JOIV : Int. J. Inform. Visualization, 5(4) - December 2021 422-429

INTERNATIONAL JOURNAL ON INFORMATICS VISUALIZATION

journal homepage : www.joiv.org/index.php/joiv

A Portable Device of Air Pollution Measurement Due to Highway Exhaust Emissions Using LabVIEW Programming

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***Abstract*— A multisensory gas device integrated with myRIO module to measure air pollution has been established. This device is programmed using the LabVIEW programming language and can measure CO_2, CO, NOX, and HC pollution on roads due to motor vehicle exhaust emissions. The device and the display system are made separately using wireless network communication to make this tool portable. Exhaust Gas Analyzer (EGA) was chosen for device calibration, obtaining 3.62% on the average error after performing 30 tests. The tests for measuring CO, CO_2, NOX, and HC gas levels were conducted in several locations in Padang City and performed in the morning, afternoon, and evening. The result showed that the system properly measured CO_2, CO, NOX and HC pollution in parks and highways in real-time in parts per million (ppm). It also displayed varied gas measurement results in terms of time and test location with a range of CO gas values at 0.034 – 0.15 ppm, CO_2 151.3 – 815.2 ppm, NOX 0.0001 – 0.004 ppm, and HC 0.04 – 0.65 ppm. In addition, the system could perform well in providing warnings by automatically activating the air indicator alert at several measurement places when the gas content on one of the gas elements and compounds at a particular location has exceeded the threshold for the clean air category. Thus, this device can be used as initial research to build a real-time air pollution measurement system using the Internet of Things (IoT).**

***Keywords*— Portable; multisensory; pollution; highway.**

Manuscript received 20 Aug. 2021; revised 10 Nov. 2021; accepted 4 Dec. 2021. Date of publication 31 Dec. 2021.

I. INTRODUCTION

According to Indonesia Statistics, the number of vehicles in Indonesia in 2019 was 133,617,012 units, specifically 350,475 units in Padang in 2020 [1]. With an average growth of 5% annually, in 2021, it is estimated that by 2021 the number of vehicles in Indonesia and Padang City will reach 150 million units and 50,000 units, respectively. The increased use of motorized vehicles is one of the biggest contributors to air pollution in the world. Subsequently, the air is polluted by exhaust gas emissions interfering with human health and other natural ecosystems [2]. Motorized vehicle exhaust emissions are the combustion residues occurred in the combustion chamber of a motorized vehicle engine. The residue contains various harmful substances and is released through the exhaust gas emission pipe. The exhaust gas contains CO (Carbon Monoxide), CO_2 (Carbon Dioxide), NOX (Nitrogen Oxide), HC (Hydro Carbon), and others that are harmful to humans, living things, and the natural surroundings [3]–[5]. Motor vehicle exhaust emissions become one of the contributors to air pollution, especially on the highway. Regular and periodic air quality monitoring must be done in order to identify and control the impact of air pollution in a place, especially the direct impact on the organisms [6]. Frequent monitoring and measuring the motor vehicle exhaust emissions regularly is an obligation for each vehicle owner and the government; hence, exhaust gas emissions remain in clean air. Currently, motor vehicle emission test locations are only available at exhaust emission testing centers owned by the government or certain institutions and are insufficient [7]. There is a lack of public awareness to test their vehicle exhaust emissions, although the emission test is one of the requirements for technical feasibility in renewing the license issued by the government. The impact is that air pollution due to motor vehicle exhaust emissions on roads, especially in the big cities in Indonesia, becomes relatively high and unmanaged [8].

Therefore, it is necessary to acquire an efficient portable air pollution meter and instantly can measure CO, CO_2, NOX, and HC levels on the highway. This tool is required to determine air pollution promptly, especially on the highway, and operated as public information concerning air pollution on the road. This problem can be solved by creating a measuring instrument that uses a multisensory gas to detect gas elements and compounds in the air around the sensor and function as an aroma sensor. The aroma sensor is a gas sensor system used to analyze simple and complex compounds contained in the air.

