Real-time analysis as an alternative for diagnosis and control of vehicle emissions in the province of Ocaña, Colombia

D M Valdes-Solano¹, L C Fonseca-Herreño², and J M Alba-Maldonado²
¹ Grupo de Investigación Laboratorio de Química Orgánica Aplicada, Universidad Manuela Beltrán, Bucaramanga, Colombia
² Grupo de Investigación Ambiental Agropecuario y Desarrollo Sostenible, Universidad Francisco de Paula Santander Seccional Ocaña, Colombia

E-mail: diana.valdes@umb.edu.co, lcfonsecah@ufpso.edu.co

Abstract. In Colombia, the increasing use of motorcycles as an informal conveyance has emerge as a means of labor survival for people with limited resources. Mototaxism has rapidly become the main means of transport in the spatial structure of the city of Ocaña; however, high emission rates may present an environmental problem. The study and implementation of strategies for the mitigation of greenhouse gas is of great help for the reduction of the emissions of these gases. Environmental control of vehicles in Colombia is carried out through an annual technical-mechanical and gas inspection, which seeks to control the emission of pollutant gases from vehicles; however, electrochemical gas sensors may provide an accurate and convenient alternative, as it can be implemented as an analytic tool in gas monitoring and control systems allowing different approaches for the control of vehicle exhaust emissions. A development board such as Arduino can be programmed with an algorithm that utilizes a combination of sensors and connectivity modules, constituting a microcontroller unit that is able to achieve successful monitoring over emission gases, one such algorithm is proposed by the authors.

1. Introduction

Technological advance and the increasing population demand a great amount of construction surfaces, reducing the amount of forests and green areas, making difficult the natural filtering of the air and endangering the integrity of the environment. One important consequence of human civilization is the emission of harmful gases to the air, cars, burning, livestock; becoming a factor that contribute to its increase [1,2]. The growing economic processes are strongly related to an increase in industrial activities, high rates of motorization, higher fuel consumption and therefore the generation of greater emissions of air pollutants [3,4].

Pollution caused by vehicle emissions is mobilized through the atmosphere, concentrating on cities with specific topography. Considering that urban pollutants are diverse, acceptable limits have been established for the most common and abundant compounds based on its impact on health; this air pollutants have been denominated "criterion pollutants" [5]. The presence of particles, carbon monoxide, photochemical oxidants and oxides of sulfur and nitrogen in urban areas has been pointed out as responsible for many health conditions [6,7]. Air quality management considers emission inventories as an essential requirement and an important tool for decision making; a growing concern for the effects of urban air quality on human health and the formation of tropospheric ozone resulting from emissions due to vehicular gases, generates the need to identify, determine and incorporate, within its guidelines,
parameters that reflect the real behavior of the study area [8,9]. There are multiple techniques to estimate pollutant emissions; these are employed according to the type of source to be studied. In general, different techniques are used when studying different sources, such as area sources, fixed sources and mobile sources [10,11].

Environmental control of vehicles in Colombia is carried out through an annual technical-mechanical and gas inspection according to Law 762 of 2002, which seeks to control the emission of pollutant gases from vehicles [12-14]. The analysis of this data is mandatory and provides information that is used to monitor air pollution and to take corrective actions to issues that may arise [15]. Engine exhaust gases originate from chemical reactions between oxygen in the air and oxidizable fuel compounds; in this way, mobile sources produce emissions of greenhouse gases, such as carbon dioxide (CO$_2$), methane (CH$_4$) and nitrous oxide (N$_2$O) from the burning of various types of fuel, however, other pollutants are produced by incomplete combustion, this is the case of carbon monoxide (CO) [16]. Other hydrocarbons (HC), particulate material (PM), or the oxidation derivatives of the non-combustible species present in the combustion chamber may cause local or regional air pollution as well [17,18].

In Colombia, the increasing use of motorcycles as an informal conveyance has been exponential in recent years, emerging as a means of labor survival for people with limited resources [19]. This form of urban transport has derived externalities that simultaneously entail the transformation of the territory; the transport of passengers on motorcycles has become represents competition for traditional public transporters, due to the nature of an inexpensive door-to-door service [20]. Thus, mototaxis is the denomination that applies to the phenomenon of massive use of motorcycles for the transport of passengers in exchange for a fee established by the driver that varies according to the distance and the type of route [21].

