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High-resolution global geopositioning system for last-mile delivery

Sistema de geoposicionamiento global de alta resolución para entrega de última milla

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ABSTRACT: High-resolution monitoring systems are commonly used to calculate mechanical and energy performance, as well as environmental impact resulting from the operation of a fleet of vehicles in a region. These systems require recording operational or vehicle position data, energy consumption in the case of electric or electric-assisted vehicles, and buttons for specific signals in the operation, such as the start of operation, end of operation, or package delivery. Some vehicle tracking devices available on the market do not allow speed and energy consumption data to be recorded and accessed at the required sampling frequency. This study presents the development and validation of a remote sensing device to record energy consumption and operational variables of a vehicle under real operating conditions with a frequency of 1 Hz. The functioning of the device, the integrated elements in its development, and the data analysis process are detailed. Finally, using the monitoring equipment data, a comparison was made between the operation of electric vehicles and internal combustion vehicles, achieving savings of up to 83% in operating costs and a 79% reduction in CO_2 emissions.

RESUMEN: Los equipos de monitoreo de alta resolución se utilizan habitualmente para calcular el rendimiento mecánico, energético y el impacto medioambiental producido por la operación de una flota de vehículos en una región. Estos equipos requieren registrar datos de operación o posición del vehículo, el consumo energético en el caso de la operación con vehículos eléctricos o electro asistidos y botones para señales especificas en la operación como lo es el inicio de operación, final de la operación o entrega de los paquetes. Algunos de los dispositivos de seguimiento de vehículos disponibles en el mercado no permiten registrar y acceder a datos de velocidad y consumo energético con la frecuencia de muestreo requerida. Este estudio presenta el desarrollo y validación de un equipo de monitoreo remoto para registrar el consumo de energía y variables de operación de un vehículo en condiciones reales de operación con una frecuencia de 1 Hz. Se presenta en detalle el esquema de funcionamiento del equipo, los elementos integrados en su desarrollo y el proceso de análisis de datos. Finalmente, con los datos obtenidos con el equipo de monitoreo se realizó la comparación entre la operación con vehículos eléctricos y vehículos de combustión interna, obteniendo ahorros hasta del 83% en los costos de operación y 79% de reducción en emisiones de CO_2.

1. Introduction

Road transport is one of the main contributors to the triple

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loss, and pollution. Transport generated nearly 60% of nitrogen dioxide (NOx) emissions, 46% of particulate matter (PM_{10}) [1, 2], and 25% of CO_2 emissions [3, 4]. In terms of energy, transport activities consume 35% of global energy resources, and road transport accounts for 91% of this energy consumption [4]. The energy and environmental effects derived from road transport affect mainly cities and urban areas, home to 55% of the world's population [5]. Moreover, transportation in urban centers faces challenges related to congestion derived from the high vehicle flow. This increases the collateral problems of air pollution, noise, and accidents.

An alternative to reduce Greenhouse Gas (GHG) emissions, polluting emissions, and the energy impact derived from road transport is the implementation of light electric vehicles in logistics operations for cargo transportation in urban areas [6, 7]. The use of this type of vehicle in conjunction with electric motor technologies presents high energy efficiency and does not generate tailpipe emissions.

Different studies have addressed the replacement of conventional fleets operating with internal combustion engines with light electric vehicle fleets. The *Bicicarga* project implemented a pilot for the city of Bogota, where a last-mile distribution model was developed based on electric bicycles and tricycles [8]. This project reported an average reduction of 31% in the cost of the distribution service compared to the baseline scenario. The outcomes of the project resulted in a reduction of around 70 kg of CO_2 per month when electric tricycles were used and 40 kg of CO_2 per month when electric bicycles were used. The *Ecologistics* project implemented in Argentina and Colombia aimed to increase the efficiency of urban freight transportation and reduce GHG, promoting sustainability throughout the production chain [9]. Within the milestones of this project, demonstration projects on low-carbon urban charging were implemented. The project results indicated that the implementation of electric vehicles in 4 different operation models can generate between 0.004 kg CO_2 / delivery and 3.30 kg CO_2 / delivery compared to the operation with conventional vehicles, which produces between 3.70 kg CO_2 / delivery and 24.4 kg CO_2 / delivery.

