Mobile Environmental Measurement Laboratory Using Electric Vehicles for Smart Cities

H. Gracia-León, E. Galvis Restrepo, A. Uribe-Jongbloed, and L. Rodríguez Urrego

Abstract

Nowadays, the capital cities and the main cities of the world have serious problems in transport and mobility, and this has a high impact on air quality due to the effects of traffic, such as traffic jams, traffic lights, and a large number of vehicles that work with an internal combustion engine. According to this, the alliance between the Ean University and the Mitsubishi Motors Company arose in 2018 to formulate a project that would impact electric mobility and increase the environmental benefits of it based on smart cities principles. This development, which was inaugurated in May 2019, shows the design of an environmental measurement system based on IoT, LTE, and data analytics that allows data to be taken with vehicles in motion and in real time for the generation of heat maps of the roads of the city. The design, installation, and dashboards for monitoring heat maps are registered in this paper. As well as, the expected impacts on environmental, social, and public policy issues applied to Bogotá city.

Keywords

Mobile laboratory • Smart cities • Electric vehicles • Environmental measurements

1 Introduction

Climate change is one of the greatest challenges that humans have ever faced. Currently, the emergence of new technologies avoids the disproportionate use of fossil fuels which is an undeniable reality. So, the electric mobility is one of the most important environmental-friendly technologies. To encourage the use of electric mobility, it is necessary to break paradigms, and at the same time demystify potentials problems of electric vehicles (EVs) in the cities. Actually, VE are one of the most promising solutions in terms of traffic, medium pollution environmental and sustainable mobility in order to avoid the worst of climate change as they will bear the brunt of its effects.

Currently, addressing the issue of environmental sustainability is a recurring action taken by cities, researchers, NGOs, multinational, the business community, and governments. These actions are not only temporary trend but also the development and execution of long-term sustainable projects. This trend of global consensus is consistent with the UN Sustainability Development Goals (United Nations).

In Colombia, there are several challenges on the issue of sustainable development. According to "Millennium Development Goals Report 2015" (United Nations, 2015) carried out the United Nations Development Program (UNDP), Colombia meets certain established objectives but encourages the national government to implement a regional policy that addresses the high disparity between urban and rural sectors to reduce the ratio of people without access to sustainable projects. Consequently, to meet objectives addressed by the UN for the country (Sustainable Development Goals, Colombia, SDGC) (ODS Colombia, 2016), and moreover recognizing the positive impact generated by the implementation of sustainable systems, it is also required that the academic community take a step forward with the promotion of projects that encourages the design, development, and execution of sustainable systems.

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F. Trapani et al. (eds.), *Advanced Studies in Efficient Environmental Design and City Planning*, Advances in Science, Technology & Innovation, https://doi.org/10.1007/978-3-030-65181-7_34

Although there are innovations in Colombia regarding the implementation of sustainable systems, the analysis for its design is not very ambitious and can be evidenced in the approach of the objective related to sustainable development (SDG) (ODS Colombia, 2016). It is here that the synergy between measuring devices and the use of renewable energies for their operation become vital in the search to find relevant tools for analysis and development of sustainable systems. These topics are related to the concept of smart cities, which are worldwide urban developments that have been defined by the Inter-American Development Bank (IDB) as "those that place people at the center of development, incorporate Information and Communication Technologies in urban management and use these elements as tools to stimulate the statement of an efficient government that includes collaborative planning processes and citizen participation"(Bouskela et al., 2016).

Nowadays, the city of Bogotá has an environmental monitoring network composed of 15 static stations with DASIBI and OPSIS measurement systems, which make permanent reports of air quality in the city, as a result of these reports, it has been identified a problem regarding the amount of PM 10 particulate material directly related to the wind speed of the city. (Gaitán et al., 2007).

On the other hand, the electric vehicle has become an option for reducing greenhouse gas emissions, mainly due to the arrival of lithium ion batteries and their development (Hauch et al.). A growing number of studies and projects related to EVs have emerged in the last 20 years. There is even the expectation that EVs reach the equivalent of 10% of the world market until 2020 (Rosolem et al., 2012) managing to capture the eyes of the most important companies in the world in these technologies seeking to reach all markets and countries by this time. An electric motor is a class of devices that converts electrical energy into mechanical energy through electromagnetic interactions. In the motor, the mechanical torque is developed by the interaction of conductors carrying current in a direction at right angles to a magnetic fiel (Chan, 1993). The development and evolution of the VEs depend on the technological evolution of the batteries (World Nuclear Association, n.d.). The efforts are currently aimed at improving efficiency, consumption, autonomy, and charging speed, which is why in a context of applied research pioneer companies in the market strive to achieve the best batteries with greater autonomy, useful life, greater efficiency, and lower market cost.