The city of Ocaña, Colombia, also presents this phenomenon, in the later years, mototaxis has rapidly become the fundamental mean of transport in the spatial structure of the city, exerting an important influence in competitiveness, productivity and environmental sustainability. However, simultaneously, mototaxis has been labeled as a social problem, since the increase of motorcycles dedicated to this work on the roads generates a greater risk for those who work in this trade [22,23], therefore, demanding perennial planning in response to the issues that may emerge in a growing city.

The challenges of climate change have resulted in mitigation commitments made by many nations, each country analyzes what type of actions will be carried out with the intention of reducing greenhouse gas (GHG) emissions. The study and implementation of strategies for the mitigation of GHG, at a local level, is of great help for the reduction of the emissions of these gases [24]. Some initiatives to mitigate the impact of emissions on climate change focus on a modification of conveyance idiosyncrasy, such as the promotion of mass transport, sharing of private vehicles, the use of light electric vehicles and alternative fuels [25].

The increasing number of potentially harmful pollutants in the environment requires the use of fast and inexpensive analytical techniques in extensive monitoring programs [26], conceiving changes in technological development, making engineering strive to improve processes with the goal of reducing the environmental impact that has originated and spread to different ecosystems as a result of polluting gas emissions [27]. Development of instruments that facilitate real-time monitoring of the most predominant pollutants in the atmosphere, due to the emissions from the combustion processes, can provide an important way to control the discharge to the environment [28,29].

Electrochemical gas sensors may provide an accurate and convenient solution, as it can be implemented as an analytic tool in gas monitoring and control systems for different industries [30-32]. Several works and models have been presented in this regard; specifically, low cost alternatives such as Arduino controlled devices have been of great interest in many proposed gas regulation systems [33,34]; some studies have propose the implementation of an alarm system that activates when the emissions surpass a pre-established threshold [35], while others focus on cellphone interface based data collection with Bluetooth or Wi-Fi connectivity modules [33,36]; thus allowing different approaches for the control of vehicle exhaust emissions, as opposed to yearly inspection as the main control mechanism.
Electrochemical gas sensors are usually accurate within a considerably low tolerance, for a specific chemical specie, requiring more than a single sensor in applications where multiple compounds must be controlled. However, inexpensive and Arduino compatible sensors have been developed prominently in recent years, enabling the design of low-cost and dependable monitoring equipment [37,38]. Therefore, a common approach is to combine different sensors in order to check a wide spectrum of chemical compounds being emitted through in vehicular exhausts [39].

In a recent study carried out in Bogota, Colombia, it was found that mass public transport systems are responsible for most of its users' exposure to air pollutants [40]. Highlighting an important point to consider when regulating vehicular emissions. With the above described technology at hand, it is possible to develop systems that allow year-round records regarding pollutant emissions, especially for the public transport sector, potentially improving the problem-solving process, as with such data a more accurate analysis can be executed [41].

In this paper, an inexpensive system for monitoring vehicular emissions is proposed, making emphasis in data recording as a tool for public transport regulations that may help in the prevention of violations and the inconveniences of yearly inspections as the only mean for vehicular emissions control.

2. Methodology

The "Universidad Francisco de Paula Santander Seccional Ocaña" and "Universidad Manuela Beltrán", in order to address the current social and environmental situation, carried out a diagnosis on motorcycle emissions employing a quantitative paradigm with a non-experimental descriptive approach; employing survey as the main tool for gathering information.

Emissions were estimated employing emission factors according to Herrera's model [42]. The collection of information was focused on four selected sampling points around the central park of Ocaña, a survey was performed to retrieve model brand and year information; type of engine and displacement; and working hours of motorcycles. This information was essential in the selection of suitable emission factors and further air pollutant mass flow calculation.

Air pollutants were estimated in kilograms per day for carbon monoxide (CO), volatile organic compounds (VOC), nitrogen oxides (NOx) and particulate material under 2.5 µm (PM 2.5). With this data in mind, a set of sensors that satisfy regulation standards and working conditions was chosen to be implemented with Arduino-like processors to enhance emissions control.