Multisensory gas has been applied in various fields to detect gas elements and compounds around the sensor [9]–[13]. When several sensors are used simultaneously, then all of these sensors can be arranged parallelly or known as a sensor array. The use of sensor arrays has been accomplished to determine the combustion conditions of the engine room. The use aligns with the gas produced when the engine combustion is inadequate, and its impact on air pollution, especially for elements and gaseous compounds CO, CO_2, NOX, and HC gases [14]–[17].

Thus, multiple gas sensors usage arranged parallelly and integrated into the myRIO module can be applied as an air pollution measurement tool. This device uses a display on a laptop or Personal Computer (PC) equipped with a Virtual Instrument (VI) from the measured data as a user interface. The device and the display system are integrated through a wireless network to become portable. Elements and compounds of CO, CO_2, NOX, and HC gases have been measured excellently by the system, and presented in ppm (parts per million) on real-time, and equipped with a hazard indicator when one of the gas elements and compounds exceeds the threshold for clean air based on World Health Organization standards (WHO).

II. Material And Method

This research was an experimental study, where the object was air pollution resulting from motor vehicle exhaust emissions. It was performed in the parks or green open spaces, highways, and crossroads in Padang, West Sumatra, Indonesia. The tool testing time was completed in 3 timeframes, as shown in Table 1.

TABLE I
TESTING TIME

No	Timespan	Time
1	Morning	8:00 - 8:30 AM
2	Midday	1:00- 1:30 PM
3	Afternoon	5:00- 5:30 PM

A. System Design And Designing Stage

This stage began with creating a multisensory gas system as an electronic nose (e-nose) input system. This multisensory was a system to detect gas elements and compounds in the air around the sensor. The system consisted of electronic sensor components that were sensitive to the changes in the elements and compounds of CO, CO_2, NOX, and HC gases levels; in consequence, it can be used as aroma detectors [14]–[19]. Meanwhile, the sensor used for CO gas was MICS-6814, MG 811 for CO_2, MICS-6814 for NOX, and TGS 2201 for HC. These sensors are parallelly arranged or known as sensor arrays to detect the level of elements and compounds of CO, CO_2, NOX, and HC gases synchronously [20], [21]. The following design stage was processing the data from multisensory detection using LabVIEW programming to present the data in ppm values and response graphs. The LabVIEW program was chosen as the ability of this program was graph-based and displayed the output in the form of a virtual instrument that allows the users to read measurement data easily [22]–[24].

This program was embedded in the myRIO module of National Instrument as a hardware interface between the multisensory and display system on the laptop. The system was designed portable and interacted with the display system using Personal Computer, Mobile Phone, or Laptop through wireless network communication. The overall system correlation diagram is shown in Figure 1. Gas elements and compounds levels in parts per million (ppm) values are presented on the screen displays, whereas the response graph is on the laptop. The Virtual Instrument (VI) display on the laptop is also equipped with a hazard indicator when the level of gas elements and compounds exceeds the WHO standards threshold. The system display in the form of a virtual instrument is shown in Figure 2. whereas the block diagram of the program designed using LabVIEW is shown in Figure 3.

B. Testing Stage

In this stage, the level of the elements and compounds of CO, CO2, NOX, and HC in the air in parks, roads, and intersections were examined. Data reading of CO, CO_2, NOX, and HC levels was performed after the heating time for all sensors met the characteristics of each sensor. This process was required to make each sensor read gas elements and compounds levels in a stable state. This testing phase was put into effect in several processes:

1) Sensor Response Test and Calibration Using Exhaust Gas Analyzer: This test attempted to determine the response and accuracy of all sensor data readings after being converted to ppm units compared to standard equipment in the form of an Exhaust Gas Analyzer (EGA). The measurement object was the exhaust emission of a 4-stroke motorcycle not fueled with gasoline, etc. The measurement results of each device used in this test were compared to obtain differences or errors that occurred between the devices created with EGA. In addition, the calculation of deviation values was performed on each result measurement system. It was by employing the average value of all measurement data to obtain each gas element and compound's minimum and maximum deviation values.

2) Air Pollution Measurement Test in the Park: This test was taken to determine the system's ability to measure the elements and compounds of CO, CO_2, NOX, and HC gases levels found in parks with the absence of air pollution, primarily due to motor vehicle exhaust emissions. The test was conducted in the park area of the State Polytechnic of Padang.