In addition, to assess the environmental and energy impact of implementing light electric vehicles in last-mile logistics, it is necessary to collect operation data that allows the GHG produced, and the energy consumed to be estimated. In these projects, the systems used for the process of monitoring, reporting, and verifying the energy consumed and GHG produced and reduced have been based on manual processes and through surveys and interviews, which can be expensive, time-consuming to implement, with restrictions on periodicity and that can generate error-prone situations [10]. Nowadays, implementing digital technologies in different economic sectors, including road transport, can help tackle climate change, build climate and disaster resilience, and enhance environmental sustainability [11]. Digitalization could significantly impact on-road transport, where connectivity and automation (alongside further electrification) could dramatically reshape mobility, improving safety, efficiency, and emission reductions [12]. The digitalization of transport is transforming manual processes into automated processes using smart sensors, cloud computing processes, artificial intelligence, and the Internet of Things, among other systems, facilitating the collection and analysis processes of data and allowing improved communication and verification of emissions reduction results in almost real-time. The availability of real-time data in greater quantity and with greater frequency can help optimize vehicle and fleet operations. It will allow the generation of continuous and categorized information for each interest groups [10, 12]. For having an accurate estimation of the energy consumption and emissions produced by a vehicle fleet, it is necessary to collect data under real operation conditions. [13] established a standard for estimating fuel consumption and CO_2 emissions from speed profile and trip data generated by the global navigation satellite system (GNSS) receiver of a nomadic device. The trip data is sent via mobile communication to a database server and is used to calculate the mechanical energy contributions of aerodynamics, rolling friction, acceleration/deceleration, gradient, and standstill. [14] developed a model for simulating a specific vehicle's fuel economy over a wide range of real-world conditions. To validate the proposed model, on-road test data were collected using a highly instrumented vehicle, including fuel consumption flow.

Nowadays, different devices are capable of monitoring the operation of vehicle fleets. The ELM 327 microcontroller allows the storage of the operation data of a vehicle and to access the data manually and "offline" through a computer or a mobile phone. While Azuga, is a system used to register and remotely access the localization and operation of vehicle events such as average and high speed, aggressive accelerations, and braking. Devices like Bitbrew and Aytomic allow customizing their information platforms. However, their approach is oriented to the logistical control of the fleet, rather than to determine the energy and environmental impact of the vehicles.

2. Materials and method

The equipment must be inside the vehicle, so it must be portable, small, and operated automatically, i.e., decoupling its operation from the action of the driver. To achieve this, the remote sensing device comprises three different components, as shown in Figure 1.

The remote sensing device is controlled by a control system capable of acquiring all synchronous signals, transmitting remotely the acquired data, and allowing remote assistance. For this task, we chose a Raspberry PI 3 B+ (RPI3B), which has different peripheral ports, 1 GB of RAM, and supports up to 32 GB of storage, allowing

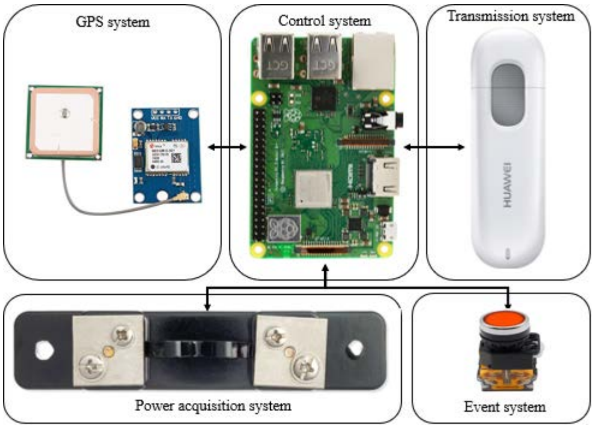


Figure 1 High-resolution global repositioning system for last-mile delivery and its components

