issues (Not recommended for exposure > 1 month)	Refresh air when possible. Increase ventilation. A search for sources is required	3-10	1.5-5	1500-5000	Poor
-5.00	Level 5	Unacceptable conditions (Not recommended)	Use only if unavoidable and only for short period of time	> 10	> 5	> 5000	Bad

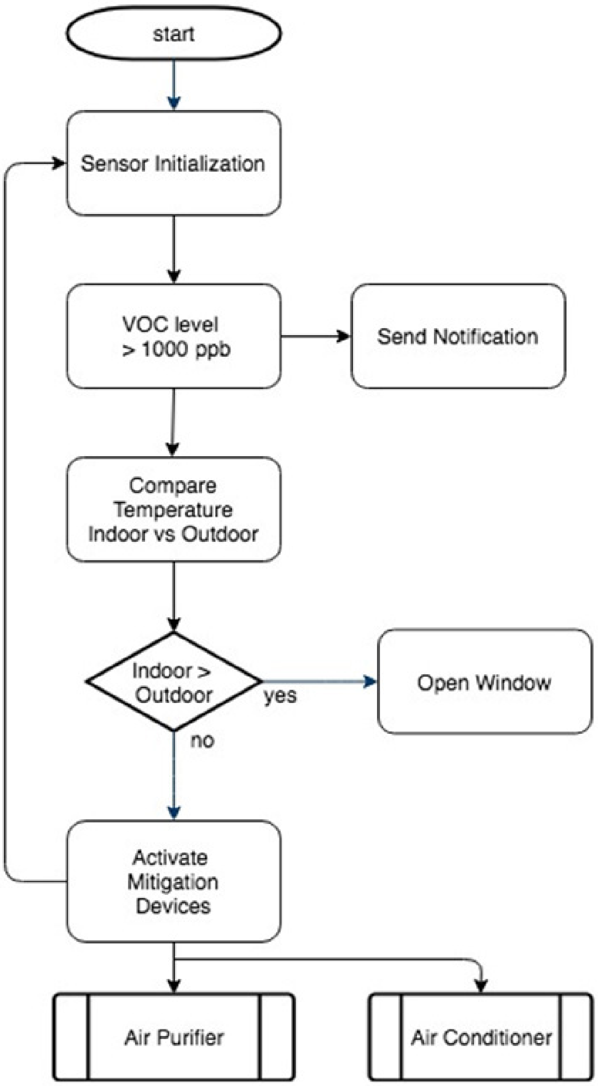

FIGURE 3. Flowchart of mitigation process

must be sent in regular intervals of 1 s to ensure proper operation of the dynamic baseline compensation algorithm. The sensor responds with 2 databytes (MSB first) and 1 CRC byte for each of the two preprocessed air quality signals in the order CO2eq (ppm) and TVOC (ppb). For the first 15 s after the "sgp30_iaq_init" command the sensor is in an initialization phase during which an "sgp30_measure_iaq" command returns fixed values

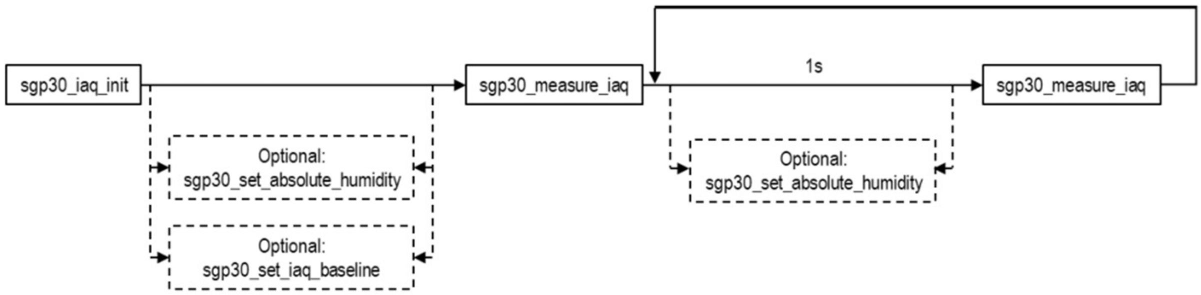

FIGURE 4. SGP30 signal initialization

of 400 ppm CO2eq and 0 ppb TVOC. A new "sgp30_iaq_init" command must be sent after every power-up or soft reset. The command sequence after start-up for initializing and repeating measurements is illustrated in Figure 4.

