Environment and Ecology Research 10(6): 824-829, 2022 http://www.hrpub.org
DOI: 10.13189/eer.2022.100616

The Air Quality Monitoring Tool Based on Internet of Things to Monitor Pollution Emissions Continuously

Sri Listyarini[1,*], Lina Warlina[1], Aceng Sambas[2]

[1]Department of Environment, Universitas Terbuka, Indonesia
[2]Department of Mechanical Engineering, Universitas Muhammadiyah Tasikmalaya, Indonesia

Received October 14, 2022; Revised December 9, 2022; Accepted December 27, 2022

Cite This Paper in the Following Citation Styles

(a): *[1] Sri Listyarini, Lina Warlina, Aceng Sambas , "The Air Quality Monitoring Tool Based on Internet of Things to Monitor Pollution Emissions Continuously," Environment and Ecology Research, Vol. 10, No. 6, pp. 824 - 829, 2022. DOI: 10.13189/eer.2022.100616.*

(b): *Sri Listyarini, Lina Warlina, Aceng Sambas (2022). The Air Quality Monitoring Tool Based on Internet of Things to Monitor Pollution Emissions Continuously. Environment and Ecology Research, 10(6), 824 - 829. DOI: 10.13189/eer.2022.100616.*

Abstract As a result of pollutant emissions, air pollution occurs which causes various problems such as global climate change, environmental degradation, and diseases due to reduced air quality such as respiratory infections, asthma, and even lung cancer. Polluted air cannot be insulated; therefore, a tool is needed to monitor air quality. So far, in Indonesia the tool for monitoring air quality in the form of an ISPU (Indeks Standar Pencemaran Udara = Air Pollution Standard Index) monitoring station submitted the data daily or not continuously. Whereas air pollution creating from emissions needs to be carried out continuously, so that in 2021, the Minister of Environment and Forestry issued a regulation on the Information System for Continuous Emission Monitoring System (CEMS). Monitoring using CEMS is deemed necessary because correct, accurate, and continuous emission data and information need to be carried out to find out emissions in an integrated manner. This research was conducted to develop CEMS based on internet of things. Pollutant sensors in the form of methane (CH_4), butane (C_4H_{10}), carbon monoxide (CO), particulate ($PM_{2.5}$), and ammonia (NH_3) are assembled on the Arduino Uno microcontroller. MQ-4 sensors are used for measuring methane (CH_4), MQ-2 sensors for butane (C_4H_{10}), MQ-7 sensors for carbon monoxide (CO), GP2Y1010AU0F sensors for particles ($PM_{2.5}$), and MQ-137 sensors for ammonia (NH_3). Data from the sensor is transmitted to the Liquid Crystal Display (LCD) via the Arduino Uno microcontroller, where it is shown on smartphones as numbers. This web-based air quality monitoring program should continuously track air pollution emissions. The main finding shows that the concentration of particulate matter has the highest concentration (above the emission quality standard) among other sensors, namely 52.29 $\mu g/m^3$ on June 15, 2022 in South Tangerang, Indonesia. Based on these results, air quality monitoring for ($PM_{2.5}$) should be checked periodically.

Keywords Air Quality, Air Pollution, Arduino Uno Microcontroller, Internet of Thing (IoT), Sensors

1. Introduction

In many nations, human health, the environment, and the economy are all significantly impacted by air quality. Research has been done in several nations, including Europe and the United States, to reduce emissions of several air pollutants, including lead (Pb), nitrogen dioxide (NO_2), benzene (C_6H_6), sulfur dioxide (SO_2), ozone (O_3), particulates matter (PM), and several other organic compounds. These pollutants can endanger public health.

The decreased air quality caused by pollution is characteristic in all countries and it is known that air quality has a significant role in health, climate and ecosystems as stated by Swart *et al*. [2], Kan *et al*. [3], Peel *et al*. [4], and Kiss *et al*. [1]. Poor air quality can lead poor health and premature death according to research conducted by Perera [6], Bhandari and Bijlwan [8], Matos *et al*. [7], Wilson *et al*. [5], and Listyarini [9].