3) Air Pollution Measurement Test on Highway: The air pollution measurement was carried out in 2 locations categories; on highways and intersections with traffic lights. The tests on the highway were effectuated on Indarung and Andalas University highway. Meanwhile, the intersection of The Great Mosque of West Sumatera, Regional office of Indonesian Post, and Lubuk Begalung were chosen for the intersection with traffic lights.

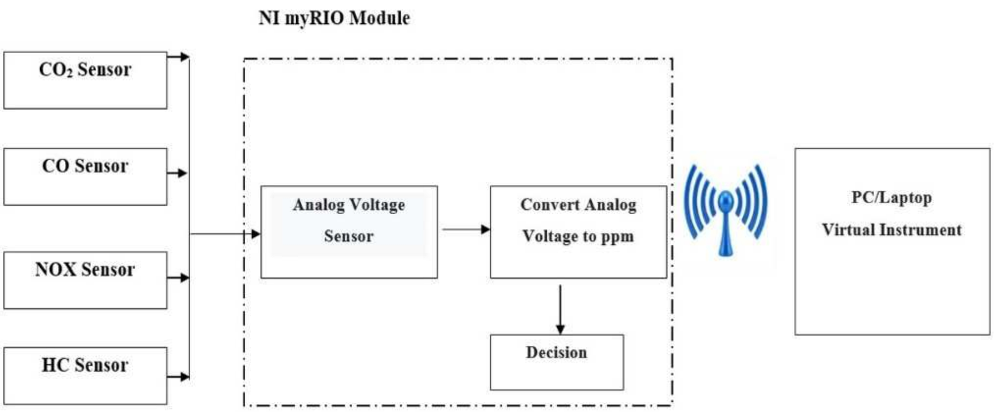

Fig. 1 System block diagram

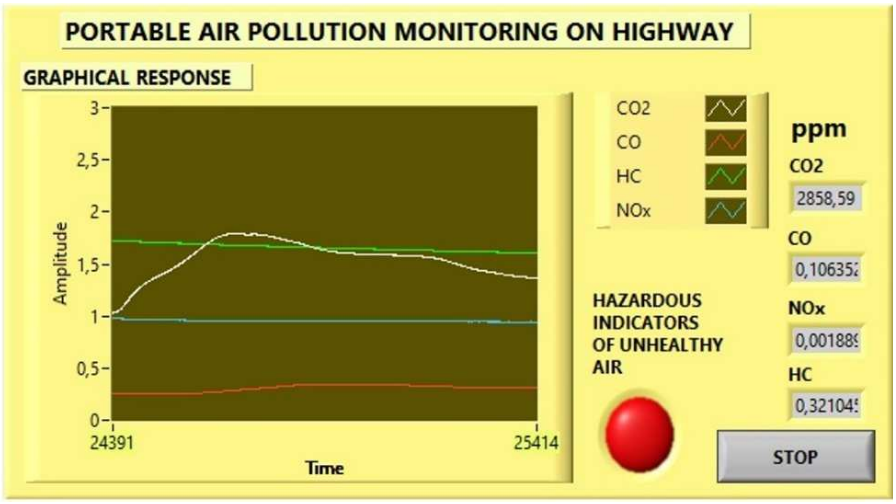

Fig. 2 User interface

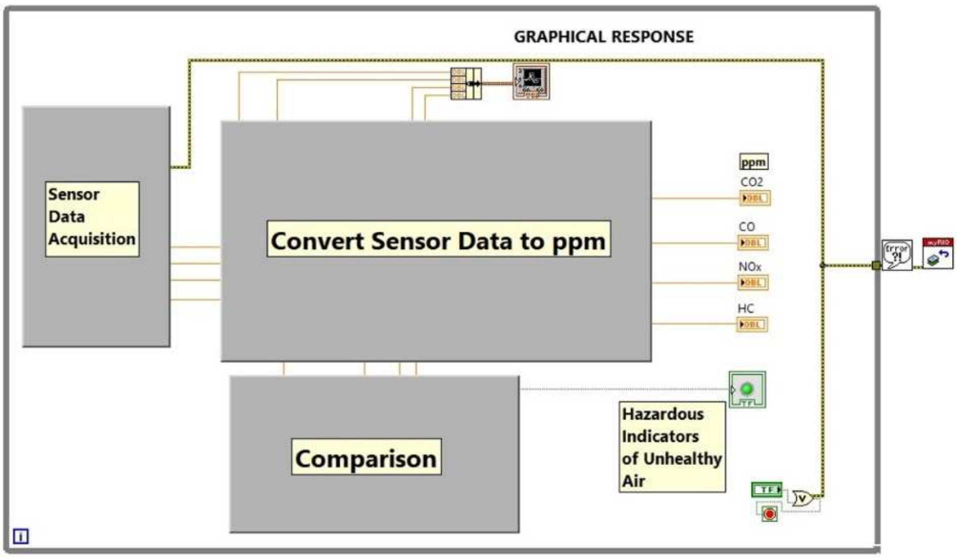

Fig. 3 LabVIEW Programming block diagrams

III. Results and Discussion

The tests are carried out in stages. Initially begins with testing the ability to measure gas levels in the air and continues to testing calibration using an Exhaust Gas Analyzer, finally ends with testing the system's ability to measure CO, CO_2, NOX, and HC gas levels resulted from air pollution on highways and intersections with traffic lights.

To obtain data in ppm value units, the analog voltage value of each sensor is converted through a comparison of the ratio value (rs/ro) and the ppm value using the regression method. The output of the CO sensor is still a value sensor that has not shown the ppm value of gas. Then the data is processed to be converted into a ppm value with the formula:

$$y = (a\frac{rs}{r0})^b \quad (1)$$

$$rs = \left(Vcc\frac{Rl}{Vout}\right)Rl \quad (2)$$

For example, for CO gas data, using the regression method as shown in Figure 4, the following equation is obtained:

$$y = (95.05\frac{rs}{ro})^{-1.206} \quad (3)$$

In the equation, the values of rs are obtained with 2.044.329.85 Ohm, ro are 6,890.18 Ohm, 95.05 is the value of the scaling factor, and -1.206 is the exponential value.

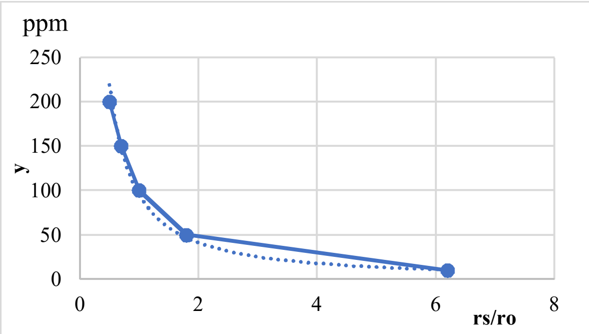

Fig. 4 Graph of CO sensor line equation

Figure 4 is a comparison of the ratio value (rs/ro) with the ppm value obtained from the CO sensor data sheet. If a relationship is made between rs/ro and the ppm value, it can be displayed in the form of table 2.

TABLE II
COMPARISON OF THE RATIO VALUE (RS/RO) AND THE PPM VALUE OF CO GAS

No	rs/ro	ppm
1	6.200	10
2	1.800	50
3	1.000	100
4	0.700	150
5	0.500	200

This linear equation model is applied to CO2, NOX, and HC gas data. These equations are implemented in the LabVIEW program to convert the analog voltage data of each sensor into ppm values. The tool's calibration is performed using an exhaust gas analyzer owned by a motor vehicle repair shop by conducting detection tests and measuring levels of CO, CO2, NOX, and HC exhaust gas emissions of 4-stroke motorcycles fueled by gasoline or similar. Figure 5 shows the type of EGA utilized in calibrating the device. The calibration process is by reading the measurement data 30 times on each tool. Then the average value of the gas element and compound readings is calculated as shown in Table 3. The measurement results are displayed in ppm values obtained from the conversion of the analog voltage values of each sensor using the equations of each sensor and translated in the program block diagram seen in Fig. 3.