3. Results and discussion

The average quantity of air pollutants being emitted from motorcycles in the center of Ocaña was estimated to an average of 3694.662 kg of CO per day, 890.28 kg of VOC per day, 133.542 kg of NOx per day, and 13.3542 kg of PM 2.5 per day, as it is shown in Table 1.

| Sampling point | CO (kg/day) | VOC (kg/day) | NOx (kg/day) | PM2.5 (kg/day) |
|----------------|-------------|--------------|--------------|---------------|
| 1              | 4207.104    | 1013.76      | 152.064      | 15.2064       |
| 2              | 3489.984    | 840.96       | 126.144      | 12.6144       |
| 3              | 3705.120    | 892.80       | 133.920      | 13.3920       |
| 4              | 3376.440    | 813.60       | 122.040      | 12.2040       |
| Average        | 3694.662    | 890.28       | 133.542      | 13.3542       |

Thus, evidencing a potential environmental problem, due to the high emission rates when compared to other, urban centers [7]. To address this, a group of sensors that can be implemented to work in a monitor and control system along with the chemical specie and normativity for motorcycles that may apply are listed in Table 2.

With this information in mind, it is evident that a distance sensor is a necessity for the system to compare the measurements with the threshold, this can be achieved with either an infrared sensor module, an ultrasonic distance sensor or the built-in tachometer of the motorcycle. All collected data can be stored in an internal memory module or wirelessly with the use of a Wi-Fi or Bluetooth modules.
Operation conditions may vary in the final application; however, the sensors can be calibrated to different values with a calibration curve provided by the fabricant.

### Table 2. Review of gas sensors. Extracted from fabricants datasheet and regulations in force [43].

| Sensor   | Gas     | Working temperature (°C) | Working humidity (%) | Threshold (g/km) |
|----------|---------|--------------------------|----------------------|-----------------|
| MQ-135   | Hidrocarbons | 20±2                     | 65±5                 | 1.2             |
| MQ-5     | Hidrocarbons | 20±2                     | 65±5                 | 1.2             |
| MQ-7     | CO      | 20±2                     | 65±5                 | 5.5             |
| MQ-9     | CO      | 20±2                     | 65±5                 | 5.5             |
| MQ-135   | NOx     | 20±2                     | 65±5                 | 0.3             |
| TGS 2201 | CO      | 20±2                     | 65±5                 | 5.5             |
| TGS 2201 | NOx     | 20±2                     | 65±5                 | 0.3             |
| SDS 021  | MP 2.5  | -10±50                   | Max. 70              | N/A             |

A development board such as Arduino can be programmed with an algorithm that utilizes all the above, constituting a microcontroller unit that is able to achieve successful monitoring over emission gases. One such algorithm is proposed by the authors and can be seen in Figure 1. In this algorithm, the program will remain running as long as the vehicle is moving, end when the vehicle stops, and it can reset once the vehicle is moving again.

![Flowchart](image)

**Figure 1.** Monitoring algorithm.

### 4. Conclusion

The pollution contribution of motorcycles in the city of Ocaña, Colombia, was evaluated, consequently a monitoring system, that employs freeware and low-cost components, was proposed. It is important to inquire in this kind of solutions for a better understanding of environmental damages caused by vehicular operation, and monitoring systems may help to report most exhaust issues in pertinent time, instead of an annual basis. Low-cost component and freeware systems are representative of an open opportunity of advancement towards more efficient operation and control in many applications, which, in turn, will result in a more responsible use of resources and environmental conservation.
References

[1] Pinzón A, Castillo M, González E, Arauúz J and Villarreal V 2018 Sistema de detección de sustancias y partículas contaminantes para el ambiente a través de sensores Arduino Revista de Iniciación Científica 4(1) 55

[2] Ortiz Mateo M 2010 Reducción de las emisiones de CO2 en vehículos de transporte: combustibles alternativos Energía & Minas: Revista Profesional, Técnica y Cultural de los Ingenieros Técnicos de Minas 8 28

[3] Franco J F 2012 Contaminación atmosférica en centros urbanos. Desafío para lograr su sostenibilidad: caso de estudio Bogotá Revista Bogotá de Administración de Negocios 72 193