Since air quality monitoring is subject to legal restrictions in every nation, it is crucial for people to be aware of the air quality in their surroundings. This is governed in Indonesia by Government Regulation (*Peraturan Pemerintah* = PP) No. 41 of 1999 concerning Air Pollution Control, which governs the Emission Quality Standard (*Baku Mutu Emisi* = BME), ambient air quality standards (*Baku Mutu udara Ambien* = BMA), emissions, and monitoring of air pollutant parameters. The limit values and average periods for CO and $PM_{2.5}$, (determined by Directive 2008/50/EC of the European Parliament and of the Council) and limit values for Hydrocarbon (methane and butane) and ammonia from Government Regulation (Peraturan Pemerintah = PP) No. 41 of 1999 can be seen in Table 1.

Table 1. Average Period and limit for CO, $PM_{2.5}$, HC, and NH_3

Polutant	Average Period	Emission Quality Standard
Carbon monoxide CO	Eight-hour averages	10 mg/m^3
Particulate $PM_{2.5}$	One measurement a week at random	50 µg/m^3
Hydrocarbon/HC (CH_4 and C_4H_{10})	Three hours averages	160 µg/m^3
Ammonia (NH_3)	24 hours averages	150 µg/m^3

However, obtaining such data has been challenging for residents thus far. In fact, expensive monitoring stations that are built in specific areas and are under government control are typically the only method for keeping a focus on the quality of the air. In Indonesia, this station is called the Air Pollution Standard Index (ISPU= *Indeks Standar Pencemaran Udara*) monitoring station. DKI Jakarta Province as capital city of Indonesia only has 5 air quality monitoring stations for measuring ISPU. ISPU measurements are carried out every day, but the publication of air quality dataset is carried out monthly. Air quality data is published in the form of a dataset containing the ISPU measured from 5 air quality monitoring stations in DKI Jakarta Province.

On the other hand, air quality monitoring needs to be carried out automatically and continuously, as stated in the Regulation of the Minister of Environment and Forestry of the Republic of Indonesia Number 13 of 2021 concerning Information Systems for Continuous Monitoring of Industrial Emissions. In an effort to control air pollution, the Ministry of Environment and Forestry (KLHK= *Kementerian Lingkungan Hidup dan Kehutanan*) is committed to provide precise and accurate air quality information to the public. Through an Android-based application and the ISPU Net website, the general public can obtain the results of the real-time air quality monitoring in Indonesia. 39 places in Indonesia's largest cities have air quality monitoring equipment installed as of March 2021, according to KLHK [10]. Due to the expense of creation and maintenance, analysis of air quality monitoring systems requires great precision. According to study by Saravanana & Santhosh [11], when the Internet of Things (IoT) is utilized to monitor air quality conditions, the process becomes dynamic. The development of an Internet of Things (IoT) based air quality monitoring tool utilizing the Arduino Uno microcontroller to continually track pollutant emissions is described in this article.

Despite extensive scientific study of the internet-based air quality monitoring system, more research is required to build on earlier findings. In 2016, Fioccola, *et al*. [12] created Polluino, an Internet of Things (IoT)-based Arduino microcontroller-based air pollution monitoring system. Data on air quality were gathered in Marigliano neighborhood, Naples, Italy. The server receives the sensor data, which is then processed by a cloud-based server. Platform as a Service (PaaS) is the type of cloud that is utilized, and Node-RED is the deployment interface [13]. The solution provided by Fioccola et al. is still cable-based, hence it cannot be used outside. In [13], Benammar, *et al*. have succeeded in creating an Indoor Air Quality Monitoring (IAQM) system that can measure CO_2, CO, SO_2, NO_2, O_3, Cl_2 levels, temperature, and humidity. The sensor data transmission system uses Wireless Sensor Network (WSNs) technology and data transmission to the internet uses the Internet-of-Things (IoT) concept. However, this system was deemed too expensive and could only be used indoors. Kumar and Sasikala [14] developed a system to monitor air quality by detecting levels of CO, CO_2, and $PM_{2.5}$ in the air using the Arduino UNO module and MCU nodes for conventional and UAV applications. The results show that the cost of installing the system is low, and has high sensitivity for measuring various gases and pollutants in ambient air (CO, CO_2, and $PM_{2.5}$) both indoors and outdoors, IoT application systems can monitor air pollutants using smartphones.