data to be stored continuously. The RPI3B operates using a Linux-based operating system and is responsible for implementing the Python-based acquisition methodology. The remote sensing device acquires all signals at 1 Hz in a constant and interrupted manner (including the GPS signal). The GPS signal, through satellite triangulation, does not make 3G or 4G coverage necessary for the acquisition. It should be noted that the above allows us to present an excellent monitoring tool since it generates exact displacement calculations. The device is initially composed of a GPS (latitude and longitude with a neo6mv2 sensor), which allows the building of a map that represents the vehicle's route. On the other hand, the current and voltage of the vehicle's battery are acquired through a SHUNT (10A - 73mV), which is installed through the negative cable of the battery. Now, using a button, the driver can mark an event, which will be seen in all the signals as a reference point. Finally, a Huawei e303 USB transmission system with 3G technology is connected to the RPI3B, which allows connectivity and data transmission in an organized and unencrypted manner to a cloud server. Although the entire system can be powered from the vehicle, a 10000-mA power bank is chosen to be the least invasive with the vehicle. In terms of costs, the device has a value of USD 150 only for its physical devices, maintenance, and final disposal. For 3G communication and storage, the initial cost is $4 USD, with a monthly payment of $10 USD.

2.1 Description of the remote sensing device

Three different types of devices for monitoring and tracking vehicle fleets are identified on the market. However, none of the equipment that was analyzed was designed to collect detailed information on the operation of the fleet to carry out an energy and environmental analysis. To face this issue, the remote sensing device obtains different intrinsic signals from the vehicle synchronously, organized, and with a frequency of 1 Hz. The system was programmed with Python to acquire the signals presented in Table 1.

Table 1 Measured and calculated signals through the remote-sensing device

Signals	Units	Method of obtaining the signal
Latitude (LAT) and longitude (LON)	Degree	Measured
Current	A	Measured
Voltage	V	Measured
Power	W	Calculated
Energy	Wh	Calculated
Event	N/A	Measured
Speed	km/h	Calculated
Distance	km	Calculated
Altitude	m.a.s.l	Calculated

LAT and LON data are established through a digital geolocation sensor neo6mv2. This sensor delivers the vehicle location with a position accuracy of 2.5 m at 1 Hz. Using LAT and LON as a function of a time series, we can calculate the distance between the positions using Equation 1 and Equation 2.

$$A = \sin\left(\frac{LAT_i - LAT_{i+1}}{2}\right)^2 + \cos\left(LAT_i\right) * \cos\left(LAT_{i+1}\right) * \sin\left(\frac{LON_i - LON_{i+1}}{2}\right)^2 \quad (1)$$

$$\mathrm{dis}_i = 2 * R * \mathrm{atan}\,2(\sqrt{A}, \sqrt{(1-A)}) \quad (2)$$

Where A is a step for calculating the distance and dis_i is the distance traveled between the coordinates in radians LAT_i y LON_i and LAT_{i+1} y LON_{i+1}. R is the approximate radius of the earth (6371 km). Due to calculated distance and 1Hz frequency monitoring data, the speed at which the trip was made can be calculated with high resolution.

On the other hand, using the AIRMAP API is feasible to calculate the meters above sea level (altitude) for each LAT_i and LON_i. The above allows us to highlight the slopes to which the vehicle is operated and helps to improve the characterization of the local driving cycles. In addition to the signals, an acquisition of the current and voltage used by the vehicle's electric motor is made to know the power consumed over time, which allows us to know the energy consumed over time. In most cases, when electric vehicles are implemented in companies, it is due to replacements for combustion vehicles that performed the same task. Thanks to the device taught in this article, the company's benefits with respect to said change can be quantified. The methodology can be seen in Figure 2.

First, the electric vehicle must be monitored in its positioning parameters and battery power and then compared with the company's historical data. The entire system is programmed in Python and its operation is divided into three algorithms that work simultaneously on specific tasks. The operation of the three algorithms can be seen in Figure 3.

The system starts its operating system based on Linux, which in turn executes three algorithms for energy acquisition, GPS acquisition, and data transmission. The energy acquisition algorithm works by initializing an ADS1115 (5V-16bits) connected to the Raspberry, which has a shunt (75mV – 10A) connected as a current sensor, as shown in Figure 4.

