ArduEmission: Vehicular Emissions Monitoring

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Abstract— **Air pollution is on the rise due to a number of anthropogenic activities and its monitoring is of vital importance. In cities, vehicular emissions are chiefly responsible for the rise of various air pollutant gases in the atmosphere. Due to high density of vehicles in mega cities, there is a constant need for air pollution monitoring and quality assessment of these vehicles in terms of their emission standards. This paper describes a portable, easy-to-use and cheap electronic sensor based system for monitoring the vehicular emissions. This electronic sensor based system is called '*ArduEmission*' as this device uses Arduino microcontroller for its functioning. This device is easy to use and the data obtained from it can be easily stored, analyzed and plotted in real-time using the software developed for *ArduEmission*. In this paper, the technique for using and calibrating the device has been elucidated and various vehicles are then examined using this device for their emissions of Carbon Monoxide gas in the atmosphere.**

Index Terms— **Arduino, air pollution, carbon monoxide, micro-electromechanical sensors, vehicular emissions**

I. Introduction

Air pollution is a major concern for people nowadays, especially in major cities with high density of vehicles. Air pollution is caused by the emission of hazardous pollutants in the atmosphere through various anthropogenic and natural phenomena. Air pollutants include aerosols such as dust, smoke, fog, mist, etc., whose sizes range from 5 microns to 100 microns, and various harmful gases such as SO_2, NO_x, CO, photochemical smog, O_3, hydrocarbons, HF, NH_3, H_2S, etc. Carbon Dioxide is more of a greenhouse gas, responsible for increase in an average global temperatures causing global warming, rather than an air pollutant that causes harm economically and biologically. The aforesaid air pollutants are actively responsible for causing a number of biological ailments like bronchitis, asthma, tuberculosis, broncho-pneumonia, severe head-aches, nausea, asphyxiation, eye irritation, skin irritation and even death. Air pollutants are generally classified as primary and secondary air pollutants. Primary air pollutants such as CO, SO_2, NO_x, etc. are those pollutants that directly interact with the surrounding and are released into the air directly. Secondary air pollutants like photochemical smog, PAN, formaldehyde, O_3, etc. are formed with the interaction of primary air pollutants in the atmosphere. Industries generally emit gases like SO_2, NO_x, aldehydes, particulates, HF, HCl, H_2S, etc. as their stack emissions. The pollutants emitted by vehicles generally include CO, particulates like smoke, soot, etc., unburnt carbon particles, hydrocarbons, aldehydes, lead, Nitrogen oxide, etc. Air pollution by vehicles is caused due to tail-pipe exhaust emissions. It also depends on changes in driving cycles, engine condition, air/fuel ratio and fuel composition. Malfunction of engine devices, especially fuel injection system, increases the emissions of the main exhaust components from the vehicles. Sources of vehicular pollution are:

- Engine crankcase
- Exhaust system
- Carburetor and fuel tank
- Incomplete combustion
- Varying Air/fuel ratios

Options to reduce vehicular pollution:

- Modification of engine design
- Exhaust gas re-circulation
- Thermal reactors for CO & HC oxidation
- Catalytic converter
- Use of particle traps
- Use of unleaded gasoline
- Use of low sulphur diesel
- Use of low smoke lube oil for 2 stroke and mixed lubricating engines
- Implementation of strict inspection and maintenance program Use of alternate and cleaner fuels (viz. CNG, LPG, Methanol)

We have developed a sensor and microcontroller based device, *ArduEmission*, for monitoring vehicular emissions of carbon monoxide. The results obtained from this device would be verified using the results from the pollution check certificate issued by the **Transport Department, Govt. of NCT of Delhi.**

The vehicles are monitored using *ArduEmission* by installing it near the exhaust pipe of the vehicle and then monitoring the emissions from the vehicle using the sensor and software developed. The carbon monoxide values are obtained during vehicle idling that is when the accelerator is pressed without causing any motion of the vehicle. The RPM of the engine is kept constant and same as per the guidelines of the pollution control and check station.

