Design and implementation of an embedded data logger for MAP sensors in automotive systems

Diseño e implementación de un registrador embebido para sensores MAP en sistemas automotrices

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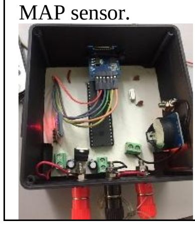
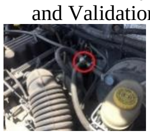
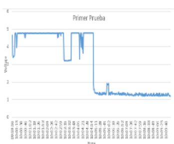
Abstract

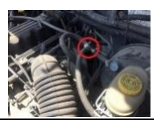
This paper presents the design and construction of an embedded system for recording and analyzing data from a Manifold Absolute Pressure (MAP) sensor. The system integrates a PIC18F4620 microcontroller, a microSD storage module, a DS3231 real-time clock, and a Bluetooth communication module. This data logger enables real-time evaluation of the performance of an ecological valve installed in a gasoline engine. Tests under different operating conditions were conducted, assessing its impact on engine efficiency and fuel consumption.

Objetive	Methodology	Contribution
To design and implement an embedded system to record and analyze data generated by a MAP sensor. 	1. System Design 2. Prototype Implementation 3. Experimental Testing 4. Data Analysis and Validation 	1. Design of a functional embedded logger 2. Real-time evaluation 3. Mobile application 

Manifold, Ecological, Evaluation

Resumen

Este artículo presenta el diseño y la construcción de un sistema embebido para el registro y análisis de datos provenientes de un sensor de presión absoluta del múltiple de admisión (MAP). El sistema integra un microcontrolador PIC18F4620, un módulo de almacenamiento en microSD, un reloj en tiempo real DS3231 y un módulo de comunicación Bluetooth. Este registrador permite la evaluación en tiempo real del desempeño de una válvula ecológica instalada en un motor a gasolina. Se incluyeron pruebas en distintas condiciones de operación, evaluando su impacto en la eficiencia del motor y el consumo de combustible.

Objetivo	Metodología	Contribución
Diseñar e implementar un sistema embebido para registrar y analizar los datos generados por un sensor MAP. 	1. Diseño del Sistema 2. Implementación del Prototipo 3. Pruebas Experimentales 4. Análisis de Datos y Validación 	1. Diseño de un registrador embebido funcional 2. Evaluación en tiempo real 3. Aplicación móvil 

Múltiple de admisión, Ecológica, Evaluación

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Introduction

Internal combustion engines play an essential role in global transport and industry. However, their efficiency and sustainability are constantly challenged by environmental factors, such as variations in atmospheric pressure due to altitude. These variations affect the air-fuel mixture, negatively impacting engine performance, increasing fuel consumption and contributing to environmental pollution (Heywood, 2018), (Stone, 2012), (Zhao, Lai, Harrington, 1999).

Internal combustion engines face numerous challenges in maintaining their efficiency and sustainability, especially at high altitudes. Technologies such as the eco-valve offer effective solutions by dynamically adjusting the proportion of air in the air-fuel mixture, optimising engine performance and reducing pollutant emissions.

Against this background, technologies that optimise engine performance, such as eco-valves and associated monitoring systems, are of great relevance to mitigate these effects and promote more sustainable practices.

The Manifold Absolute Pressure (MAP) sensor is a device designed to measure the volume of air entering the engine. Its signal is interpreted in terms of flow rate, expressed in grams per second. An increase in air flow to the engine translates into an increase in revolutions per minute (RPM). The MAP sensor plays a critical role in the accurate calculation of fuel injection timing.

When the MAP sensor malfunctions, black smoke, an indication of high fuel consumption, is common. These faults are often reflected in the codes P0101, P0102 and P0103 when the system is scanned (Booster, 2014). The MAP sensor has three wires: one to receive the supply voltage, connected via a fuse located in the engine fuse box; another that connects to earth ground (chassis); and a third that transmits the detected air flow data directly to the computer.