The present work proposes a versatile electric mobility system, which involves strategies and activities that seek to positively impact the use of EVs as well as in-situ monitoring of some environmental variables of cities. The project has been developed by the Ean University in Bogotá, Colombia within the framework of an institutional project called Smart Block Ean (Rojas et al., 2018). The project from its structure has been raised from several approaches, namely academic, social, economic, and environmental. In the project, the novel integration of the usability of electric cars is carried out, with the adoption of applied research strategies toward measuring environmental parameters, as well as time measurements and road traffic. This integration also considers strategies for the use of EVs and the social appropriation of these technologies by the academic community of the university.

The main contribution of this work relies on a synergistic system in which two VEs (Mitsubishi-I MIEV) are used as an extension of a mobile monitoring station. With these cars, it is intended to carry out applied research based on an environmental mapping of the streets in Bogotá city. The measurements are taken in real time, while these vehicles are used by the community, the university has made an alliance with a car sharing company to allow the use of the vehicles by the students and the institution workers. In addition to this, research tasks are proposed regarding the autonomy, use, and efficiency of the vehicle in the city, to demystify a bit about the use of electric cars today and thus, also promote its use.

Finally, in the proposed project, the establishment of mobile stations, taking advantage of the EVs to receive pollution at the height of people and on the city roads, having direct contact with the sources of emission by transport and the actual exposure of the population. The work is organized as follows: Sect. 2 describes the methods used for the construction of the prototype, the components, and installation inside the vehicles and the advantage of using this type of laboratory to support the construction of smart cities. In Sect. 3, some of the results obtained with the development of the project are presented; and Sects. 4 and 5 discuss the results and presents the conclusions.

2 Methods

Currently there is a need to be able to carry out a timely analysis of the concentration of air pollutants and microclimate variables. In the case of study of Bogotá city, it should be considered that it has an approximate urban area of 307 km^2, which includes residential, commercial, and industrial areas. Particularly, the Capital District has the Air Quality Monitoring Network of Bogotá. The monitoring network consists of 13 fixed stations and a mobile one to collect information (Gaitán et al., 2007). In this district network, a mathematical interpolation model is used to estimate the concentration of air pollutants at intermediate points across the city, which lends itself to some inaccuracies given the size of the city.

On the other hand, it is noteworthy a study carried out by Google related to determine air quality in cities by using a mapping process on the streets of four cities around the world (Alexeeff et al., 2018). The study was launched in 2018 and does not include any city in South America. Finally, the work of the Ean University in Bogotá is highlighted with the project called " Live Ci Project," which is a research developed in a parallel way with similar techniques to those implemented by Google. The project seeks the measurement of greenhouse gases in Bogotá, with the hypothesis of the use of EVs and how a combustion vehicle directly interferes with the taking of environmental measures.

Consequently, in the initiative to implement EVs to setting up a mobile environmental measurement laboratory using EVs for Bogotá, a system has been designed which incorporates an electric vehicle, sensors for measuring the air pollutants concentration and environmental variables, as well as an electronic system for global positioning system, record of mentioned variables and a human–machine interface (see Fig. 1).The procedure for the global positioning (GPS) sensor is stated and tests were carried out in different locations dynamically, and the GPS has been used with a tolerance of 4 mts2 and at the end when a point shares the location the point shows the average of the location. Once sensors are characterized and calibrated, the design and implementation of the electronic device is achieved.

The application of methods for measuring toxic concentrations in the environment (Isakov et al., 2007) is a great help within the project, in addition to benchmarks in which the applications of similar work (Wang et al., 2009) make the proposed design of the project feasible and also considering the mathematical models (Chen et al., 2019; Muntean, 1999) and application of commercial products (Amanatidis et al., 2013). In this work, four phases are considered in the design and implementation processes.

In this work, four phases are considered in the design and implementation processes. As a first phase, the assembly and programming of the devices in the university laboratory were developed, there, with the appropriate equipment, performance tests were performed, and reading/recording of the variables. In a second phase, the connection to the communications network was tested for sending data to a server located using cloud computing technology. In this phase, the test was initially done with a connection to the local wireless network and then to make a mobile wireless test, taking the device out of the laboratory. Once a satisfactory operation of the device was obtained, the VE is adjusted and installed. For installation purposes in the vehicle, different aspects such as connection, aesthetics, ergonomics, and usability are considered. Once the adjustments are finished, in a third phase, field tests are carried out using the mobile wireless connection at different points previously determined across the city.