The paper also describes the calibration technique of the device and the readings obtained from the device are verified with a trusted and adopted method for monitoring vehicular emissions.

I. System design

A. Hardware

ArduEmission consists of three parts as shown in Fig. 1(a). MQ5 gas sensor module from EleSof Technologies [1] is used to sense the carbon monoxide concentration that is present in the emissions from the vehicle's exhaust pipe. The sensor makes use of the change in voltage and resistance of the sensor's tin dioxide (SnO_2) layer which adsorbs the gas present in the ambient air or the sample of air in contact with the layer. This adsorption of CO by the tin dioxide layer

Manuscript received November 13, 2014.

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changes its resistance and hence the voltage given by the sensor system to the Arduino Uno [2] microcontroller board varies which is converted to corresponding value of concentration of carbon monoxide. The Arduino Uno microcontroller board is connected to the MQ5 sensor module as shown in Fig. 1(a) and connected via USB serial communication to a computer system for logging real-time data from the sensor. This sensor based system is low cost and the components are available easily thus making it more portable and for general use.

Gas Sensor working principle. Fig. 1(b) shows the working principle of the gas sensor used for making this device such that when a metal oxide crystal such as SnO_2 is heated, gas is adsorbed on the crystal surface with a negative charge. Then the donor electrons in the crystal surface are transferred to the adsorbed oxygen that results in leaving positive charges in a space charge layer. Thus, a surface potential is formed to serve as a potential barrier against the electron flow. Inside the sensor, current flows through the grain boundary (conjunction parts). At conjunction parts, adsorbed oxygen forms a potential barrier which prevents the carriers from moving freely. The reduced barrier height thus decreases sensor resistance. From Ohms Law, voltage value is directly proportional to the current and resistance value in the circuit. Therefore, as the sensor detects higher gas level concentration, resistance value in grain boundary will increase. As the resistance increases, the output voltage will also be increased. This particular gas sensor works for adsorbing carbon monoxide gas on its SnO_2 crystal. So if there is more concentration of CO gas in ambient air then more gas would get adsorbed on the surface of the metal oxide crystal and so the resistance of the metal oxide crystal would increase thus causing an increase in voltage value that is returned to the microcontroller.

Figure 1. *(a) ArduEmission Hardware*

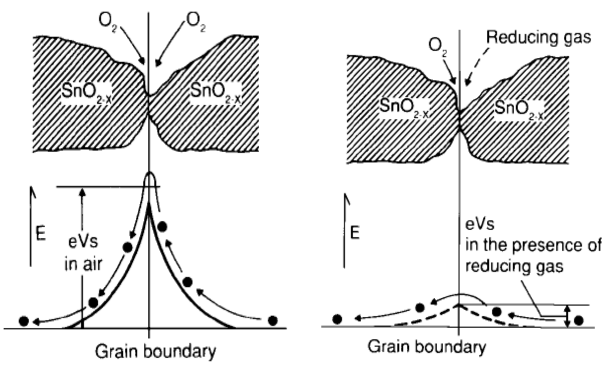

Figure 1. *(b) Gas sensor working principle*

B. Software

The software part of the device includes the coding of the Arduino Uno microcontroller for interacting with the sensor module and the software. Arduino is coded in its Integrated Development Environment known as Arduino IDE and the real-time data plotting software is developed in Microsoft Visual Basic 2010 Express [3]. The serial communication between the arduino microcontroller and the computer system is established using the serial library of the arduino. The concentration of the gas sensor depends on the resistance of the sensor which further depends on the voltage output from the analog pin of the sensor. The arduino microcontroller converts this returned voltage to appropriate concentration of carbon monoxide gas emitted by the exhaust pipe of the vehicle. The concentration of the gas measured is in parts per million (ppm) which is converted to micrograms per cubic meter (µg/m^3). The equations used for converting the measured voltage to gas concentration are:

$$Vrl = Va * (5.00 / 1024.0) \quad (1)$$

$$Rs = 20000 * (5.00 - Vrl) / Vrl \quad (2)$$

$$Concentration = 37143 * [(Rs/Ro)^{-3.178}] \quad (3)$$

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Where Va represents the analog output send by the sensor to arduino and Vrl is the equivalent voltage from the analog output (in volts). Rs is the sensor resistance at various concentrations of gases and also at different temperatures and humidities. Here, Ro = 10000 Ω which is the load resistance or sensing resistance used for calibration of the sensor and for its sensitivity adjustments.

