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ARTICLE

Design of Multi-gas Monitoring Device for Indoor Air Quality

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ABSTRACT

Besides the need for low-cost instruments for air pollution measurement and detection, nowadays there are many concerns about air pollution due to the fast changes and used technologies. This research was applied using an MQ_2 gas detector, and microcontroller/Arduino-Uno. The design steps included bonding and connecting readymade sensors, coding, and finally testing the device. Testing has been conducted in Environment and Pollution Engineering Department laboratories, at the Technical Engineering College of Kirkuk. This study proposed the use of an MQ_2 sensor for multi-gas rate detection which can exist indoors. The system uses also a DHT22 sensor for measuring environment temperature and humidity. The sensors are connected to Arduino and LCD to present data on LCD by powering the system with external power. Overall, the testing was conducted, and the device served as a measuring tool for indoor air as an accurate multi-gas rate detector.

Keywords: MQ_2 sensor; Arduino Uno; Indoor air quality (IAQ); Multi gas; DHT22

1. Introduction

While official attempts to control air contamination have usually concerned the outdoor environment, it is now apparent that raised pollutant levels are more common inside public buildings and houses [1]. Indoor pollution has been classified among the highest five environmental hazards to public health [2]. People are spending their time in homes, offices, or any workplace in long-termly, so it is necessary to

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monitor environmental air quality which may affect human health [1]. It stances a serious health threat to humans [3-5]. Particularly for children and, persons who spend much time indoors [6]. Besides, the various health problems faced by workers in modern closed office buildings [7], where, levels of some pollutants are greater indoors than outdoor levels, and the personal exposures cannot be characterized sufficiently by outdoor measurements (for some contaminants) [1].

Also, the dependency on solid fuels and incompetent stoves has other, far-reaching concerns of health, environment, and economic development [6]. So, presented studies specify that Indoor Air Pollution (IAP) produced from cooking and heating causes notable health impacts in addition to penetrated outdoor pollution [8]. Therefore, a comprehensive strategy for the detection of indoor pollution, health impacts, control methods, and policy alternatives must be provided [1].

To evaluate the air quality it required an air pollutant concentration is introduced from a model or a monitoring tool [9]. In air quality monitoring aspects, the commercial availability of micro-sensors technology is allowing the adoption of low-cost sensors [10-12]. Indoor Air Quality (IAQ) is considered an important feature to be monitored and controlled for health aspects and comfort [2]. Various conventional devices are presented to monitor contaminants to detect indoor air quality, most of these tools are expensive and inadequate in providing high-resolution spatial-temporal measurements, which are necessary to identify the peak exposure concentrations and detect the sources responsible for the indoor pollution [4]. Moreover, risky gases like methane and propane are combustible so cause explosions when restricted in a closed place [13]. Studies on the early detection of fires were applied by using sensors [14]. The sensor MQ_2 detects gas leakages in small or large places and is a protective system against explosions and fires [15]. Generally, gas sensors are categorized by their operational system, the most common are thermal, electrochemical, ampere-metric, potentiometric, and optical sensors [16]. MQ_2 sensors detect harmful gases [17]. Where, it has a small heater along with an electrochemical detector that reacts with a range of gases, It's used to detect some toxin gases and radiations in case of any poisonous gases or radiation in industrial and living areas [18]. In spite of their limitations, the MQ sensor is used in many applications and Arduino-based projects. For instance, based on air quality we can turn a fan off, or make an alarm system to warn us about smoke [15]. Typically, the Arduino-based project needs slight information about programming or little knowledge of electronics theories and code usage. This may involve indoor and outdoor air quality monitoring using wireless applications [19]. According to the US Environmental Protection Agency, people's exposure to indoor pollutants can on occasion be higher than outdoor pollutants exposure due to interior buildings accumulating and concentrating contaminants that result from furnishings, and the activity of these building's occupants. In effect, indoor pollutants were considered a serious environmental risk to human health and most importantly, if we take into account that most public currently spends higher than 80% of their time in an artificial environment [2].