An eco-valve acts as a height compensator and is installed in the intake manifold to maintain the proper proportions of air and petrol entering the engine.

This adjustment is made according to altitude above sea level, allowing the optimum amount of air to be metered for efficient mixing with the petrol. As a result, the overall performance of new or used engines in any type of automobile is improved (Marclais, 2014).

The air intake regulated by the eco-valve depends on both how quickly the throttle is depressed and changes in atmospheric pressure associated with altitude. During hard acceleration, such as when starting or overtaking another vehicle, excess fuel is generated in the mixture; in these situations, the eco-valve acts immediately to allow additional air intake to balance the air/fuel ratios. Conversely, when the accelerator is released or when the mixture is already adequate, the valve suspends the entry of additional air into the engine (Marclais, 2014).

This work addresses the design and implementation of an embedded data logging system specifically designed for MAP sensors. This system not only allows real-time monitoring of the performance of devices such as eco-valves, but also provides a cost-effective and efficient platform for the collection of critical data on engine behaviour under different operating conditions.

The added value of the developed system lies in its integration of compact, inexpensive and easy-to-implement technologies, such as a PIC18F4620 microcontroller, a microSD storage module, a DS3231 real-time clock and a Bluetooth module. Unlike other techniques that often require expensive and more complex equipment (Bosch, 2022), this system offers an affordable and versatile solution that not only monitors but also stores the data in a readable format and allows for subsequent analysis in an efficient way. In addition, Bluetooth connectivity enables real-time monitoring via mobile devices, significantly improving the user experience and responsiveness to changing engine conditions.

The proposed design is notable for the following features:

- Portability and versatility: The system can be implemented in various vehicle models and adapted to other applications.

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- Hardware and software integration: Its modular design includes electronic components and a mobile application developed in App Inventor for real-time data visualisation and storage.

- Accuracy and reliability: The use of a real-time clock ensures the traceability of recorded data, while the microSD module facilitates its storage in an organised and secure manner.

- Economic efficiency: The components used are affordable, which significantly reduces the overall cost of the system without compromising its functionality.

The problem to be solved centres on the need to monitor and analyse the performance of eco-valves installed in gasoline engines, especially under critical operating conditions, such as high altitudes and steep slopes. These conditions generate a variation in the air-fuel ratio, which compromises engine performance and increases fuel consumption (Santamaria, 2010). The central hypothesis argues that the developed data logger will accurately and reliably demonstrate the operational and environmental benefits of eco-valves, providing a valuable tool for their evaluation, validation and mass adoption.

The proposed embedded system not only addresses a relevant technical and environmental problem, but also introduces an innovative and affordable solution, broadening the field of applications in the automotive industry and strengthening efforts towards sustainability.

The following sections detail the structure and operation of the MAP sensor recorder, addressing each of its key components and their integration into the system. A description of the developed mobile application is included, which allows the visualisation and storage of the collected data in real time. Likewise, the design and configuration of the electronic circuit used to carry out the experimental tests is presented, highlighting its implementation and validation. Finally, the results obtained during the tests are analysed, emphasising the impact of the recorder in the evaluation of the performance of the eco-valve under various operating conditions.

MAP sensor recorder

The intake manifold absolute pressure (MAP) sensor is essential for measuring the air pressure in the engine, providing fundamental data for calculating the air-fuel mixture and optimising engine performance (Bravo Morocho, 2022). The implementation of data loggers, such as those described by (Sanchez Perez and Galindo Valencia, 2024), highlights the importance of recording key parameters such as temperature and pressure in real time to optimise engine operation.

The developed system consists of an embedded data logger designed to collect and analyse the information generated by a MAP sensor. This system allows to evaluate the performance of devices such as eco-valves in internal combustion engines under different operating conditions.

The system design included the integration of hardware and software, allowing the development of an electronic circuit and the programming of the PIC18F4620 microcontroller. This approach is consistent with that described by (Betancourt Rodriguez, 2024), who emphasises the importance of integrated solutions that combine both elements to meet specific automation requirements.