After initializing in ADS, it acquires the date, battery voltage and current coming out of the battery once a second. The acquisition takes 300 seconds, and all data is saved in a CSV file. On the other hand, a GPS acquisition algorithm is executed with the same logic as the energy acquisition algorithm. It should be noted that separate acquisitions are made to guarantee that current and voltage are acquired in places with no GPS signal. Finally, there is the transmission algorithm which updates the time and date of the device and immediately begins to transmit the data generated by the two previous algorithms to the cloud. The device has been tested in different cities in Colombia (Bogota, Barranquilla, Medellin, and Pereira) and has successfully measured all the variables mentioned above. Specifically, the signals shown as a result of this research are acquired in the city of Bogota (the city where most monitoring has been carried out) on a tricycle designed for last-mile delivery of goods in urban communities. The tricycle can be seen in Figure 5.

The tricycle is electrically assisted, and its autonomy is 35 km with a load capacity of 250 kg, thanks to its 48 V, 16 Ah lithium battery. The measurements were carried out over 3 months, generating a database that was cleaned of atypical data, processed, and consolidated to enhance data analysis.

3. Results

This section shows the results of the acquisition of the signals with the proposed remote sensing device. First, the results of the acquisition of the LAT and LON signals are shown, which are processed with Python, and using the FOLIUM API, a map of the vehicle's driving cycle can be generated, which allows the driving cycle to be verified. An example of this map can be seen in Figure 6.

Furthermore, using the AMAPI API and Python, it is possible to determine the altitude (meters above sea level) of each point with LAT and LON coordinates, enabling tracking altitude changes throughout the tricycle route. An example of the signal can be seen in Figure 7a. LAT and LON captured at 1Hz enable the calculation of the vehicle's speed and the acceleration to which it is subjected. An example of the signals can be seen in Figure 7b.

In addition to the signals, an acquisition of the current and voltage used by the vehicle's electric motor is made to know the power consumed over time, which allows us to know the energy consumed over time. An example of these signs can be seen in Figure 8.

The voltage signal does not present relevant disturbances over time, which is expected because it should only change when a large load is placed on the motor. On the other hand, the current signal increases at the beginning of the signal, and then present temporarily drops due to the vehicle stopping at different points in the driving cycle.

In Table 2, we present the results of the measurements analysis that were carried out for three months on the days that the vehicle was used; these measurements include the number of events and the distance traveled by the vehicle during monitoring campaign. It should be noted that previously, the route was carried out with a CHEVROLET N300 VAN (consumption of 9.5 liters of gasoline per 100 km), and thanks to the remote sensing device, the true real impact of the electric vehicle can be determined.

For the environmental impact assessment, a quantitative comparison of wheel-tank and tank-wheel [15] is carried out, starting by using an estimated CO_2 emission factor for the electrical generation of the Colombian interconnected system of 164.38 g of CO_2 per kWh and each liter of gasoline consumed emits an average of 2.35 kg of CO_2 [16]. Therefore, we obtained a percentage reduction of 79.89% in emissions of CO_2 sent to the