Indoor air quality is subject to pollution with chemicals, or any toxins that impact human health, as internal air contaminants are related to numerous health risks, such as asthma. In recent years it has been confirmed that interior air quality indoors is rather contaminated than in open air or outdoors. Actually, air types indoors are rather hazardous than outdoor air types. Quality of indoor air methods analysis involves air sampling, building surface samples, and indoor airflow modeling. The process of analyzing indoor air helps in understanding the causes of contamination, then can control it or remove undesirable materials from the air. Ideal air-type measuring systems involve expensive instrument usage. The essential purpose of this paper was to presen t an instrument for measuring the indoor quality of air along with room temperature and humidity, where it was tested in a laboratory/building in a college set-up.

2. System design

The project in the main is based on Arduino run by a power supply provided for the system via USB. The used sensor for detecting multi gases rates is the MQ_2 sensor which will be set up and bonded to the Arduino with humidity and temperature sensor. To sense the existence of any gas, and measure the temperature of ambient and relative humidity a signal will be sent to the Arduino, then based on programming the data will be collected.

The upcoming explanation involves the details of the system and its components.

2.1 Gas sensor MQ_2

Data acquirement related to gaseous contaminants, and air quality is extensive [20]. The portable air pollution sensing instruments enable the determination of exposure to air pollutants [21]. The sensor MQ_2 is used to measure the smoke and combustible gasses [13,19,22-25], such as propane, methane gas, hydrogen gas, alcohol, and carbon monoxide [19,23-27]. It is useful for detecting leakage of gases inside buildings as an indoor air quality detector [19,22]. It is a metal oxide semiconductor kind of sensor (chemiresistor), which contains a voltage divider network that measures released gas concentration with the ability to detect 200-10000 ppm gas concentration range, working on 5 Volt DC [22-24].

Figure 1 represents the used MQ_2 sensor module. Furthermore, the technical specifications of the used MQ_2 sensor module are described in **Table 1**.

Figure 1. The used MQ_2 sensor module [23].

The MQ_2 sensor is circumfluent by two layers of a fine mesh made of stainless steel named an anti-explosion network. Because MQ_2 senses flammable gases, this network will prevent the heater element from causing an explosion inside the sensor. This mesh is bonded to the body of the sensor with a clamping ring plated by copper as shown in **Figure 1**.

Table 1. The technical specifications of the used MQ_2 sensor module [23].

Sensor details	Specifications
Sensor operating voltage	5 Volt
Electrical load resistance	20 Kilo ohm (KΩ)
Heat resistance	33Ω ± 5%
Heat consumption	<800 mw
Sensing resistance	10 KΩ-60 KΩ
Concentration measure range	200-10000 ppm

As well, works by filtering out the suspended particles to ensure only gaseous pollutants pass into the chamber in addition to protecting the sensor. **Figure 2** represents the internal structure of the MQ_2 sensor when an outer part is set aside. It seems like a star-shaped structure consisting of an element of sensing and connecting legs. Beyond the leads, two of them (H) work to heat the sensor and are bonded by a conductive alloy (Nickel-Chromium coil). The other four leads (A) and (B) responsible for the output signal are bonded by platinum wires. The wires are bonded to the element of sensing and transfer little changes in the current that goes through the sensing element. The element of sensing is a tubular shape and manufactured as (Al_2O_3) Aluminum Oxide based ceramic and also coated by Tin Dioxide (SnO_2). This material (SnO_2) is the most sensitive part of flammable gases. However, the ceramic is heating the sensor area constantly at working temperature and is only increasing the heating efficiency.

The sensor provides an analog output voltage that changes proportionally with the smoke or gas concentration. A higher gas concentration results in high output voltage, while a lower gas concentration results in a lesser output voltage [23].

Moreover, **Figure 3** represents the sensor MQ_2 pinout, where VCC supplies power for the module and it could be connected to 5 volt output from the Arduino. GND: The ground pin must be connected to the Arduino GND pin. DO presents a digital form of the existence of flammable gases. AO presents an analog output voltage that is proportionate to the smoke or gas concentration [23,28].

Since the MQ_2 is a heater-driven sensor, the sensor calibration may drift if you leave it for a long time. For the first usage after being left in storage for one month or more, for example, you should fully heat it for one or two days to achieve high accuracy in measuring. While if it recently has been utilized, the sensor only takes five to ten minutes to fully heat. Over the heating time, the MQ_2 sensor typically measures high but gradually becomes low and decreases until measurements are stabilized [23].