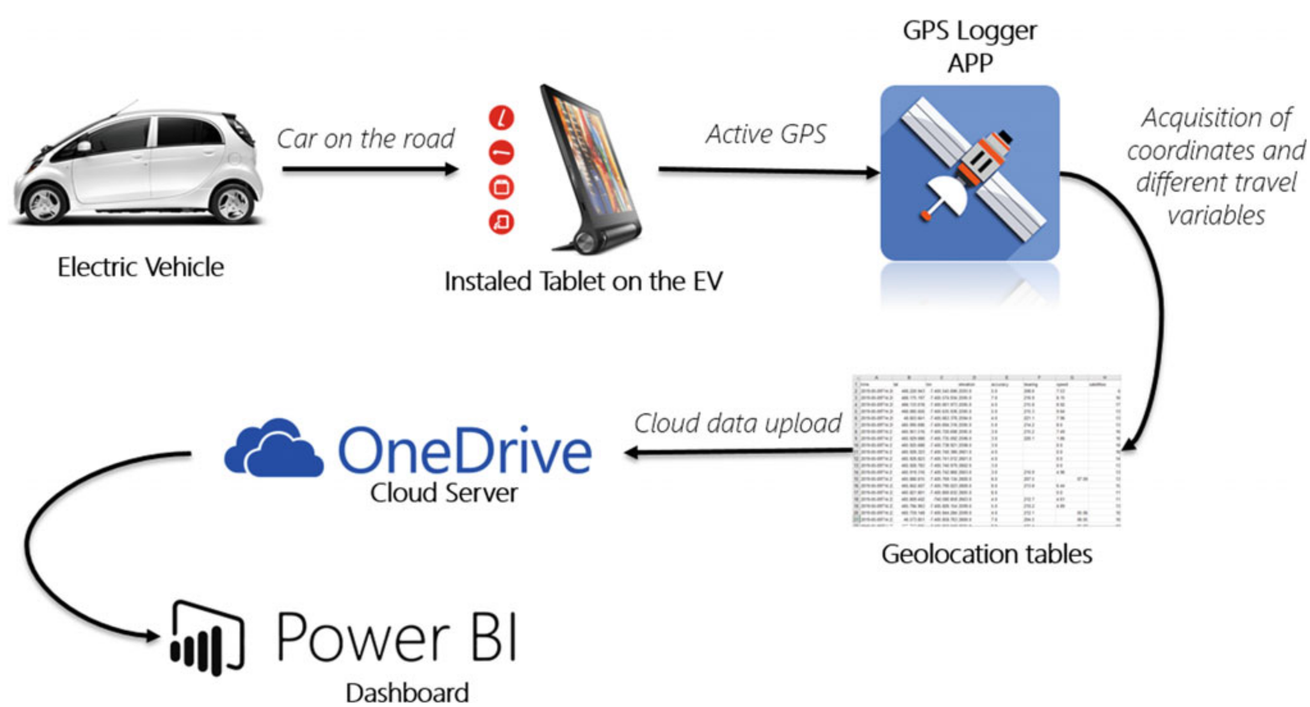

Fig. 1 Information flux

Table 1 Variable, measurement, and sensor

Variable	Measurement	Sensor
Noise	Intensity of noise in the streets. (dB)	Microphone MEMS (ADM401)
CO2	Carbon emissions in the streets (ppm)	CCS811/BME280
Temperature	Air temperature on city roads, considering traffic on the road and location (°C)	CCS811/BME280
Luminosity	Lighting level within the city roads day and night (Luxes)	VEML7700 o TSL2561
Humidity	humidity outside EV (%)	CCS811/BME280
Particulate matter	Particulate matter in the environment (TVO)	CCS811/BME280

2.1 Mobile Data Acquisition Hardware

In this project, the mobile acquisition device (DaqM) is the core of the system, and this device is responsible for reading signal distribution within the mobile laboratory. The device was developed using commercially available microcontroller and open-source microprocessor-based development cards. Some commercially available industrial quality sensors have been considered in the selection. According to the designed system, the measured variables are carbon dioxide, temperature, luminosity, noise, relative humidity, and particulate matter. Variables and its units measured in the mobile environmental laboratory using EVs are shown in Table 1.

For the operation of the monitoring system, it was necessary to develop an algorithm in the C++ programming language to characterize the acquired sensors, with this, monitoring tests were performed on variables locally. In the configuration of the wireless machine-to-machine communication system between devices, several communication channels have been programmed, namely connection via Wi-Fi with cloud computing server and connections via Bluetooth with some sensors to make easier installation inside the vehicle.