[4] Arciniégas Suárez C A 2012 Diagnóstico y control de material particulado: partículas suspendidas totales y fracción respirable PM10 Revista Lunar 34 195

[5] O’Ryan R and Larraguibel L 2000 Contaminación del aire en Santiago: estado actual y soluciones Revista Perspectivas en Política, Economía y Gestión 4(1) 153

[6] Londoño J, Correa M A and Palacio C A 2011 Estimación de las emisiones contaminantes atmosféricos provenientes de fuentes móviles en el área urbana de Envigado, Colombia Revista Ela 8(16) 149

[7] Herrera Murillo J, Rodríguez Román S and Rojas Marín J F 2012 Determinación de las emisiones de contaminantes del aire generadas por fuentes móviles en carreteras de Costa Rica Tecnología en Marcha 25(1) 54

[8] Colvile R N, Hutchison E J, Mindell J S and Warren R F 2001 The transport sector as a source of air pollution Atmospheric Environment 35(9) 1537

[9] Salini Calderón G A 2014 Estudio acerca del material particulado emitido en ciudades de tamaño medio al sur de Santiago de Chile Revista INGEN CUC 10(1) 97

[10] Pareja A, Hinojosa M and Luján M 2012 Inventario de emisiones atmosféricas contaminantes de la ciudad de Cochabamba, Bolivia, año 2008 Acta Nova 5(3) 344

[11] Zuurbier M, Willems J, Schaap I, Van der Zee S and Hoek G 2019 The contribution of moped emissions to ultrafine and fine particle concentrations on bike lanes Science of the Total Environment 686 191

[12] Granada L. and Cabrera B 2009 Comparación de las emisiones de gases vehiculares para dos tipos de combustible en Cali, Colombia Avances Investigación en Ingeniería 11 6

[13] Flores Meneses O F 2017 Medición de emisiones vehiculares y de desempeño de potencia de un motor dedicado a gasolina convertido a gas natural vehicular Journal of the Selva Andina Biosphere 5(1) 39

[14] Rentería V., Toledo E., Bravo Benavides D. and Ochoa Jiménez D 2016 Relación entre emisiones contaminantes, crecimiento económico y consumo de energía. El caso de Ecuador 1971-2010 Revista Politécnica 38(1) 1

[15] Tipanilusa L E, Remache A P, Ayabaca C R and Reina S W 2017 Emisiones contaminantes de un motor de gasolina funcionando a dos cotas con combustibles de dos calidades Información Tecnológica 28(1) 3

[16] Pérez Darquea D G 2018 Estudio de emisiones contaminantes utilizando combustibles locales INNOVA Research Journal 3(3) 23

[17] European Environment Agency 2016 EMEP/EEA air pollutant emission inventory guidebook 2016 (Luxembourg: European Environment Agency)

[18] Gu X, Yin S, Lu X, Zhang H, Wang L, Bai L, Wang C, Zhang R and Yuan M 2019 Recent development of a refined multiple air pollutant emission inventory of vehicles in the central plains of China Journal Environmental Science 84 80

[19] Castillo Avila I Y, Galanze Herrera B and Palomino Gómez H 2013 Condiciones de trabajo y salud de mototaxistas Cartagena – Colombia Salud Uninorte 29(3) 514

[20] Burgos Ortiz S Y 2015 El mototaxismo: Un medio de transporte urbano como alternativa económica de San Juan de Pasto Revista de Sociología 5(1) 11

[21] Cogollo Palomino J J and Palomo Castilla Y E 2015 Efectos del mototaxismo en el transporte público colectivo y la movilidad urbana en las rutas S: 2, 3A, 4, 6, 7, 31, 35, Bayunca; de la ciudad de Cartagena (Cartagena de Indias: Universidad De Cartagena)

[22] Silva A R and Alves da Silva T A 2013 O desempenho e o mototaxismo no município de Moreno-Pernambuco Revista Cadernos de Ciências Sociais da UFRPE 1(2) 39

[23] Morales Pinzón T and Arias Mendoza J J 2013 Contaminación vehicular en la conurbación Pereira-Dosquebradas Revista Luna Azul 37 101