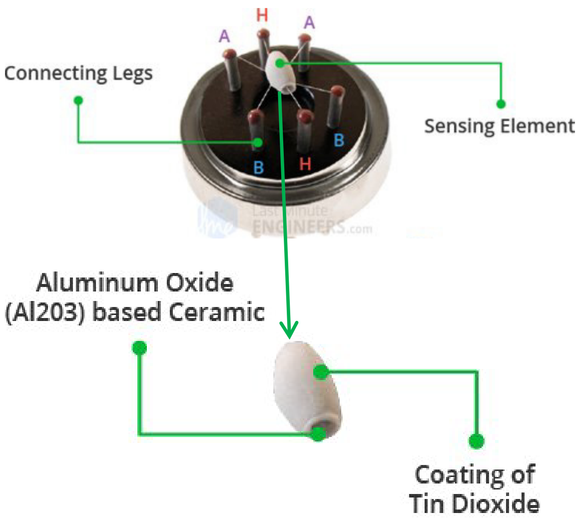

Figure 2. The internal structure of the MQ_2 sensor [23].

Figure 3. The sensor MQ_2 pinout [23].

2.2 Temperature and humidity sensor/DHT22/AM230x/RHT0x

The DHT22 sensor deals with both room temperature and humidity. The occupied high temperature is + 80 °C and the low temperature of –40 °C while humidity ranges from 0-100%. The measuring accuracy is 0.5 °C for temperature, and 2% for humidity accuracy. DHT22 is a digital sensor comprising a temperature measurement called a thermistor and another sensor called a capacitive sensor to determine the humidity. This sensor constituents 4 pins: Pin 1 represents the power pin, pin 2 represents the data pin, pin 3 represents the NULL pine, and pin 4 represents the ground pine. It needs a voltage supply between 3.3-6 volts. This module DHT22 has the best specifications which consider the highest expensive type. Though it has high accuracy and workability at a higher rate of temperature [29]. **Figure 4** represents the DHT22 sensor module. Furthermore, the technical specifications of the DHT22 sensor module are described in **Table 2**.

Figure 4. DHT22 sensor module [29].

Table 2. The technical specifications of the DHT22 sensor module [29].

DHT22 details	DHT22 sensor specifications
Power	3.3 to 6 V
Output signals	Digital signals by single-bus
Sensor element	Polymer capacitor
Range	Humidity (0-100)% and temperature (–40~80) °C
Accuracy	Humidity ±2% and temperature <±0.5 °C
Sensitivity	Humidity 0.1% and Temperature 0.1 °C
Sensing Time	Two seconds
Interchangeability	Fully

Moreover, **Figure 5** represents the DHT22 sensor Pinout, where VCC: Supplies the power to the module, and it is recommended 5 V. Data pin: To communicate the sensor with the microcontroller. NC: Will not be connected. GND: Will be connected to the Arduino ground. Like the DH11 temperature sensor, it is easy to bond the DHT22 sensor to Arduino. It has quite a long 0.1”-pitch pin so it can simply be attached to any board. After powering the sensor by 5 V and connecting ground to ground then, bond the data pin with digital pin #2 [29].

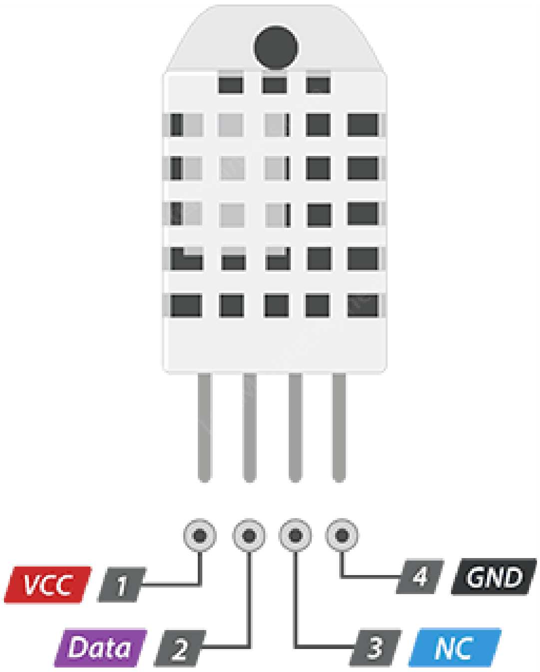

Figure 5. The DHT22 sensor pinout [29].