Prior to the measurement process, the sensor has been warmed up for 5-10 minutes, referring to the characteristics of the sensor manufacturer to obtain stable measurement results.

Fig. 5 Exhaust Gas Analyzer (EGA).

TABLE III
COMPARISON OF READING AVERAGE GAS LEVELS DATA SYSTEM DESIGNED WITH EXHAUST GAS ANALYZE

No	Gas Type	Data Reading Results (ppm)		% Error
		Designed System	Exhaust Gas Analyzer	
1	CO	4.720	4.870	3.080
2	CO_2	1,175.700	1,208.300	2.690
3	NOX	0.130	0.130	3.970
4	HC	2.210	2.110	4.740

The error value is the difference between the measurement results of the device and the EGA with the following formula:

$$e = \frac{data\ DS - data\ EGA}{data\ EGA} 100\% \quad (4)$$

$$\text{e Average} = \frac{\text{eCO+eCO2+eNOX+eHC}}{4} \quad (5)$$

$$\text{Tdata} = \text{d1} + \text{d2} + \text{d3} + \cdots + \text{d30} \quad (6)$$

$$\text{d Average} = \frac{\text{Tdata}}{30} \quad (7)$$

$$\text{dv} = \text{data DS} - \text{d Average} \quad (8)$$

Seen in Table 3 is that the system created has the lowest error value in CO2 levels reading and the highest on NOX levels reading compared to CO2 and NOX levels data reading on the EGA. Hence, the average error value is 3.62%, which made this device usable as a measuring or testing instrument because the error is less than 5% [25].

Then the error value is calculated from the measurement results and compared with the exhaust analyzer measurement results. In addition, the minimum and maximum deviations for each measurement result of CO, CO2, NOX, and HC gas are also calculated and compared with the average value of the measurement. Deviation for the minimum CO level is 0.0003 ppm, whereas the maximum is 0.0014 ppm. Meanwhile, the minimum deviation for CO2 is 0.450 ppm, and the maximum is 1.72 ppm. For NOX, the minimum is 0.0012 ppm, the maximum is 0.0035 ppm, the minimum for HC is 0.420 ppm, and the maximum is 2.340 ppm.

The next measurement is the ability test on the device built to measure the level of elements and gas compounds CO, CO2, NOX, and HC in green open space. This space is considered free from air pollution, especially from vehicle exhaust emissions. The results of measuring gas levels in the air in Padang State Polytechnic Campus Park are illustrated in Table 4.

TABLE IV
RESULTS OF MEASUREMENT CO, CO2, NOX AND HC LEVELS IN GREEN OPEN SPACES OR GARDENS

No	Gas Type	Data Reading (ppm)
1	CO	0.020
2	CO2	150.700
3	NOX	0.001
4	HC	0.040

Table 3 presents the system that can respond and measure CO, CO2, NOX, and HC gas levels in the parks in the absence of air pollution and where all gas elements and compounds measured are in clean air condition.

The measurement of CO, CO2, NOX, and HC gas levels on the highway is initiated from the Andalas University campus and Indarung highway. However, the intersection test with traffic lights is employed at three different places: the intersection of the Masjid Raya Sumatera Barat, Lubuk Begalung, and the intersection of Regional Office of Indonesian Post. The test was set from July to August 2021 in 3 measurement time periods.

The results of air pollution level on Andalas University campus highway at 8:00 local time on July 5, 2021, are shown in Figure 6. As seen in Figure 6, the CO2 value has increased significantly, with values varying from 139.233 ppm to 413.560 ppm due to crowded higway packed with motorized vehicles. CO, NOX, and HC levels are increased at 8:20 A.M as a consequence of the local government regulation that allows cargo trucks on the city road during that time.