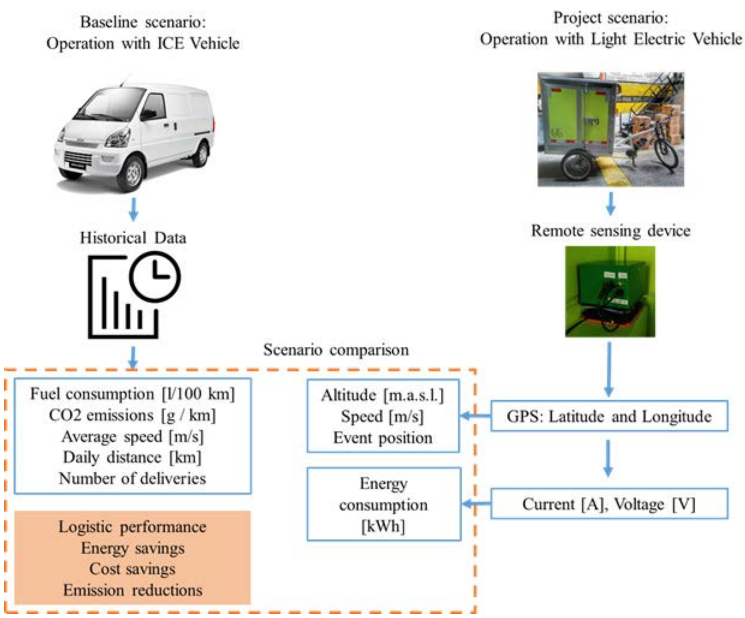


Figure 2 Control methodology diagram of the remote sensing device

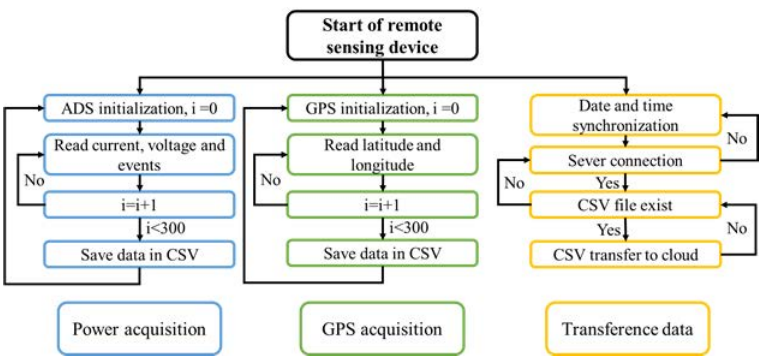


Figure 3 Control methodology diagram of the remote sensing device

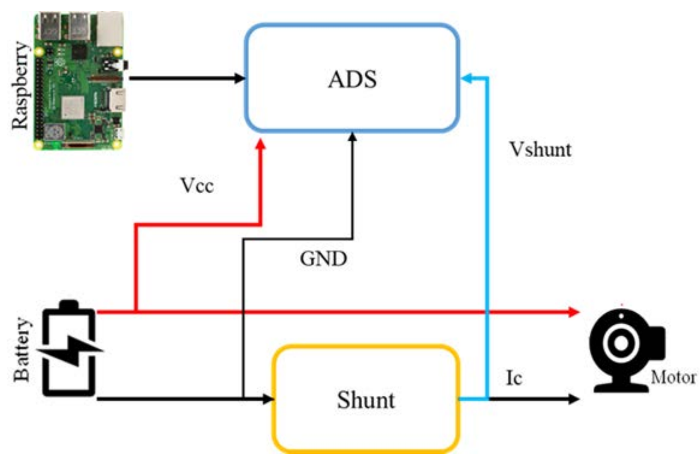


Figure 4 Current sensor diagram connection

atmosphere when using electric light vehicles. The gasoline in Colombia has an average price of $14564 COP per gallon of gasoline and $884.93 for the price per kWh, which represents a percentage reduction of 82.53% of the

Table 2 Monitoring campaign using the remote sensing device.

Date (MM/DD)	Event (-)	Average speed (m/s)	Distance (km)	Energy (kWh)	Maximum altitude (m.a.s.l.)	Maximum altitude (m.a.s.l.)
09/20	19	2.45	15.99	5.11	2576	2544
09/21	4	3.15	6.23	1.55	2579	2544
09/25	7	2.35	7.37	2.45	2575	2543
09/26	26	2.86	13.46	3.68	2576	2545
09/27	8	1.46	2.17	2.71	2574	2544
09/29	17	3.13	14.53	3.58	2583	2544
10/02	12	3.06	13.40	3.39	2566	2543
10/05	14	3.38	18.21	4.16	2575	2545
10/12	14	3.32	21.31	6.14	2576	2544
10/13	16	2.95	14.4	5.85	2575	2544
10/24	20	3.17	16.52	4.03	2575	2543
11/15	13	3.17	9.89	2.43	2575	2545
11/16	20	3.20	14.84	3.58	2572	2544
11/17	21	3.24	13.396	3.2	2575	2544
11/20	21	2.22	13.31	3.2	2575	2543
11/21	20	3.18	16.58	4.03	2569	2545
11/22	12	3.26	17.80	4.22	2575	2544
11/23	18	3.27	14.07	3.33	2575	2544
11/24	25	3.33	19.54	4.54	2580	2543
11/28	13	4.26	17.24	4.1	2566	2545
11/29	10	3.37	19.52	4.48	2575	2551
12/01	15	3.24	19.32	4.61	2558	2551
12/05	19	2.10	14.89	3.71	2575	2551
12/06	20	3.24	17.16	4.1	2575	2544
12/07	24	3.21	15.12	3.65	2575	2544
12/11	9	3.39	18.89	4.99	2576	2543