2.3 Arduino Uno R3

In this study, we presented an air detector device, which consists of a gas sensor based on Arduino. Arduino Uno has the option to acquire info on environs in excess of many sensors then could be practiced simply. The utilized Arduino in our design is Arduino/Uno R3. It comprises the following parts: Microcontroller, USB port, power pins, DC power jack, analog pins, reset bottom, and digital inputs-output pins. **Figure 6** represents Arduino UNO R3.

Arduino Uno considers the preferred board for beginning with electronics, programming, and coding. The Uno is highly robust that can be used mostly. The Arduino Uno is a highly-rated used one and the standard board in the entire Arduino family. The board functional voltage is almost 5, and can be run using a laptop or PC by a USB connector besides an AD-to-DC electric plug or battery operated by an external power supply, here used a battery provides 9 V.

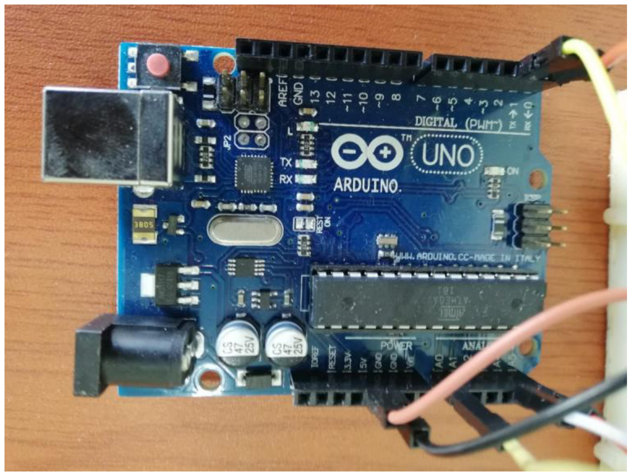

Figure 6. Arduino UNO R3.

2.4 Liquid color displays Lcd-i2C

For any microcontroller, inspecting and combining the characters on Lcd, getting familiar with the data on the Lcd, and configuring it, is the essential task, and among microcontrollers, Arduino is the better one. Arduino is an extraordinary step to interface the LCDs. **Figure 7** represents the Lcd-i2C.

Figure 7. The Lcd-i2C.

2.5 Power supply

In order to run the board a power supply (6-20 V), the power source must be set to turn on the board. The range set is 7-12 V. 9 V functions excellently can be used. Also, Arduino can be organized by a USB link to the computer. Nevertheless, you need to collect outlines that will be self-governing and organized by a battery. It's best for controlling Arduino definitely with a battery instead of voltage controllers which need additional power.

3. Procedure

The study procedure included two steps: Design and testing. To design the presented device for indoor air testing we used Arduino, an MQ_2 sensor, DH22 humidity, and temperature sensor. The representative form of the suggested system is shown in **Figure 8**, which represents the MQ_2 gas detection circuit diagram.

In this design, and based on **Figure 8** the MQ_2 gas detection circuit diagram, the procedure involved connecting the gas sensor MQ_2 and DHT22 temperature and humidity sensor on the Arduino board beside the supplementary apparatuses. The Arduino Uno is programmed using the software of Arduino (IDE) version 1.8.9.

Primarily, each sensor was linked with the Arduino, later we uploaded all codes. After the experiment and the success of the obtained results of independently applied codes other sensors with supplementary components of the system were linked with Arduino. We similarly combined all the codes and applied them with the display type on an Lcd monitor. Consequently, the obtained results will appear as the MQ_2 gas value PPM, temperature value in °C and humidity value in %.

Moreover, **Figure 9** represents the operating Arduino software with uploaded codes.

To call the tools from the Arduino library, first the libraries are defined inside the Arduino. The second step involves defining the sensor type and defining the inputs for the sensors. Here, it starts displaying the temperature and humidity values in fractional form, then it starts displaying the data on the screen and shows the results as numbers. Our designed device will detect air quality based on butane, propane, hydrogen, smoke, methane, alcohol, and carbon monoxide, which will be displayed as a rate of multi-gases values.