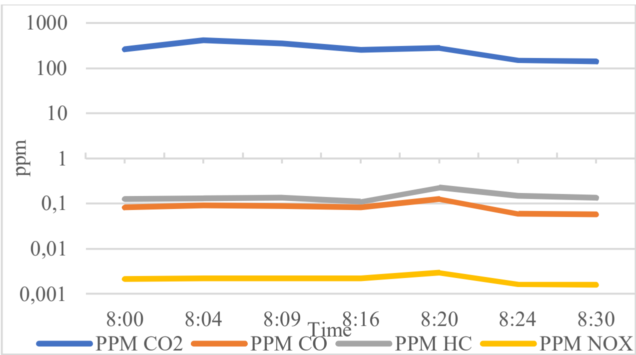

Fig. 6 CO, CO2, NOX and HC gas level of Andalas University campus highway in the morning.

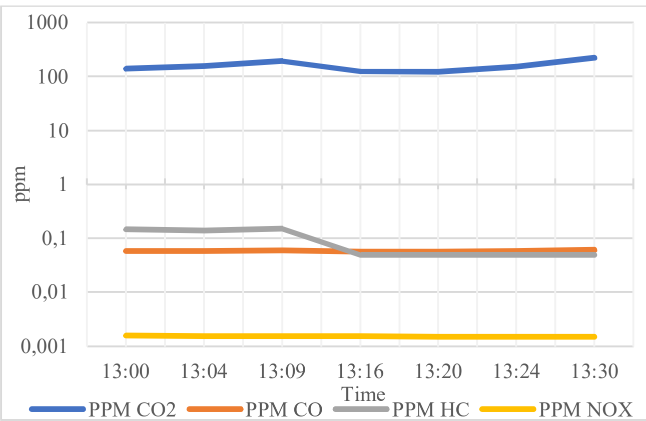

Fig. 7 CO, CO2, NOX and HC gas levels of Andalas University Highway during the mid-day.

Figure 7 presents the results of air pollution testing of Andalas University Campus Highway at 1:00 PM, on July 5, 2021. During the mid-day, the CO2 level is decreased in line with the number of vehicles passing this route. CO2 level is varied from 135.850 ppm to 225.730 ppm. Likewise in the afternoon where CO2 values is ranged from 119.640 ppm to 218.470 ppm. However, there are no significant changes for CO, NOX, and HC gases in all day periods: morning, afternoon, and evening time.

The overall test results on the Andalas University Campus emphasize the ability of the system to measure CO2, CO, NOX, and HC concerning the air pollution conditions occurred during the measurement. Figure 8 illustrates the measurement in afternoon time, at 17:20. There is an increase in HC gas in line with the increase on a number of vehicles passing through the test location, especially heavy vehicles or trucks transporting materials.

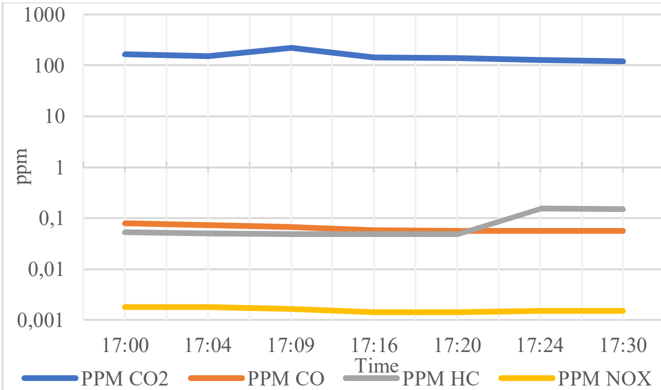

Fig. 8 CO, CO2, NOX and HC gas levels of Andalas University Highway in the afternoon time.

Furthermore, air pollution levels on Indarung highway are measured on July 10, 2021. The testing in the morning time is presented in Figure 9. There is a significant change in the NOX value at 8:24 A.M as the cargo trucks has been permitted to be on the city roads during that time. Seen in Figure 10 is the daytime measurement conditions showing an increase in HC and CO2 gases at 13:09. This condition is due to an increase in the number of vehicles at that location. On the other hand, the air pollution in the afternoon is relatively stable even though there is a slight increase in CO2 gas, as shown in Figure 11.