A. *C. Calibration*

ArduEmission system is calibrated by powering it with 5 volts battery or computer through USB connection for a minimum of 20 minutes so that the metal oxide crystal of the gas sensor gets heated up for adsorption of gas and giving out accurate readings. The system is calibrated by leaving it in operation for 20 minutes and until the readings and real-time plot on the ArduEmission software becomes stable.

We took the readings of Punjabi Bagh region of Delhi at various time intervals and then compared them with the readings of Delhi Pollution Control Committee (DPCC) readings for Punjabi Bagh region that are available on their website for the same time intervals. We found our readings in accordance with the DPCC data and under the permissible limit that is 4 µg/m^3 as per DPCC's website. Below in Fig. 4, we give the readings of ArduEmission and that of DPCC and also a screenshot of their website. In this way we calibrated the sensor based system and deduced that ArduEmission was working correctly and was now ready for collecting data for other regions and producing pollution maps for various regions of Delhi.

Time interval	Carbon Monoxide concentration (mg/m^3)
10:25:00 am	1.87
10:40:00 am	1.67
10:55:00 am	1.45
11:10:00 am	1.50
11:25:00 am	1.60
	Average: 1.618 mg/m^3

Table 1 (a): *This table shows the readings collected by ArduEmission device for Punjabi Bagh region for 1 hour duration from 10:25 am to 11:25 am at intervals of 15 minutes on Saturday, April 12, 2014.*

Time interval	Carbon Monoxide concentration (mg/m^3)
10:25:00 am	1.92
10:40:00 am	1.85
10:55:00 am	1.74
11:10:00 am	1.78
11:25:00 am	1.80
	Average: 1.818 mg/m^3

Table 1 (b): *This table shows the readings collected by DPCC, Delhi as shown on their website for Punjabi Bagh region for 1 hour duration from 10:25 am to 11:25 am at intervals of 15 minutes on Saturday, April 12, 2014.*

Percent error = ((observed value – true value) / true value) x 100

= (|1.618 – 1.818| / 1.818) x 100

= **11%**

Vehicle Type	Year	Fuel	Prescribed Standard of CO (%)	(ppm)	Measured level of CO by the pollution station (%)	(ppm)	Measure value of CO by *ArduE-mission* (in ppm)	% Error
Hyundai i10 (Bh. II or III) (4 wheeler)	2008	Petrol	0.5	5000	0.02	200	230	13%
Honda CBZ (2 wheeler 4 stroke)	2008	Petrol	3.5	35000	0.05	500	460	8%
Maruti WagonR (Bh. IV)(4 wheeler)	2012	Petrol	0.3	3000	0.01	100	110	9.1%
Maruti Ritz (Bh. II)(4 wheeler)	2011	Petrol	0.5	5000	0.01	100	80	20%
Honda City (Bh. II) (4 wheeler)	2008	Petrol	0.5	5000	0.1	1000	958	4.2%
Toyota Innova (Bh. II) (4 wheeler)	2006	Petrol	0.5	5000	0.3	3000	2840	5.3%
Hyundai Verna (Bh. IV) (4 wheeler)	2011	Petrol	0.3	3000	0.01	100	150	3.3%
Bajaj Pulsar (2 wheeler)	2009	Petrol	3.5	35000	0.04	400	392	2%
Maruti WagonR (Bh. IV) (4 wheeler)	2012	CNG	0.3	3000	0.01	100	122	18%
Maruti Ritz (Bh. II) (4 wheeler)	2011	CNG	0.5	5000	0.31	3100	3250	4.6%
Hero Splendor (2 wheeler)	2007	Petrol	3.5	35000	0.5	5000	5120	2.3%
TVS Apache (2 wheeler)	2012	Petrol	3.5	35000	0.03	300	322	6.8%