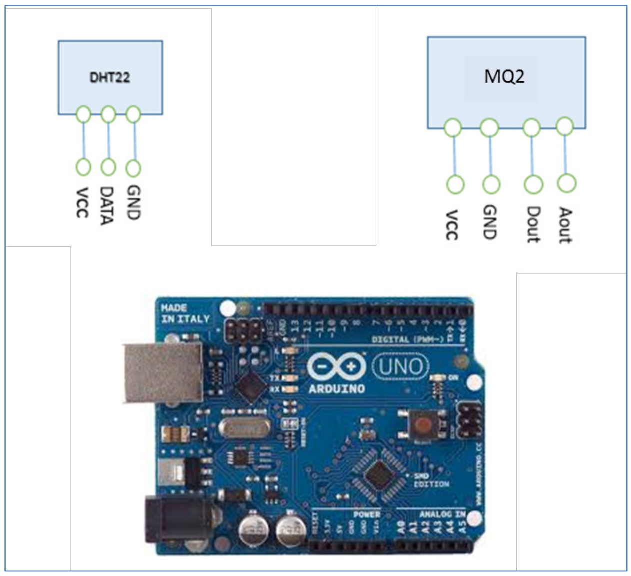

Figure 8. The MQ_2 gas detection circuit diagram.

Figure 9. The operating Arduino software with uploaded codes.

To test the device four testing areas have been selected inside the building. To ensure the workability of the system it was tested at different periods. The measurements were conducted from February to April 2021. The data were collected at four educational laboratories. The range of MQ_2 was within 301 PPM to 807 PPM which was programmed to appear as Smoke on the LCD.

The collected data appeared different readings. The highest values were detected in the Chemistry and Water Pollution laboratories at the Technical Engineering College of Kirkuk.

Maximum humidity was 95% detected in February 2021. While the minimum humidity was 10% detected in April 2021. Moreover, the maximum temperature was 35 °C in April 2021, and the minimum temperature was 16 °C in February 2021.

4. Experimental and practical results

We have been engaged in the design of a portable air quality monitor (MQ_2 gas monitoring) with low-cost and useful, using the Arduino platform.

The used sensors and Arduino are commercially available in the market. Where the device is operated either from the power provided by the computer or from an external supply as a 9-volt battery, and the result appears as a measure of indoor air pollution on the display screen in units Part Per Million PPM which refers to the rate of multi gases values, with the room temperature and rate of relative humidity displayed during the measurement period.

Figure 10 displays the comprehensive experimental progress.

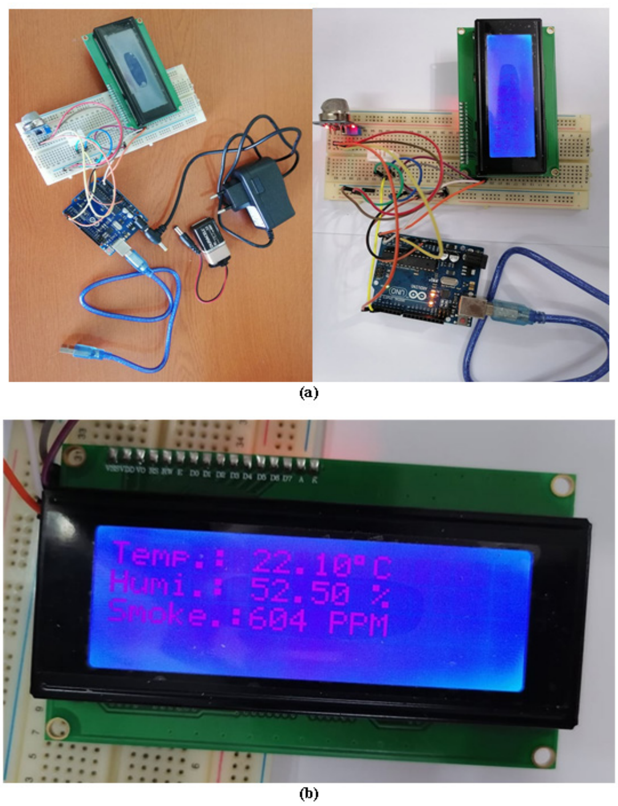

Figure 10. The comprehensive experimental progress: (a) Apparatuses of MQ_2 multi-gas monitoring device, (b) output results.