The MAP recorder consists of the following elements:

- PIC18F4620 microcontroller: Responsible for processing the signals coming from the MAP sensor.

- microSD module: Allows the data to be stored in a readable format (CSV), facilitating subsequent analysis.

- DS3231 Real Time Clock: Provides accurate time stamps for each data record.

- Bluetooth Module HC-06: Facilitates real-time display via a mobile application.

- MAP Sensor: Detects the pressure in the intake manifold, emitting signals proportional to the air flow.

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This device allows real-time monitoring of engine operating conditions, with a particular focus on the evaluation of the eco-valve. A microcontroller-based system aims to provide an accessible and efficient tool for recording signals, processing and storing them together with time stamps. This facilitates the evaluation of engine performance and the optimisation of engine operation under various conditions.

Mobile application

The mobile application developed for this project allows the visualisation and management of the data collected by the MAP sensor logger in real time. Using wireless connectivity technologies, such as Bluetooth, an efficient and reliable transmission is ensured. This aligns with the principles described by (Rubio-Quintanilla, 2024) on the use of communication standards in embedded systems to ensure interoperability and reliability. The design should provide an intuitive and accessible interface for users (Chennakesava, 2009).

The application was created using App Inventor, a platform that allows the development of Android applications using visual block programming. This tool simplifies the design of interfaces and the integration of specific functionalities, such as Bluetooth connection and data storage. Figure 1 shows the user interface of the developed application.

Box 1

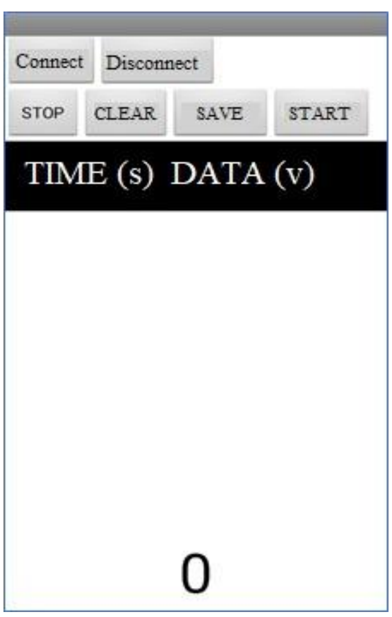

Figure 1
Mobile application

The interface was designed to be user-friendly and functional. It includes clearly identified buttons to perform specific actions, such as:

- Connect: Allows you to select the Bluetooth module and establish communication.

- Start: Activates the reception and display of data in real time.

- Stop: Ends data transmission.

- Save: Generates a CSV file with the stored readings.

- Restart: Clears the logs and restarts the interface.

The application includes the following functionalities:

- Bluetooth connection: Scanning of paired devices. Selection and connection to the MAP logger.

- Real Time Monitoring: Continuous display of MAP sensor readings. Data representation in a simple and clear interface.

- Data Storage: Generation of files in CSV format with the recorded readings. Possibility to name and save files for later analysis.

- Operations Management: Buttons to start, stop and restart data transmission. Options to delete logs stored in the application.

The application was tested on Android devices with different versions of the operating system, ensuring its compatibility and functionality. During the tests, the connection to the MAP logger proved to be stable, with smooth and uninterrupted data transmission.

The addition of the mobile app significantly enhances the user experience, allowing the user to monitor and analyse engine performance immediately and conveniently. In addition, the ability to store data facilitates detailed log analysis, contributing to predictive maintenance and fuel consumption optimisation.