4. **Results and Discussion.** In the experiment, the following steps were performed to test the whole system. 1) Validating the sensors' detection: the sensor's accuracy was validated by exposing the sensors to pollutants within the designated time frame. 2) Testing the system's integration: the model was integrated with IOAdaFruit and Blynk for the purpose of providing user interface to monitor the data collected. 3) Validating feedback from the system to the actuators: the system should run the actuators based on the feedback.

4.1. **Validating sensor's detection.** The model was set up in a room equipped with mitigation devices, air purifier, air conditioner, and exhaust fan. The size of the room is $3.5 \times 3.5 \times 3$ m^3. First, the sensors were set up with 10 second refresh rate to collect TVOC, temperature and humidity for 1 hour. Second, we determine the parameter of TVOC level in the system. Third, we exposed the sensors to VOC pollutants until it reached several levels on the parameter set prior. Based on the experiment, we were able to validate that the sensor managed to sense the VOC concentration and was able to detect several levels of TVOC.

The obtained data which are presented through web pages or mobile devices can be used to show the statistical trends of air quality within a certain period of time. And based on the collected data, we can compare which mitigation device and method are more effective in reducing the VOC level.

4.2. **Testing system's integration.** In order to create user interface, shown in Figure 4, we used IOAdaFruit and Blynk application. The collected data were successfully pushed to the cloud and can be monitored through web and on the user's mobile device.

4.3. **Validating system's feedback to the actuators.** The logic of the systems is using indoor air quality level in Table 1 as parameter. During the experiment duration, the writers determined 4 states.

1) Ventilation Recommended: when the condition of the room reaches level 2, the system triggers notification "Ventilations Recommended" to the mobile device.

2) Ventilation Required: when the condition of the room reaches level 3, first the system will send notification to the user "Ventilation required". Simultaneously, the system will check the outdoor air condition, if the outdoor air quality is in a good rate, the system continues to run the 3rd state. And if the outdoor air quality is polluted, the system will continue to mitigate actuators.

3) Open Window: when the system detects level 3, and if the outdoor air quality is in good level, the system sends notification to the user "Open Window". And this will trigger the dynamo servo to automatically open the window.

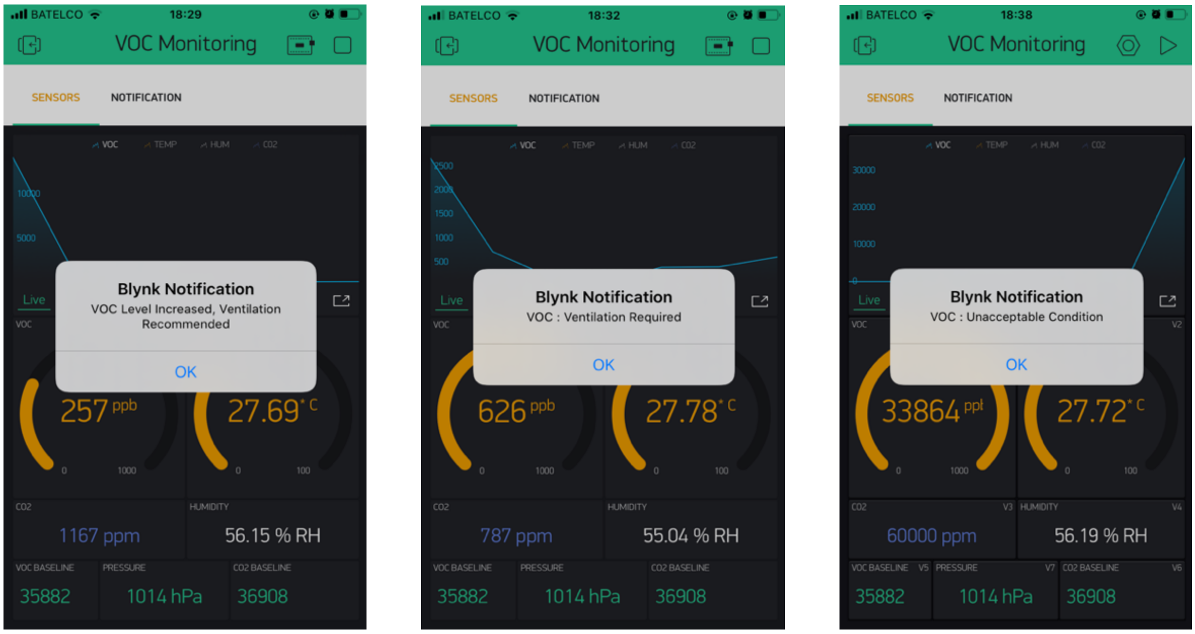

FIGURE 5. User interface & notifications

4) Fresh Air Required: when this notification is sent to the user, it indicates the level of TVOC in the room reaches level 4, and the system activates both air purifier and exhaust fan. Figure 5 shows the user interface and notifications.