The designed system also considers basic tests of charging times, battery capacity, price per charge, autonomy within the city, behavior of the vehicle on usual routes, and finally tests to define the cost per km traveled by the VE were performed. In addition, a software platform was developed to data acquisition, visualization (dashboard) and monitoring of environmental variables, as well as routes and time spent from destination to destination.

2.2 Measurement of Environmental Variables and GPS

Having an electric vehicle on the streets gives to the system an excellent outlook to activate its circulation as a research tool. In this project, there is a device to control the global position of the vehicle; in addition, CO_2 levels are measured by the places where the vehicle passes. In the system, there is a datalogger of variables such as noise levels, brightness levels, temperature, the amount of energy used per car, and carbon dioxide levels. For instance, to analyze the level of CO_2 in a street with traffic jam, temperature in different areas of land use, noise levels across main streets of the city, hours in which more CO_2 is generated, and levels of increased noise pollution, among others.

With the information of the measured variables, the monitoring system performs environmental analysis of the city's roads. For the information processing, big data techniques are used, which allow to locate the measurements within a cross-map where they are correlated, and thus identify problems and early warnings caused by mobility to environment, likewise, environmental and health awareness. One of the main objectives is making the electrical vehicle a mobile laboratory that continuously develops tests within the city streets. So, the mobile environmental measurement laboratory automatically gets outcomes such as heat maps and particulate matter graphics information on test streets (see Fig. 2).

3 Results

The project has already yielded some preliminary results through which trends have been identified within the routes of the mobile environmental laboratory. Some of these trends occur mainly in vehicular congestion, traffic lights, and the busiest areas. Although the results are preliminary, as can be seen in the heat maps of Fig. 2, two specific zones with high averages at the decibel level were identified, one zone is due to a construction, and the second zone to a traffic lights. However, there are not yet significant results for decision making since there is not enough data.

Although the electric vehicle serves the university community to move from one place to another, we consider it a laboratory, since it is in the ability to perform measurements, corrections, and analysis on the fly, allowing the acquisition in real time of variables of the environment, while providing a service to the community. The application of technological

Fig. 2 Test results heat map

trends such as the Internet of things and big data allow great versatility and robustness in this type of solutions, generating spaces to reimagine all these processes, improving their efficiency and facilitating their application.

In Fig. 2, you can identify consistent results that show relationships between the generation of particulate matter and CO_2. Noise problems can be found graphically within the traffic lights that the route has. It is worth noting that in lighting issues the tests were performed during the day, so the graph represents high range values because there was always daylight. These results are preliminary and untreated but present a giant possibility when developing a real-time monitoring system for the city, with a greater number of mobile laboratories, data, and routes.

Regarding the results of the first tests, it is important to narrow down the dimension of the test, because the first measurements were made in a 2.5 km stretch in the Bogotá city surrounding four headquarters of the Ean University. Although the results are preliminary, the impact of this laboratory in the future will be reflected in issues such as the paving of new urban roads, street lighting according to levels of lighting and types of luminaires, urban arborization and the types thereof, the location of vehicular electric recharging points, the behavior of the batteries in the EVs and the environmental characteristics of the roads, their certifications, and location of bicycle routes.

3.1 Housing and Installation

The presented housing was designed to enable the installation of the sensors on the EV. It has five holes to anchor the housing to the vehicle, spaces to allow the flow of air inside the device, and a transparent covering to allow the passage of light. Figure 3 shows the CAD design of the housing. We are currently optimizing the housing in