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Electronic circuit

This section presents the design of the electronic circuit of the MAP recorder, which must efficiently integrate the necessary components for data collection, processing and storage (Wolf, 2022). The circuit includes the following key elements: PIC18F4620 microcontroller, MAP sensor, DS3231 RTC module, microSD module, HC-06 Bluetooth module and power supply. The system design includes a plastic housing manufactured based on the technical specifications of the MAP sensor and the installation requirements in the car. This design, made in SolidWorks, aims to protect the electronic components, ensure accessibility to the functional elements of the recorder and facilitate its integration in various vehicular environments. Figure 2 presents the finished housing, showing a compact and functional design that houses all the components of the data logger. Power is supplied to the system via clearly labelled slots. There is one slot labelled ‘SD’, specifically designed for the safe insertion and removal of the microSD memory, where the data collected by the embedded system is stored. Another slot is for the connection of the MAP sensor signal. This input allows the logger to capture the data from the sensor and process it for storage in the microSD memory. The strategic arrangement of these slots ensures fast and efficient installation of the system in the engine compartment.

Box 2

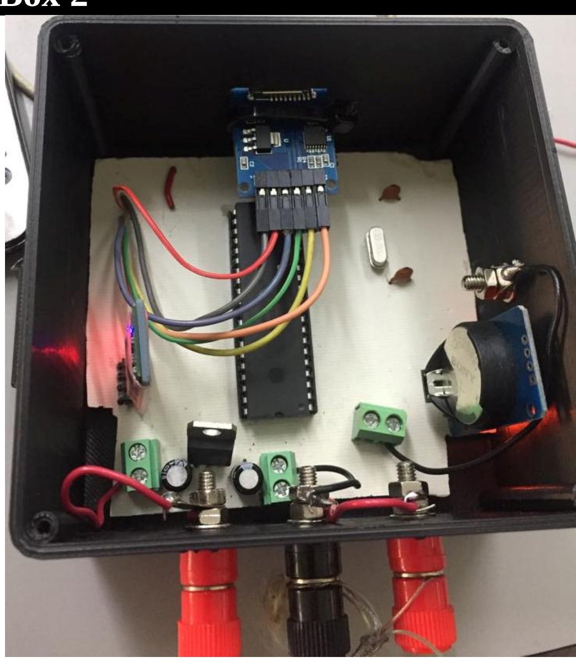

Figure 2
Circuit mounted in the housing

This housing not only protects the internal hardware from adverse conditions, such as dust or moisture, but also contributes to the durability and transportability of the device. This compact and secure design ensures the protection of the electronic components and facilitates their integration into the automotive environment.

Tests and results

The mechanical installation of the recorder was carried out on a 1985 Volkswagen Golf. The process consisted of making a bifurcation in the vehicle's intake manifold, where a hose was connected to extend the air signal to the cabin. Inside the cabin, the eco-valve was installed, to which another hose was connected, leading the flow to the MAP sensor. This design allows data to be monitored and recorded directly from the engine compartment. Figure 3 shows the bifurcation made in the intake manifold to connect the eco-valve to the engine.

Box 3

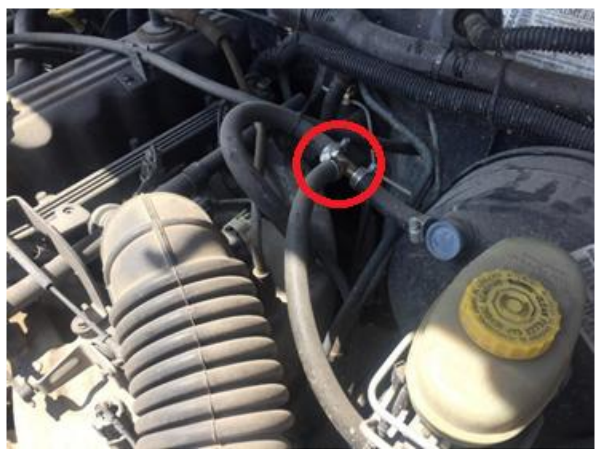

Figure 3
Bifurcation for connection inside the engine compartment of the vehicle

Inside the vehicle cabin, the eco-valve was connected via the hose coming from the intake manifold. This hose runs through the driver's compartment and connects to the MAP sensor input, allowing the data required to evaluate the system's performance to be recorded.