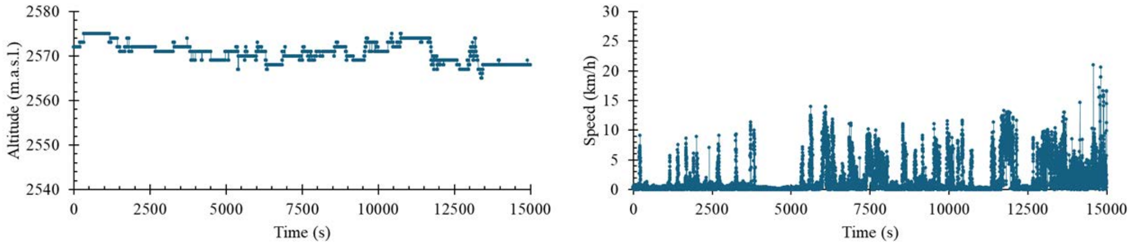
Figure 5 Last-mile delivery electric vehicles used in this study

Figure 6 Last-mile delivery electric vehicles used in this study

company's operation expenses.

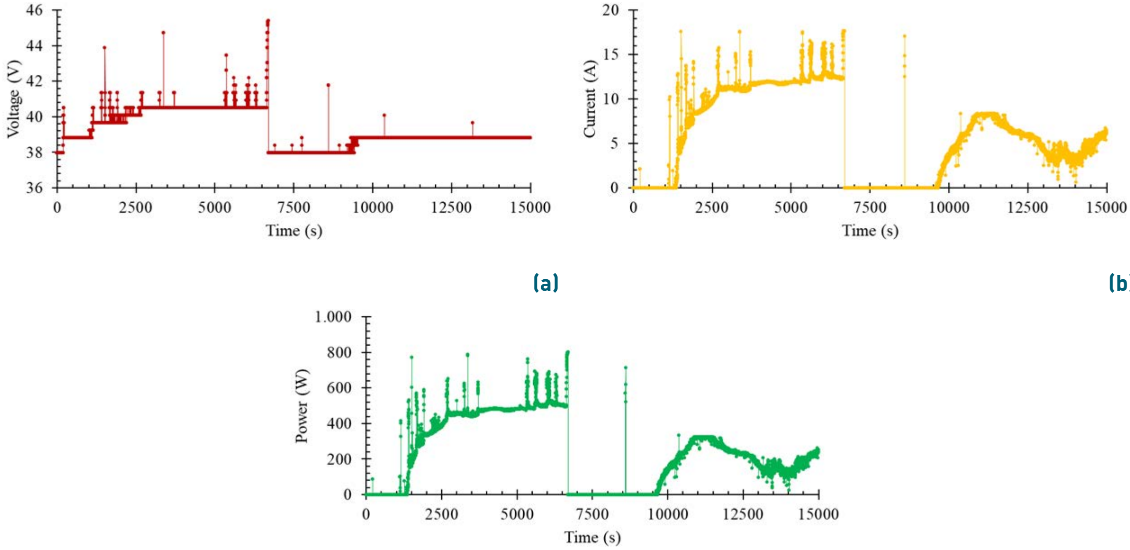
4. Conclusions

This study presents the development of a remote sensing device designed to estimate the mechanical, energy, and environmental performance indicators, as well as efficiency indicators in the last-mile cargo logistics operations in urban areas. To do this, a remote sensing device registers the location (latitude and longitude) of the vehicle, the current and voltage of the battery, and delivery through an event button. The equipment is designed to collect operation data with a sample frequency of 1 Hz. This sampling frequency facilitates the accurate collection under real operation conditions of the driving parameters, traffic and congestion externalities, and driving behavior. Thanks to these signals and their sampling frequency, the speed, acceleration, power, and energy consumed by the vehicle are computed. The equipment available on the market for fleet monitoring does not operate with the



(a) (b)

Figure 7 Variables calculated for an aleatory trip with the remote sensing device: a. altitude and b. speed.