The system is also capable of generating statistical data on the effectiveness of VOC reduction methods that were mitigated by the system. This will allow the user to analyze which mitigation device is more effective to reduce the VOC level and improve the indoor air quality.

5. **Conclusions.** The main contributions of this paper are as the following. 1) The writers developed a suitable system integrated to a prototype/model, in order to monitor the indoor air quality, especially VOC. 2) The system not only monitored indoor air quality, but also triggered notifications and was able to mitigate actuators that can reduce the VOC level. 3) As has been noted by analyzing over time, the system was able to provide suggestion on effective methods to neutralize the air quality rate after VOC exposure. 4) The integrated mitigation actuators were able to maintain the air quality level, within the acceptable comfort level. In the purpose for this system to be applied to improving air quality and benefiting our health, the writers believe that future research on detecting VOC with more detailed capabilities to specify the type of VOC pollutants shall give better results.

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REFERENCES

[1] T. V. Tran, N. T. Dang and W.-Y. Chung, Battery-free smart-sensor system for real-time indoor air quality monitoring, *Sensors and Actuators B: Chemical*, vol.248, pp.930-939, 2017.
[2] J. D. Spengler, J. F. McCarthy and J. M. Samet, *Indoor Air Quality Handbook*, McGraw-Hill, 2001.
[3] S. Abraham and X. Li, A cost-effective wireless sensor network system for indoor air quality monitoring applications, *The 9th International Conference on Future Networks and Communications (FNC-2014)*, 2014.

[4] J.-Y. Kim and C.-H. C. A. S.-M. Shin, ISSAQ: An integrated sensing systems for real-time indoor air quality monitoring, *IEEE Sensors Journal*, vol.14, no.12, pp.4230-4244, 2014.

[5] M. Benammar, A. Abdaoui, S. H. M. Ahmad, F. Touati and A. Kadri, A modular IoT platform for real-time indoor air quality monitoring, *Sensors*, vol.18, no.2, DOI: 10.3390/s18020581, 2018.

[6] C. Peng, K. Qian and C. Wang, Design and application of a VOC monitoring system based on a ZigBee wireless sensor network, *IEEE Sensors Journal*, vol.15, pp.2255-2268, 2015.

[7] Y. Deng, C. Chen, X. Xian, F. Tsow, G. Verma, R. McConnell, S. Fruin, N. Tao and E. S. Forzani, A novel wireless wearable volatile organic compound (VOC) monitoring device with disposable sensors, *Sensors*, vol.16, no.12, DOI: 10.3390/s16122060, 2016.

[8] J. Ahn, E. K. H. Kim and J. Ko, Designing a low-cost IoT sensing platform for VOC material classification, *2019 15th International Conference on Distributed Computing in Sensor Systems*, Greece, 2019.

[9] C. Meyer, *Overview of TVOC and Indoor Air Quality*, https://www.mouser.com/pdfdocs/IDT_ZMOD4410-Overview-TVOC-IAQ_WHP_20180524.pdf, Accessed on 15 November 2019.

[10] *Wikipedia*, https://en.wikipedia.org/wiki/Internet_of_things, Accessed in January 2019.

[11] U. E. P. A. (USEPA), *Indoor Air Quality for Schools. Communication Guide*, www.epa.gov, Accessed in January 2019.

[12] Y. Li, Privacy protection algorithm for source node location based on phantom routing in the Internet of Things environment, *International Journal of Innovative Computing, Information and Control*, vol.17, no.3, pp.973-989, 2021.

[13] S. N. N. Htun, T. T. Zin and P. Tin, Consumer behavior analyzer in Internet of Things (IoT) environments, *International Journal of Innovative Computing, Information and Control*, vol.17, no.1, pp.345-353, 2021.