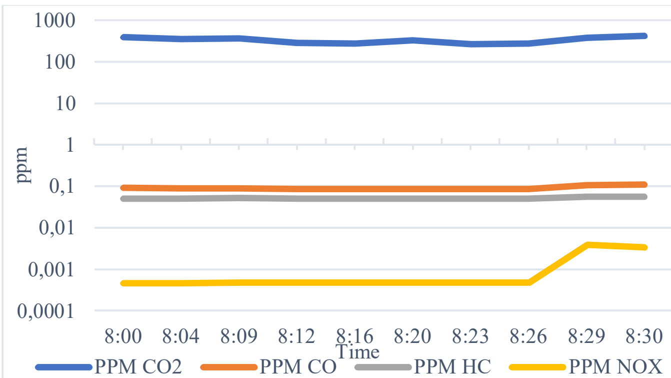

Fig. 9 CO, CO2, NOX and HC gas levels of Indarung Highway in the morning.

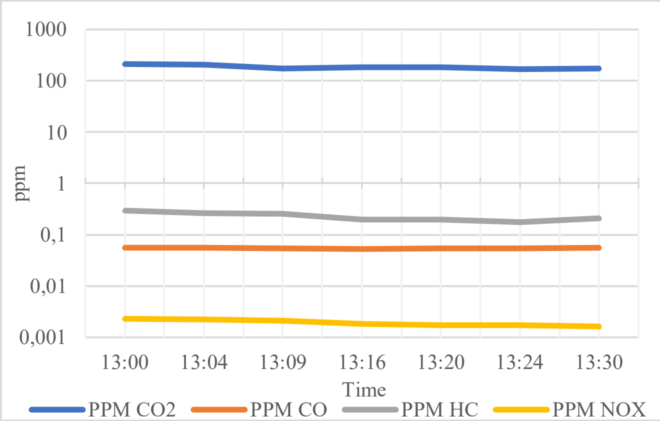

Fig. 10 CO, CO2, NOX and HC gas levels of Indarung Highway in the mid-day.

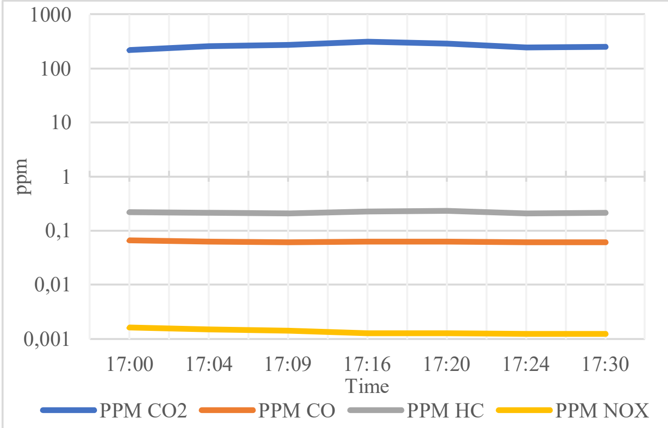

Fig. 11 CO, CO2, NOX and HC gas levels of Indarung Highway in the afternoon time.

TABLE V
RESULTS OF MEASUREMENT CO, CO2, NOX AND HC LEVELS IN SOME PLACES

No	Gas	Sampling location in the morning					
		Masjid Raya Sumatera Barat Intersection		**Lubuk Begalung Intersection**		**PT POS Indonesia Intersection**	
		Minimum (ppm)	**Maximum (ppm)**	**Minimum (ppm)**	**Maximum (ppm)**	**Minimum (ppm)**	**Maximum (ppm)**
1	CO	0.060	0.080	0.060	0.080	0.070	0.090
2	CO2	151.300	384.800	380.400	715.700	377.600	700.700
3	NOX	0.001	0.002	0.001	0.003	0.001	0.001
4	HC	0.050	0.090	0.120	0.360	0.060	0.080

Table 5 highlights the results of system tests measuring CO, CO2, NOX and HC gas levels at several intersections in the morning time at 8:00 AM. In addition, Table 6 and Table 7 illustrate the results of system measurements at mid-day and in the evening time. Seen from the table of measurement results that the system is able to display the measurement data of CO, CO2, NOX and HC levels. It is worth noting that the system established is able to display the level of elements and compounds of CO, CO2, NOX, and HC gases instantly. Correspondingly, the system can also display varied values of the levels of these compounds, referring to the occurrence of air pollution conditions at a particular location at the time of measurement.