In this work, a monitoring system that can continuously display air quality parameters utilizing sensors attached to the Arduino microcontroller is proposed based on the experience of those same researchers. The results of the air quality monitoring will be shown on a web page in real time that the entire community can access using smartphones to know about the air quality in the region.

2. Materials and Methods

In this study, an 8-bit microcontroller and a modem connected to the internet via the HTTP concept were used to develop an air quality monitoring system. This instrument can test the air quality with a sampling time of 1 minute for each pollutant and is equipped with MQ-131 for ozone (O_3), MQ-2 for butane (C_4H_{10}), MQ-7 for carbon monoxide (CO), GP2Y1010AU0F for particulates ($PM_{2.5}$), and MQ-137 for ammonia (NH_3) sensors. GP2Y1010AU sensor for dust or particles is used by Azeez, et al. Murad, et al. used the MQ-2 sensor to monitor carbon dioxide gas in parallel to butane gas. Saravanana & Santhosh [11] stated that hardware cost is reduced in air pollution detection since the system accommodates the monitoring area through the sensor network. In addition, this tool was programmed using the C programming language and was equipped with an antenna, an activation button, and 6600 mAh rechargeable battery. The monitor device block diagram is shown in Figure 1.

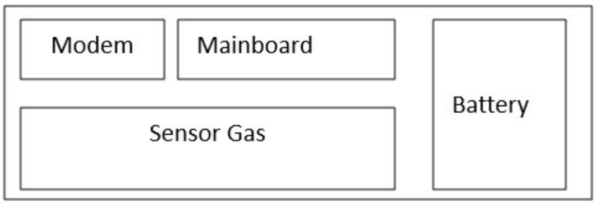


Figure 1. Block Diagram of Air Quality Monitoring Device

Each sensor node needs to be calibrated separately in order to obtain accuracy. The sensors often have quite wide parameter tolerances, therefore this calibration process is necessary. This explains why various samples using the same type of sensor (like a CO sensor) will not have the same response in terms of gas response curves. In this study, the MQ-7 sensor was used to monitor CO concentrations, not a sensor to determine CO_2 concentrations. This is in line with Jiao, *et al.* [16] that mention CO_2 is not an air pollutant.

All sensors to be used are resistive types and their responses are almost linear in the log plot, as shown in the datasheet for each sensor. To calculate the gas concentration can be seen in equation (1).

$$\log(C) = k_1 \log_{10}(R) + k_2 \qquad (1)$$

Where R is the sensor resistance, C is the gas concentration, and k_1 and k_2 are constants that vary depending on the type of sensor. The Internet of Things (IoT) technology is used in the sensor data delivery system, and the sensor data is transferred to a website Air quality App.

There are 3 phases of this air quality monitoring tool development. The first phase is to analyze the sensors used, and calibrates each sensor. The second phase is to design a monitoring device that is used to measure air quality. The third or final phase is to analyze the data generated from the measurement results so that it can be used as a reference for air quality.

The Analog Digital Converter (ADC) of the microcontroller reads the various data from the sensors using 8-bit digital data (0 to 255 digital data). Because the ADC features are already present in the Microcontroller features, ADC hardware is not necessary in this design. Using the general equation, the microcontroller will turn the ADC data into a voltage value. The voltage data is added to the sensor equation using the sensor data sheet and the sensor equation which are implemented into the Microcontroller program. In [14], Arduino UNO was used to convert the sensor signals into the respective gas concentration in the ppm unit as well as in the unit of $mg.m^{-3}$.

Data is sent to the Server via Modem (modulation and demodulation system) which is communicated with the Microcontroller using Universal Asynchronous Receiver Transmitter (UART) RS232. The microcontroller sends several commands to the Modem based on the ATtention Command (AT Command) using several functions in the program. The modem uses a GSM module and a GSM card is installed in it to send data to the server via the internet independently. Schematic diagrams of air quality monitoring architecture and hardware devices can be seen in Figure 2 and Figure 3.