The datalogger is wired via a USB adapter connected to the vehicle's 12V socket, which provides power to the system. The MAP sensor has three cables: two power cables and one signal cable.

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Figure 4 shows the path taken during the testing of the eco-valve. This path was specifically designed to evaluate the performance of the system under varying conditions, including significant changes in altitude. During the tests, key data such as distance travelled, travel time, altitude, average speed and maximum speed were recorded.

Box 4

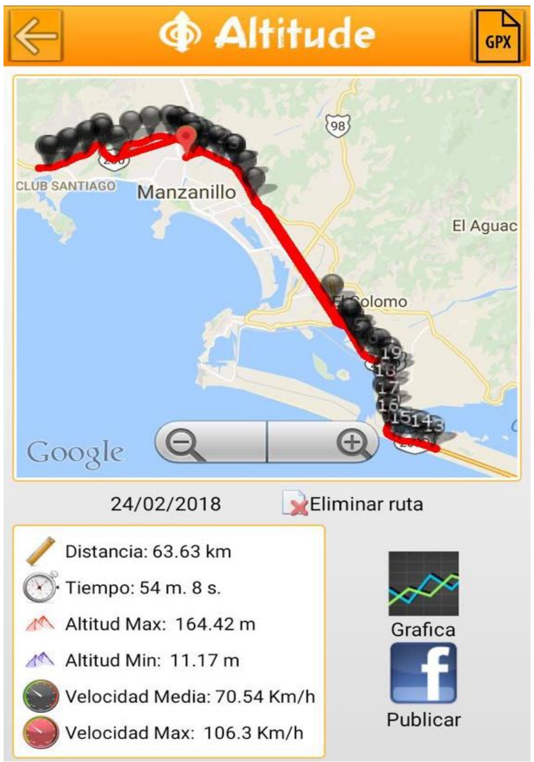

Figure 4
Path

Among all the variables analysed, altitude was identified as the most relevant (Ferguson, Kirkpatrick, 2016), as the main objective of the eco-valve is to compensate for the decrease in available oxygen at high altitudes. By adjusting the proportion of air entering the engine, the valve improves combustion efficiency, thus optimising engine performance. To evaluate this behaviour, a route was selected that included different altitude levels, ensuring challenging conditions for the engine. This allowed us to observe how the valve is activated to balance the air-fuel mixture in response to oxygen depletion at higher altitudes. In the graph shown in figure 5, the variations in altitude along the route can be clearly seen, providing a visual representation of the environment in which the system operated.

Box 5

Figure 5
Altitudes during the journey

The design of these tests not only verified the functionality of the system, but also highlighted its ability to record and analyse data in real time. This ensures that the MAP logger is a reliable tool for assessing the impact of devices such as the eco-valve in real operating environments.

During testing, the system collected critical data on engine behaviour and eco-valve activation under different operating conditions. This supports the need for reliable systems to monitor processes in real time, as highlighted by (Asmad Vereau and Falero Siancas, 2024) in industrial monitoring and control applications.

Figure 6 shows the results obtained when the eco-valve is connected and operational. The graph shows how the recorded voltage varies over time, indicating the activations of the valve. When the voltage reaches 5V, it is evident that the engine requires additional oxygen supply, which activates the valve to compensate for the lack of oxygen in the air-fuel mixture. Thus, the graph reflects the number of times the valve was actuated during the trip.