So, air pollution increased in the afternoon time at all test locations, especially for CO2 gas. It is as a result of the significant increase on the number of vehicles. Thus, this device is able to clarify the correlation on the increasing number of vehicles with the increase on air pollution, especially CO2. As a result, the air quality indicator is always on alert code indicating the air condition at that time is not good for living things, especially humans.

TABLE VI
RESULTS OF MEASUREMENT CO, CO2, NOX AND HC LEVELS IN SOME PLACES

No	Gas	Sampling location in the midday					
		Masjid Raya Sumatera Barat Intersection		**Lubuk Begalung Intersection**		**PT POS Intersection**	
		Minimum (ppm)	**Maximum (ppm)**	**Minimum (ppm)**	**Maximum (ppm)**	**Minimum (ppm)**	**Maximum (ppm)**
1	CO	0.070	0.100	0.050	0.090	0.050	0.080
2	CO2	171.200	424.700	400.600	755.200	280.00	382.700
3	NOX	0.001	0.003	0.001	0.004	0.001	0.001
4	HC	0.070	0.120	0.100	0.420	0.040	0.060

TABLE VII
RESULTS OF MEASUREMENT CO, CO2, NOX AND HC LEVELS IN SOME PLACES

No	Gas	Sampling location in the afternoon					
		Masjid Raya Sumatera Barat Intersection		**Lubuk Begalung Intersection**		**PT POS Intersection**	
		Minimum (ppm)	**Maximum (ppm)**	**Minimum (ppm)**	**Maximum (ppm)**	**Minimum (ppm)**	**Maximum (ppm)**
1	CO	0.200	0.400	0.060	0.090	0.100	0.150
2	CO2	490.800	620.200	560.800	815.200	470.700	689.800
3	NOX	0.001	0.004	0.002	0.006	0.001	0.001
4	HC	0.060	0.090	0.410	0.620	0.220	0.650

IV. Conclusion

Based on the data obtained from the tests and their analysis, it can be concluded that the device established can be used as a portable measurement tool of air pollution on the highway due to motor vehicle pollution instantly. Compared to the Exhaust Gas Analyzer, this system is able to measure the level of CO, CO2, NOX, and HC with an average error of 3.62%. Likewise, the system is also able to measure the level of CO, CO2, NOX, and HC where the results are varied, conforming to the occurrence of air pollution conditions at the location when measurements are made. Further, the system can also provide an alert on air pollution when one of the measured levels of gaseous elements and compounds exceeds the threshold permitted by WHO.

The highest CO level of 815.200 ppm occurred at the Lubuk Begalung intersection in the afternoon. This is due to traffic congestion at the test location, which is packed by transporting coals, Crude Palm Oil (CPO), and other commodities towards Teluk Bayur. This device has shown promising results to determine air pollution due to the increasing number of vehicles on the highway.

Nomenclature

y	output equation with the result in the form of ppm	ppm
a	scaling factor	-
b	exponent	-
rs	sensor resistance on the displayed gas at various concentrations	ohm
ro	hold sensor in clean air	ohm
e	error	%
Rl	sensor load resistance	Ohm
Vcc	sensor voltage source	Volt
Vout	sensor output voltage	Volt
Tdata	total data	ppm
dataDS	measurement result data of the designed system	ppm
dataEGA	measurement result data of the EGA	ppm
eCO	error CO	ppm
eCO2	error CO2	ppm
eNOX	error NOX	ppm
eHC	error HC	ppm
eAverage	average error	%
dv	data deviation	ppm
di	data I	ppm
d Average	data average	ppm

Acknowledgment

This research was funded by the Ministry of Education, Culture, Research, and Technology through DIKTI Directorate of Subs Resources with the scheme "Excellent Higher Education Institution Research" (EHEIR) in 2021, with the contract number 572/PL9.15/PG/2021 dated July 16, 2021. We would like to thank the Ministry of Education, Culture, Research, and Technology, and Center for Research and Community Service (CRCS), State Polytechnic of Padang for their support toward this research.

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