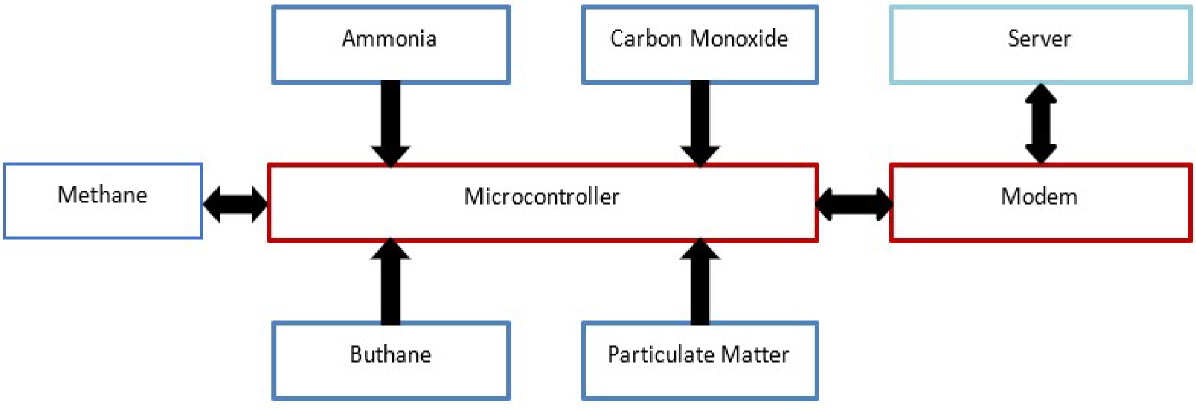
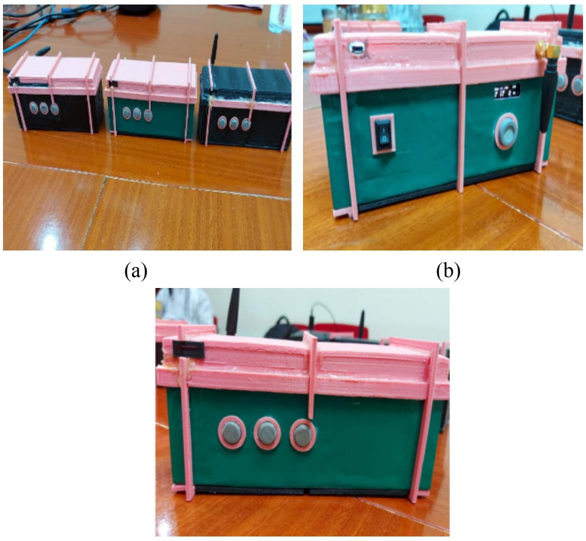


Figure 2. Block diagram of air quality monitoring microcontroller



(a) (b)

(c)

Figure 3. Air Quality Monitoring Device (Hardware), (a) Three tools developed, (b) Front view: numbers indicate pollutant concentration, (c) Rear view: pollutant sensor