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Box 6

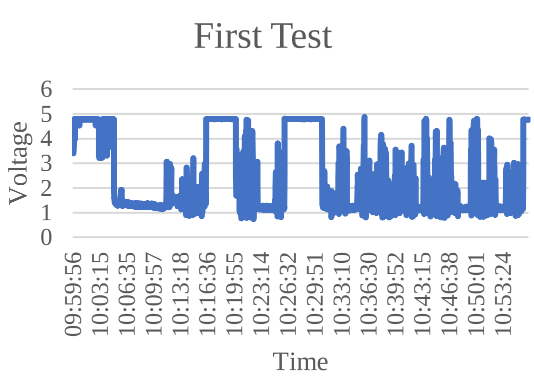

Figure 6
Results when the valve is active

Figure 7 highlights the data obtained during the first 10 minutes of the first test. During this period, frequent activations of the valve are observed, particularly in situations such as passing another vehicle, which requires a sharp acceleration, or when ascending steep slopes, where oxygen levels decrease due to the altitude. In these cases, the valve helps to maintain engine efficiency by delivering more oxygen rather than increasing fuel consumption.

Box 7

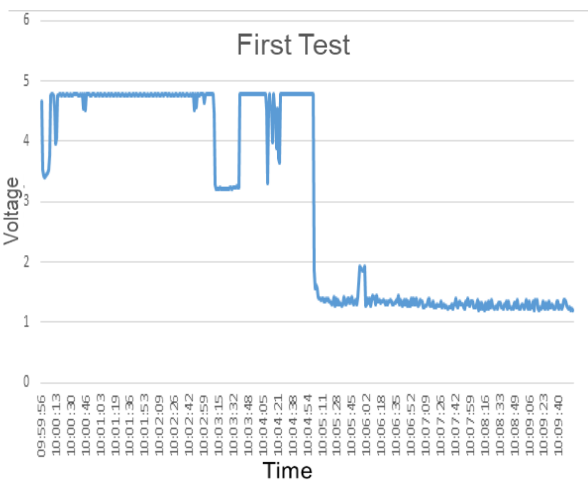

Figure 7
Results when the valve is active (extract)

On the other hand, Figure 8 shows the results obtained when the eco-valve is not connected. Under these conditions, the graph indicates that the valve is not activated, which negatively affects the efficiency of the engine. The lack of compensation for oxygen depletion in similar situations reduces combustion efficiency, which can lead to higher fuel consumption and lower performance.

Box 8

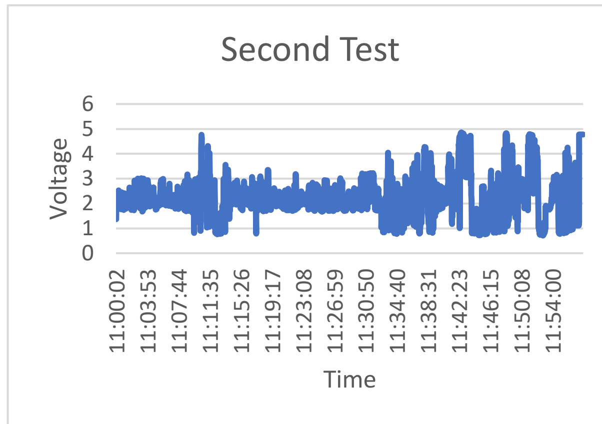

Figure 8
Results when the valve is not active

Figure 9 presents the data obtained during the first 10 minutes of the second test, where the same path was repeated as in the first test, but without the valve connection. When comparing both results, it is evident that the engine did not receive the benefit of oxygen compensation, which reinforces the importance of the valve in improving engine performance under these conditions.

Box 9

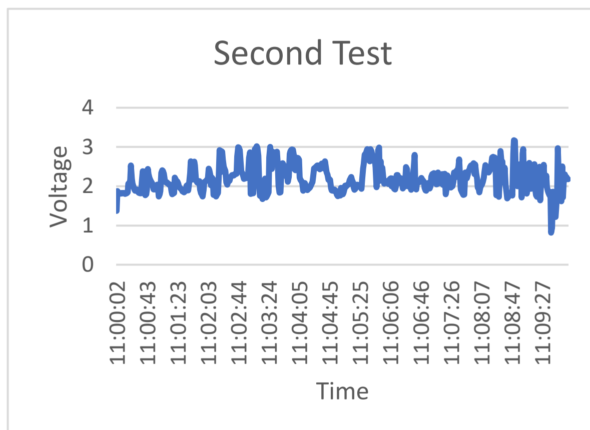

Figure 9
Results when the valve is not active (excerpt)

Finally, Figure 10 shows the results of a third test performed to evaluate the operation of the prototype over a longer period of time. This analysis confirmed the stability and reliability of the system in long-term data collection, as well as the effectiveness of the valve in responding to the needs of the engine in different scenarios.