Table 2: *This table shows the results of monitoring various vehicles using ArduEmission device and also the standards and measured values of carbon monoxide as obtained from the pollution certificates of these vehicles issued by the Pollution control station of Transport Department, Govt. of NCT of Delhi.*

Average Error = 96.6/12 = 8.05%

II. Monitoring of Vehicular Emissions

A. Working

The *ArduEmission* device with the CO sensor is kept near the exhaust pipe of the vehicle. The vehicle is in idle state i.e. the engine is accelerated or raced but there is no motion in the vehicle. Accelerator is pressed and a steady and constant RPM of the engine is achieved as set by the guidelines of the Pollution Control and Check Station. This process is known as vehicle idling. The emissions from the exhaust pipe are then collected by the sensor for a certain long period of time until which constant RPM is provided by the engine. The readings then collected are sent to the computer system and the software developed which plots the readings in real-time and also stores them. Fig. 2 shows the software of *ArduEmission* and the real-time plot of the readings of thecollected concentration of CO gas from the exhaust pipe of a vehicle.

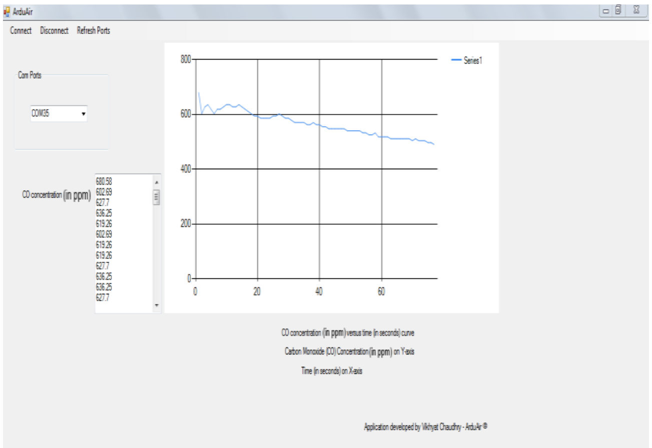

Figure 2. *This figure shows the software and the readings plotted in real-time in the software using ArduEmission for vehicular emissions of CO. The y-axis shows the concentrations of CO (in ppm) collected by the sensor for a vehicle. The x-axis shows the time (in seconds) elapsed for taking the readings at a given RPM of the vehicle engine*

III. Conclusions

The paper clearly shows how *ArduEmission* sensor based system can be used for monitoring vehicular emissions. This system is cost efficient and can be easily used by the general public for monitoring and maintaining the quality of air around them. The vehicles with emissions more than the emission standards should be maintained and the engines should be checked by the responsible authorities. The various advantages of *ArduEmission* are:

- This sensor based system is very low cost and low power operating system.
- It can be easily operated by anyone
- This system can be used by a large number of people thus making efficient air quality monitoring at domestic level.
- This system can also be used for monitoring other gases such as O_3, methane, propane, SO_2, oxides of nitrogen etc.

The various applications for *ArduEmission* include:

- ArduEmission can be used at traffic signals of various regions in a state to monitor the concentrations of CO at the signals and thus take appropriate measure for lowering them.
- Can be used in homes to monitor the air quality.
- Can be used by institutions, government buildings, communities, etc. to monitor the concentrations of carbon monoxide in ambient air.
- ArduEmission gas sensors can be used in satellites to measure the gas concentrations in the upper layers of atmosphere.
- This sensor based system can also be used in cars so as to detect and monitor greenhouse gases such as methane and carbon dioxide.
- ArduEmission can be used to generate and produce pollution maps for various regions.

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