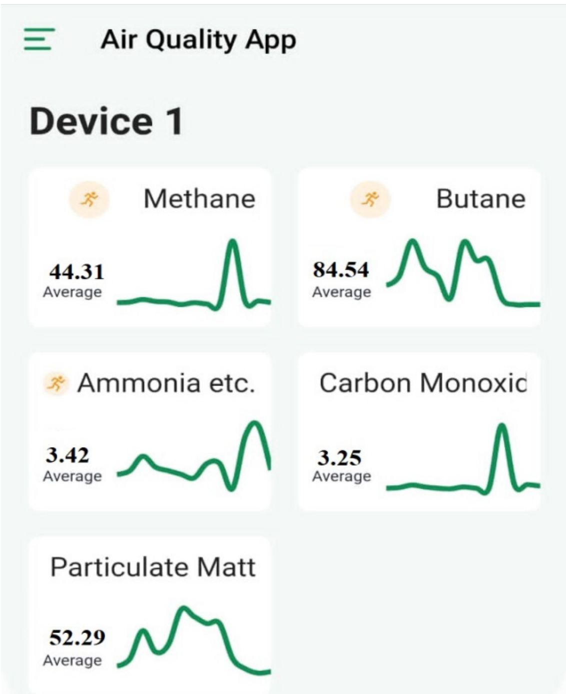


Figure 4. Display of air quality data collection on mobile phones

The sensor data delivery system uses Internet-of-Things (IoT) technology that is sent to smartphones. Data collection was carried out on Jalan Raya Pondok Cabe, Kec. Pamulang, South Tangerang City. Data collection was carried out in the morning (07.00 Am) with a dense volume of vehicles. In the mobile phones one example of data collection can be seen as Figure 4.

The average concentration of carbon monoxide (CO) is 3.08 mg/m^3, Butane (C_4H_{10}) is 83.10 mg/m^3, methane (CH_4) is 38.96 µg/m^3, ammonia (NH_3) respectively. Lastly, particulate ($PM_{2.5}$) is 41.45 µg/m^3.

The results of monitoring $PM_{2.5}$ concentrations in South Tangerang show that in June 2022 the average concentration of $PM_{2.5}$ is at the level of 41.45 µg/m^3. $PM_{2.5}$ concentrations tend to increase in the morning and decrease in the afternoon to the evening. Especially in the last few days $PM_{2.5}$ concentrations have increased and the highest was at the level of 52.29 µg/m^3 on June 15 2022, this concentration is above the emission quality standard.

We have studied and analyzed that the increase in particulate matter ($PM._{2.5}$) is caused by various factors including emission sources from transportation and residential areas, as well as from regional sources from industrial areas close to South Tangerang. In addition, the stagnation of air movement causes air pollutants that have accumulated in this region to persist and impact conditions that tend to last a long time.

In addition, the sensor must be validated first so that the data obtained is more accurate. In experiments with these 5 sensors, a monitor with the smartphones can be detected only in a moment, it cannot be carried out continuously. However, by using this Internet of Thing-based air quality monitoring tool, air quality monitoring can be carried out continuously. It is hoped that this tool can be operated in various public areas and the monitoring data can be accessed by the wider community via smartphones. Azeez *et al*. [15] stated that although the data accumulated from sensors are not as accurate as those coming from the official stations, they have the advantage of being able to increase the coverage of air pollution monitoring considerably, and the collected data is demonstrated every minute continuously. The total results of air quality monitoring can be seen in Table 2.

Table 2. Results of air quality monitoring in the city of South Tangerang

Date	Methane (CH_4) (μg/m^3)	Butane (C_4H_{10}) (mg/m^3)	Carbon Monoxide (CO) (mg/m^3)	Particulate Matter ($PM_{2.5}$) (μg/m^3)	Ammonia (NH_3) (mg/m^3)
10 Juni 2022	40.14	84.02	2.75	38.20	3.21
11 Juni 2022	37.28	83.50	3.66	39.40	4.21
12 Juni 2022	49.16	81.15	3.89	40.25	3.12
13 Juni 2022	38.19	83.57	2.89	37.40	2.15
14 Juni 2022	48.20	83.60	1.76	42.38	3.24
15 Juni 2022	44.31	84.54	3.25	52.29	3.42
16 Juni 2022	39.46	83.48	3.21	42.84	2.85
17 Juni 2022	48.78	83.29	1.60	41.25	4.10
18 Juni 2022	50.12	80.94	4.12	38.13	2.54
19 Juni 2022	42.18	83.36	3.66	42.43	3.19
Average	**38.96**	**83.10**	**3.08**	**41.45**	**3.20**

The air quality monitoring tool developed in this study can be tried out to measure the emission of methane, butane, carbon monoxide, particulate matter, and ammonia pollutants from factory emission sources that emit their emissions through chimneys. So far, factories that have source emissions from chimneys only conduct emission tests at certain times, due to the high cost and limited testing equipment. With this tool, measurement of chimney factory emissions can be carried out continuously at a relatively low cost, so that the ministerial regulation of the Ministry of Environment and Forestry number 13 of 2021 can be fulfilled. Kumar & Sasikala [14] mention that this proposed prototype model incorporates an open-source cloud facility with Arduino for air quality monitoring, confirming low cost, comfort, and convenience for a customizable air quality monitoring system [17-20].