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Box 10

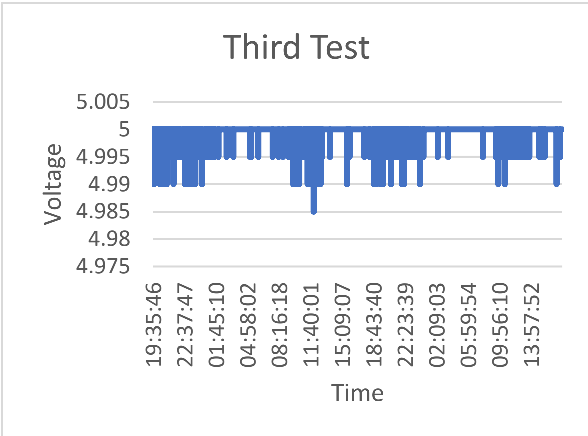

Figure 10
Test results over a longer period of time

This series of tests clearly demonstrates the ability of the embedded system to accurately monitor and record the performance of the eco-valve, providing key information to assess its impact on engine efficiency.

Conclusions

The eco-valve has proven to be highly efficient in cars operating at altitudes above 1,000 metres above sea level. Its implementation not only optimises engine performance by maintaining more efficient combustion, but also contributes to prolonging engine life. In addition, the valve generates significant fuel savings by dynamically adjusting the proportion of air in the air-fuel mixture, thus reducing energy waste and pollutant emissions.

In the present work, a detailed sampling and continuous recording of the behaviour of this fuel-saving device was carried out. The results show that the eco-valve is mainly activated in critical operating situations, such as steep gradients and abrupt acceleration changes. In these scenarios, the valve regulates the additional oxygen supply needed to optimise combustion, thus improving overall engine efficiency. In addition, the data collected provides valuable information about the driving patterns of each user, which can be useful for studies related to driving habits and their impact on fuel consumption.

The development and analysis of the data loggers used in this study highlight the importance of having accurate tools to monitor and evaluate the behaviour of technological devices. The information generated not only supports research tasks, but also allows validation of the effectiveness of technologies such as the eco-valve under different operating conditions.

The designed device has a high degree of versatility, as it can be adapted to various applications where signal recording is required. Its only limitation is that the recorded signals must be within the range of 0 to 5V, which makes it suitable for a wide variety of sensors in automotive and other systems. This aspect underlines its potential to be used in future projects focusing on engine optimisation and monitoring of similar devices.

Disclosures

Conflict of interest

The authors declare that they have no conflicts of interest. They have no known competing financial interests or personal relationships that might have appeared to influence the article reported in this paper.

Authors' contribution

The contribution of each researcher in each of the points developed in this research, are:

Durán-Fonseca, Miguel-Ángel: He contributed with the revision of the prototype design, experimental tests, analysis of results and the integration of the final document.

Charre-Ibarra, Saida: Contributed with the central idea of the project, design of the prototype and coordinated the work of the members.

Murgan-Ibañez, Jorge: Built the prototype, developed the mobile application and participated in the experimental tests.

Gudiño-Lau, Jorge: Contributed with the programming of the microcontroller and data analysis.

Availability of data and materials

For more information on project data and materials contact scharre@ucol.mx

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Abbreviations

CSV	Comma-Separated Values (valores separados por comas)
MAP	Manifold Absolute Pressure (Manifold Absolute Pressure)
RPM	Revolutions Per Minute
SD	Secure Digital
USB	Universal Serial Bus

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