Where **Figure 10(a)** represents apparatuses of the MQ_2 multi-gas monitoring system, involving all components required for starting the sampling of indoor air. While **Figure 10(b)** represents output results, which it displayed on Lcd as Smoke, value in PPM for MQ_2 gas as a multi-gas rate, Temp. for temperature value in °C and Humi. for humidity value in %.

The data collected by the device were compared with other data for the purpose of verifying the accuracy of the readings. The results were identical and somewhat equal to the readings and measurements.

The major advantages of this indoor monitoring device can be described as a simple design consisting of readymade apparatuses the calibration can be made easily, obtainable sensors, and open source codes, the device can be extended by programming additional sensors, besides its lightweight, it is portable and it easily samples the data, and design cost is low in comparison to other instruments.

Nowadays, getting indoor air quality and pollutants data by means of Arduino-based projects has become popular and useful. Sensor gathering for air quality measurements demonstrates the prospect and potential for many monitoring purposes and sensing [11].

5. Conclusions

In this presented paper, a monitoring instrument for IAQ monitoring applications was designed. The system is established utilizing a low-cost gas sensor MQ_2 that is commercially available in the market in addition to temperature and humidity sensors. Relying on the open-source microcontroller development platform using Arduino the device has been developed. The measuring ability of the system was achieved by testing in different locations and periods. Such a device is very useful in monitoring air quality conditions inside buildings to better understand the current status of air quality as well as to study the long-term impacts of bad and polluted air on public health. Furthermore, the developed device based on the MQ_2 sensor has potential applications in many aspects that required the detection of some harmful gas levels in the air.

Conflict of Interest

There is no conflict of interest.

Acknowledgment

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References

[1] Spengler, J.D., Sexton, K., 1983. Indoor air pollution: A public health perspective. Science. 221(4605), 9-17.

[2] Pitarma, R., Marques, G., Ferreira, B.R., 2017. Monitoring indoor air quality for enhanced occupational health. Journal of Medical Systems. 41(2), 1-8.
DOI: https://doi.org/10.1007/s10916-016-0667-2

[3] Abraham, S., Li, X., 2014. A cost-effective wireless sensor network system for indoor air quality monitoring applications. Procedia Computer Science. 34, 165-171.
DOI: https://doi.org/10.1016/j.procs.2014.07.090

[4] Kumar, P., Skouloudis, A.N., Bell, M., et al., 2016. Real-time sensors for indoor air monitoring and challenges ahead in deploying them to urban buildings. Science of the Total Environment. 560, 150-159.
DOI: https://doi.org/10.1016/j.scitotenv.2016.04.032

[5] Brilli, F., Fares, S., Ghirardo, A., et al., 2018. Plants for sustainable improvement of indoor air quality. Trends in Plant Science. 23(6), 507-512.
DOI: https://doi.org/10.1016/j.tplants.2018.03.004

[6] Bruce, N., Perez-Padilla, R., Albalak, R., 2000. Indoor air pollution in developing countries: A major environmental and public health challenge. Bulletin of the World Health Organization. 78, 1078-1092.

[7] Samet, J.M., Marbury, M.C., Spengler, J.D., 1987. Health effects and sources of indoor air pollution. Part I. American Review of Respiratory Disease. 136(6), 1486-1508.
DOI: https://doi.org/10.1164/ajrccm/136.6.1486

[8] Smith, K.R., 2002. Indoor air pollution in developing countries: Recommendations for research. Indoor Air. 12(3), 198-207.

[9] Jumaah, H.J., Ameen, M.H., Kalantar, B., et al., 2019. Air quality index prediction using IDW geostatistical technique and OLS-based GIS technique in Kuala Lumpur, Malaysia. Geomatics, Natural Hazards and Risk. 10(1), 200-207.
DOI: https://doi.org/10.1080/19475705.2019.1683084

[10] Piedrahita, R., Xiang, Y., Masson, N., et al., 2014. The next generation of low-cost personal air quality sensors for quantitative exposure monitoring. Atmospheric Measurement Techniques. 7(10), 3325-3336.