3. Conclusions

An Internet of things-based air quality monitoring device using the Arduino Uno microcontroller has been successfully developed. The types of sensors used are MQ-4 for methane (CH_4), MQ-2 for butane (C_4H_{10}), MQ-7 for carbon monoxide (CO), GP2Y1010AU0F for particulates ($PM_{2.5}$), and MQ-137 for ammonia (NH_3). The average concentration of methane (CH_4) is 38.96 μg/m^3, butane (C_4H_{10}) is 83.10 mg/m^3, carbon monoxide (CO) is 3.08 mg/m^3, particulate ($PM_{2.5}$) is 41.45 μg/m^{3}respectively. Lastly, ammonia (NH_3) is 3.20 mg/m^3. The main finding show that the concentration of particulate matter has the highest concentration among other sensors, namely 52.29 μg/m^3 on June 15, 2022 in South Tangerang, Indonesia, because this concentration is above the emission quality standard. Data from continuous air quality monitoring system obtained from the tools developed in this research, which can be accessed by the wider community, is expected to increase public awareness of the importance of maintaining air quality. Further research also needs to be done to compare the time and cost of measuring emissions from chimney factories, as stationary emition sources, using this tool with the emission tests that have been carried out so far.

Acknowledgments

We are very grateful to Universitas Terbuka (The Indonesia Open University), this research would not have been possible without the financial support of Universitas Terbuka.

REFERENCES

[1] M. Kiss, A. Takács, R. Pogácsás & A. Gulyás. The role of ecosystem services in climate and air quality in urban areas: Evaluating carbon sequestration and air pollution removal by street and park trees in Szeged (Hungary). Moravian Geographical Reports, vol. 23, no. 3, 36-46., 2015, DOI: 10.1515/mgr-2015-0016

[2] R. Swart, M. Amann, F. Raes & W. Tuinstra. A good climate for clean air: linkages between climate change and air pollution. An editorial essay. Climatic Change, vol. 66, no. 3, 263-269., 2004,https://doi.org/10.1023/B:CLIM.0000044677.41293.39

[3] H. Kan, R. Chen & S. Tong. Ambient air pollution, climate change, and population health in China. Environment international, vol. 42, 10-19., 2012, https://doi.org/10.1016/j.envint.2011.03.003

[4] J. L. Peel, R. Haeuber, V. Garcia, A. G. Russell & L. Neas. Impact of nitrogen and climate change interactions on ambient air pollution and human health. Biogeochemistry, vol. 114, 121-134., 2013, DOI:

10.1007/s10533-012-9782-4

[5] S. R. Wilson, S. Madronich, J. D. Longstreth & K. R. Solomon. Interactive effects of changing stratospheric ozone and climate on tropospheric composition and air quality, and the consequences for human and ecosystem health. Photochemical & Photobiological Sciences, vol. 18, no. 3, 775-803., 2019, DOI: https://doi.org/10.1039/C8PP90064G

[6] F. Perera. Pollution from fossil-fuel combustion is the leading environmental threat to global pediatric health and equity: Solutions exist. International journal of environmental research and public health, vol. 15, no. 1, 1-16., 2018, doi: 10.3390/ijerph15010016

[7] P. Matos, J. Vieira, B. Rocha, C. Branquinho & P. Pinho. Modeling the provision of air-quality regulation ecosystem service provided by urban green spaces using lichens as ecological indicators. Science of the Total Environment, vol. 665, 521-530., 2019, https://doi.org/10.1016/j.scitotenv.2019.02.023

[8] B. S. Bhandari & K. Bijlwan. Effects of Atmospheric Pollutants on Biodiversity. In Global Perspectives on Air Pollution Prevention and Control System Design, 142-173., 2019, DOI: 10.4018/978-1-5225-7289-3.ch006