[24] Melero Hernández A, Quintero Núñez M and Galindo Duarte M 2013 Análisis de las estrategias de mitigación y adaptación del sector transporte en la ciudad de Mexicali Estudios Frontierizos 14(28) 79
[25] Andrade Castañeda H J, Arteaga Céspedes C C and Segura Madrigal M A 2017 Emisión de gases de efecto invernadero por uso de combustibles fósiles en Ibagué, Tolima (Colombia) Ciencia y Tecnología Agropecuaria 18(1) 103
[26] Rodríguez Mozaz S, López de Alda M J, Marco M P and Barceló D 2005 Biosensors for environmental monitoring: A global perspective Talanta 65(2) 291
[27] Escalona L, Manganiello L, López Fonseca M and Vega C 2012 Los sensores químicos y su utilidad en el control de gases contaminantes Revista INGENIERÍA UC 19(1) 74
[28] Hernandez Vargas G, Sosa Hernández J E, Saldarriaga Hernandez S, Villalba Rodriguez A M, Parra Saldivar R and Iqbal H M N 2018 Electrochemical biosensors: a solution to pollution detection with reference to environmental contaminants Biosensors 8(29) 1
[29] Arroyo P, Herrero J L, Suárez J I and Lozano J 2019 Wireless sensor network combined with cloud computing for air quality monitoring Sensors 19(3) 1
[30] Khan M A, Qazi F, Hussain Z, Idrees M U, Soomro S and Soomro S 2017 Recent trends in electrochemical detection of NH3, H2S and NOx gases International Journal of Electrochemical Science 12 1711
[31] Crețescu I, Lutic D and Manea L 2017 Electrochemical sensors for monitoring of indoor and outdoor air pollution Electrochemical Sensors Technology (London: IntechOpen) p 65
[32] Yan H H and Rahayu Y 2014 Design and development of gas leakage monitoring system using arduino and zigbee Proceeding of the Electrical Engineering Computer Science and Informatics 1(1) 207
[33] Nagarathna A A 2017 Design and implementation of vehicle emission testing system using MQ-5 and MQ-7 sensors International Journal of Innovative Research in Computer and Communication Engineering 5(5) 9388
[34] Ahasan A Al, Roy S, Saim A H M, Akter R and Hossain Z 2018 Arduino-Based real time air quality and pollution monitoring system International Journal of Innovative Research in Computer Science & Technology 6(4) 81
[35] Priyanka R, Thai Bhuvana S K, Ravendran A and Kavitha R 2017 Hyperspectral image analysis techniques on remote sensing Third International Conference on Sensing, Signal Processing and Security (California: IEEE) pp 480
[36] Hakim L, Sitorus Z and Al Maududy M M 2018 Design tool of motor vehicle emissions measurement devices with based on arduino nano with android smartphone viewer International Journal of Applied Engineering Research 13(6) 3975
[37] González Buesa J and Salvador M L 2019 An Arduino-based low cost device for the measurement of the respiration rates of fruits and vegetables Computers and Electronics in Agriculture 162 14
[38] Yang S, Liu Y, Wu N, Zhang Y, Svoronos S and Pullammanappillil P 2019 Low-Cost, Arduino-based, portable device for measurement of methane composition in biogas Renewable Energy 138 224
[39] Rajagukguk J, Pratiiwi R A and Kaewnuam E 2018 Emission gas detector (EGD) for detecting vehicle exhaust based on combined gas sensors Journal of Physics: Conference Series 1120 012020.
[40] Morales Betancourt R, Galvis B, Rincón Riveros J M, Rincón Caro M A, Rodriguez Valencia A and Sarmiento O L 2019 Personal exposure to air pollutants in a bus rapid transit system: impact of fleet age and emission standard Atmospheric Environment 202 117
[41] Mwenda R K 2017 Vehicle exhaust emissions inspection system for roadworthiness enforcement (Nairobi: Strathmore University)
[42] Herrera Montañez D 2007 Modelo emisiones vehiculares para la ciudad de Bogotá (EVB) (Bogotá: Universidad de los Andes)
[43] Ministerio de Ambiente Vivienda y Desarrollo Territorial 2008 Resolución número 910 (Bogotá: Ministerio de Ambiente Vivienda y Desarrollo Territorial)