[11] Jumaah, H.J., Kalantar, B., Halin, A.A., et al., 2021. Development of UAV-based PM 2.5 monitoring system. Drones. 5(3), 60.
DOI: https://doi.org/10.3390/drones5030060

[12] Karagulian, F., Barbiere, M., Kotsev, A., et al., 2019. Review of the performance of low-cost sensors for air quality monitoring. Atmosphere. 10(9), 506.
DOI: https://doi.org/10.3390/atmos10090506

[13] Jualayba, M., Regio, K., Quiozon, H. (editors), et al., 2018. Hazardous gas detection and notification system. Proceedings of IEEE 10th International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment and Management (HNICEM); 2018 Nov 29—Dec 2; Baguio City, Philippines. USA: IEEE. p. 1-4.
DOI: https://doi.org/10.1109/HNICEM.2018.8666358

[14] Kamelia, L., Ismail, N., Firmansyah, A.A., 2019. Fire disaster early detection system in residential areas. Journal of Physics: Conference Series. 1402(4).

DOI: https://doi.org/10.1088/1742-6596/1402/4/044001

[15] Bogdan, M., 2018. Gas detector using Arduino and LabVIEW. Proceedings of the 13th International Conference on Virtual Learning ICVL. 315-318.

[16] Villa, T.F., Salimi, F., Morton, K., et al., 2016. Development and validation of a UAV based system for air pollution measurements. Sensors. 16(12), 2202.

[17] Waworundeng, J.M.S., 2018. Prototype of gas detector with IoT platform for notification and monitoring system. Abstract Proceedings International Scholars Conference. 6(1), 160. Available from: https://jurnal.unai.edu/index.php/isc/article/view/1243

[18] Srinivas, C., Ch, M.K., 2017. Toxic gas detection and monitoring utilizing Internet of things. International Journal of Civil Engineering and Technology. 8(12), 614-622.

[19] Heyasa, B.B.L., Van Ryan Kristopher, R.G., 2017. Initial development and testing of microcontroller-MQ_2 Gas sensor for university air quality monitoring. IOSR Journal of Electrical and Electronics Engineering. 12(3), 47-53. Available from: https://scholar.google.com.hk/scholar?hl=zh-CN&as_sdt=0%2C5&q=Initial+development+and+testing+of+mi%02cro-controller-MQ2+Gas+sensor+for+university++air+quality+monitoring.&btnG=

[20] Villa, T.F., Gonzalez, F., Miljievic, B., et al., 2016. An overview of small unmanned aerial vehicles for air quality measurements: Present applications and future prospectives. Sensors. 16(7), 1072.

[21] Maag, B., Zhou, Z., Thiele, L., 2018. W-air: Enabling personal air pollution monitoring on wearables. Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies. 2(1), 1-25.

[22] Thamaraiselvi, D., 2020. Envionment monitoring system using IoT. Mukt Shabd Journal. 9(5), 915-920.

[23] Last Minute Engineers. How MQ_2 Gas/Smoke Sensor Works? & Interface it with Arduino [Internet] [cited 2021 Mar 7]. Available from: https://lastminuteengineers.com/mq2-gas-senser-arduino-tutorial/.

[24] ELPROCUS. MQ_2 Gas Sensor—Working Principle & Its Applications [Internet] [cited 2021 Mar 7]. Available from: https://www.elprocus.com/an-introduction-to-mq2-gas-sensor/.

[25] Krishnamoorthy, R., Krishnan, K., Bharatiraja, C., 2021. Deployment of IoT for smart home application and embedded real-time control system. Materials Today: Proceedings. 45, 2777-2783.
DOI: https://doi.org/10.1016/j.matpr.2020.11.741

[26] Jayakumar, D., Ezhilmaran, R., Balaji, S., et al., 2021. Mobile based gas leakage monitoring using IOT. Journal of Physics: Conference Series. 1717(1), 12068.

[27] Devi, K.I., Meivel, S., Kumar, K.R., et al., 2021. A survey report of air polluting data through cloud IoT sensors. Materials Today: Proceedings. Available from: https://linkinghub.elsevier.com/retrieve/pii/S2214785320403384.

[28] Setiawan, F.N., Kustiawan, I., 2018. IOT based air quality monitoring. IOP Conference Series: Materials Science and Engineering. 384(1), 12008.

[29] Last Minute Engineers. Interface Itwith Arduino [Internet] [cited 2021 Mar 7]. Available from: https://lastminuteengineers.com/dht11-dht22-arduino-tutorial/.