[9] S. Listyarini. Estimating the value of health degradation caused by SO2 gas air pollution in Jakarta. Der Pharma Chemica. vol. 7, no. 10, 563-565., 2015, https://www.derpharmachemica.com/abstract/estimating-the-value-of-health-degradation-caused-brny-sorn2rn-gas-air-pollution-in-rnjakarta-4321.html

[10] Kementerian Lingkungan Hidup dan Kehutanan (KLHK). (2021). Siaran Pers: Nomor: SP. 064/HUMAS/PP/HMS.3/3/2021. http://ppid.menlhk.go.id/berita/siaran-pers/5850/melalui-ispu-masyarakat-dapat-mengetahui-kualitas-udara (accessed Sept. 12, 2022)

[11] D. Saravanana & K. S. Santhosh. Improving air pollution detection accuracy and quality monitoring based on bidirectional RNN and the Internet of Things. Int. J. Nonlinear Anal. Appl. vol. 12, no. 2, 1497-1511., 2021, https://doi.org/10.1016/j.matpr.2021.04.239

[12] G. B. Fioccola, R. Sommese, I. Tufano, R. Canonico & G. Ventre. Polluino: An efficient cloud-based management of IoT devices for air quality monitoring. In 2016 IEEE 2nd International Forum on Research and Technologies for Society and Industry Leveraging a better tomorrow (RTSI), 2016, 1-6., DOI: 10.1109/RTSI.2016.7740617

[13] M. Benammar, A. Abdaoui, S. H. Ahmad, F. Touati & A. Kadri. A modular IoT platform for real-time indoor air quality monitoring. Sensors, vol. 18, no. 2, 581-598., 2001, https://doi.org/10.3390/s18020581

[14] V. V. Kumar & G. Sasikala. Internet of Things (IoT) Enabled Air Quality Monitoring System for Conventional and UAV Application. Nature Environment and Pollution Technology. vol. 21, no. 1, 71-81., 2022, https://doi.org/10.46488/NEPT.2022.v21i01.008

[15] H. L. Azeez, B. U. Ahmed & A. H. A. Al-Waeli. Internet of things-based real-time monitoring of air quality in Sulaymaniyah, Iraq. Renewable Energy and Environmental Sustainability. vol. 7, no. 19, 1-19., 2022, https://doi.org/10.1051/rees/2022010

[16] Jiao, J., Huang, Y., & Liao, C. Co-benefits of reducing CO2 and air pollutant emissions in the urban transport sector: A case of Guangzhou. Energy for Sustainable Development, vol 59, 131-143., 2020. DOI: https://doi.org/10.1016/j.esd.2020.10.005

[17] Dinas Lingkungan Hidup Provinsi DKI Jakarta. Kumpulan Data Indeks Standar Pencemaran Udara (ISPU) Tahun 2021. https://data.jakarta.go.id/dataset/indeks-standar-pencemaran-udara-ispu-tahun-2021 (accessed Sept. 12, 2022).

[18] Kementerian Lingkungan Hidup dan Kehutanan (KLHK), Siaran Pers: Nomor: SP. 064/HUMAS/PP/HMS.3/3/2021, 2021, http://ppid.menlhk.go.id/berita/siaran-pers/5850/melalui-ispu-masyarakat-dapat-mengetahui-kualitas-udara (accessed Sept. 12, 2022).

[19] A. Lambebo & S. Haghani. A wireless sensor network for environmental monitoring of greenhouse gases. In Proceeding of the ASEE Zone I Conference, Bridgpeort, CT, USA, April 3-5, 2014, https://aseecmsduq.blob.core.windows.net/aseecmsdev/asee/media/content/papers%20and%20publications/pdfs/199.pdf

[20] S. A. Z. Murad, F. A. Bakar, A. Azizan & M. A. M. Shukri. Design of internet of things-based air pollution monitoring system using thingspeak and blynk application. Journal of Physics: Conference Series, 15-16 March, 2021, vol. 1962, 1-12., https://iopscience.iop.org/article/10.1088/1742-6596/1962/1/012062.