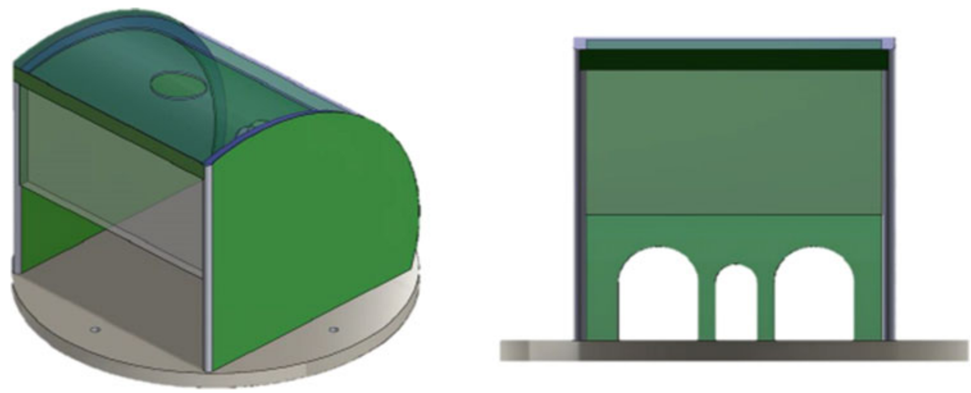

Fig. 3 Sensor housing

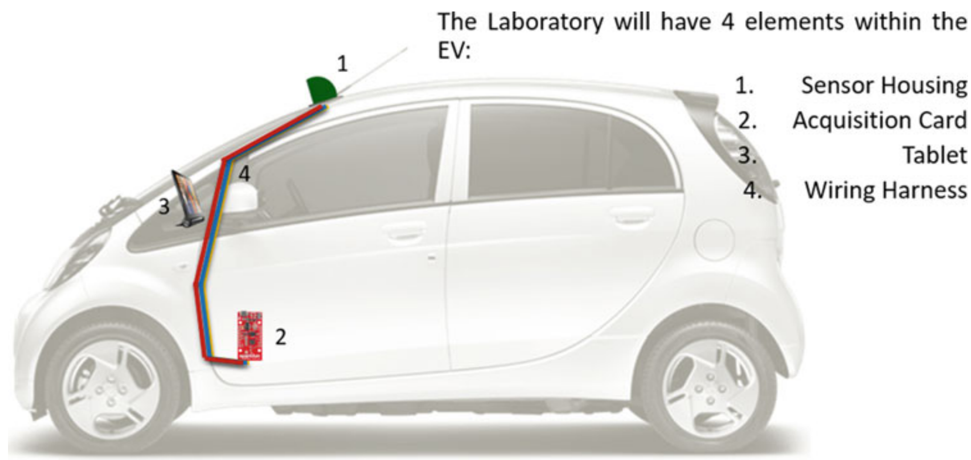

Fig. 4 Mobile laboratory installation

installation, operation, air aerodynamics, and sensor measurements.

In addition, it was defined that the installation and wiring of the sensors within the EV would be carried out with three components: display tablet, control card, and the housing for the capture of measurements and sensorization (Fig. 4).

4 Discussion

With the work carried out and the results obtained it is important, even more in Latin American countries, the implementation of sensitization and appropriation of technologies for its scalability and massification, with this it is taken into account that although the project, based on a scientific experiment must be supported by a series of trainings and disclosures to the population that refer to this knowledge within society. In the case of the aforementioned project, the team proposed two initial strategies for this work.

4.1 Social Knowledge Dissemination

Although the work carried out and the project are a clear example that should be implemented, massification and scalability to Latin American cities, it is important to carry out appropriation and awareness work toward the population that allows adopting this knowledge, technologies, and applications within society. In the case of the project, Ean University proposed two initial strategies for this social work.

4.2 Student Urban Mobility Service

The use of EVs by university students includes a structured reservation system that facilitates the management of vehicles resulting from an agreement with a private Carsharing venture called "Emobi" which rents only electric vehicles (Emobi, n.d.)

Fig. 5 Real ambient mobile laboratory

5 Conclusions

5.1 Mobile Environmental Laboratory as Part of a Smart City

The construction of this environmental laboratory, product of this project with capabilities to perform environmental measurements, calibration corrections, and analysis on the fly, allows the acquisition in real time of environmental variables of the environment. The use of EVs, taking into account its advantage of zero emission generation is the ideal element for analysis within cities, since there are no emissions or noise, nor excessive vibration, there is no interference in the measurements. Within the execution of the project presented in this article, capabilities were found to generate inputs in the identification of problems in lighting and noise issues, enabling its intervention in alliance with entities such as the National Public Lighting Association and the District Secretary of Environment. This is why the scalability of these types of solutions is vital for the transformation of cities into smart cities, to be evaluated, intervened, and revolutionized according to the population.

In the future, it is planned to implement this technique within freight transport and review the feasibility of a conversion analysis to hybrid or electric technology to suppress the amount of emissions generated by the sector, in addition to this, this laboratory will be implemented within a company of car sharing with the purpose of agglutinating as much data as possible and generating more extensive heat maps of the city.

Finally, it would be very interesting to make a scalability of this laboratory to as many cities as possible in order to impact the quantification of air quality within these laboratories and generate policies and projects that direct cities to true smart cities (Fig. 5).

Acknowledgements This project has been funded by the Ean University and supported throughout its process by Motorysa Colombia (Motorysa Corporativo, n.d.), entities committed to fostering an ecosystem of clean technologies within the cities of the world.

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