(a) (b)

(c)

Figure 8 Variables monitored and calculated for an aleatory trip with the remote sensing device: a. monitored voltage, b. monitored current, and c. calculated power

required sampling frequency or has access restrictions to the information on its platforms. The remote sensing device integrates a GPS sensor for vehicle location, a SHUNT (10A - 73mV) for measuring the current and voltage of the vehicle's battery, and a Huawei e303 USB transmission system with 3G technology connected to the RPI3B.

This equipment was developed to monitor the operation of a fleet of electric vehicles under real driving conditions, record energy consumption data, and present real data to the company on the economic, environmental, and social advantages of migrating to zero-emission vehicles. The company provided historical data that was used to estimate the fuel consumption of the company's baseline operation using an internal combustion engine vehicle fleet. To reduce the vehicle emissions, a fleet of 8 electric vehicle fleet was deployed. The vehicle was monitored during 26 days of operation in three months. The number of deliveries per day ranged between 4 to 26 according to according to the number of purchases made by customers. During the monitoring campaign, the electric vehicle covered a daily distance between 2.2 km and 21.3 km, and the energy consumption ranges between 1.55 kWh and 6.14 kWh.

Finally, an economic and environmental comparison was made concerning the baseline scenario, assessing the expenses necessary to carry out the operating driving routes. While the ICE vehicles used under the baseline scenario consumed 5.77kWh of energy, the project scenario using electric vehicles consumed 3.88kWh. This represents an energy savings of 82.53% and an energy cost reduction of close to 83%. A well-to-wheel emission analysis indicated a reduction of 79% in CO_2 emissions between the electric vehicle fleet to the combustion engine vehicle. The implementation of electric vehicles avoids the production of PM emissions which improve air quality, as well as noise reduction, especially in urban areas. The logistics operation was carried out successfully when the electric vehicles were implemented. Moreover, the operation of electric vehicles produced financial savings due to the reduction in energy costs. A positive environmental impact is also observed. These results allow the company to make decisions about the feasibility of operating with this type of electric vehicle in a city. The autonomy of the remote sensing device was designed to store vehicle operation data for up to 462 days of continuous acquisition, while the power sources were calculated for having continuous operation of 26 days. Both, the battery capacity, and the autonomy to store data were validated during the monitoring campaign.

In future work, it is expected to monitor vehicles of the same type but in different cities to estimate how traffic, topographic, environmental, and operation conditions change energy consumption and the GHG produced.

Declaration of competing interest

We declare that we have no significant competing interests, including financial or non-financial, professional, or personal interests interfering with the full and objective presentation of the work described in this manuscript.

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Author contributions

L. F. Quirama-Londoño, M. D. Giraldo-Galindo, J. C. Mejía-Hernández and J. E. Tibaquirá-Giraldo: Conceived and designed the analysis. L. F. Quirama-Londoño, M. D. Giraldo-Galindo and J. C. Mejía-Hernández: Collected the data. L. F. Quirama-Londoño, M. D. Giraldo-Galindo and J. C. Mejía-Hernández: Contributed data or analysis tools. L. F. Quirama-Londoño, M. D. Giraldo-Galindo and J. C. Mejía-Hernández: Performed the analysis. L. F. Quirama-Londoño, M. D. Giraldo-Galindo, J. C. Mejía-Hernández and J. E. Tibaquirá-Giraldo: Wrote the paper.

Data available statement

Data were collected in real conditions in Bogota, Colombia from September to December 2022. We used a Raspberry PI 3 B+ (RPI3B), neo6mv2 sensor, SHUNT (10A - 73mV), and Huawei e303 USB transmission system to construct the remote sensing device. The authors confirm that the data supporting the findings of this study are available within the article and for raw data you need to contact the authors.

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