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DATA ACQUISITION SYSTEM FOR VEHICLE ENGINE SENSORS: A REVIEW

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Abstract
Monitoring the operation of car engines using a smartphone and cloud services is a concept that falls within the field of intelligent vehicle technologies. Using information collection system, vehicle fleet companies can effectively manage the usage of their vehicles, minimizing investment and maintenance costs, preventing accidents and failures, identifying poor driving behaviour among employees, and reducing expenses associated with fuel, tires, and other resources. This approach involves collecting real-time data from the vehicle engine sensors, transferring data to the cloud via a smartphone, and then using cloud services to analyse and manage the information, making it understandable in a simple way. This review reflects on the working efficiency of internal combustion engines and the reduction of pollution to the environment, also gathers existing literature to gain insights into vehicle sensor data acquisition technology and systems in the automotive industry identifying gaps in current knowledge and provide a conceptual framework for next practical research in this field. After explaining the general idea of logistics tasks in technology development, various sensors and their methods are associated with engine properties are introduced. The research results show that most articles are about data acquisition systems from different systems. They can provide convenience and flexibility for users, allowing them to easily access and adjust settings on-the-go, enabling real-time monitoring and adjustment of engine performance, helping users optimize efficiency and performance based on their specific needs and preferences.
Key words: data acquisition systems, intelligent vehicle technologies, engine data collection.

Introduction

The continuous evolution and advancements in the automotive industry have propelled the sector forward, leading to improved safety standards, innovative technologies. Each decade brings new opportunities and challenges that drive the industry towards a future that prioritizes efficient, safe, and eco-friendly transportation solutions.

Every industrial processing system, factory, piece of equipment, testing ground, and automobile is made up of computer software and hardware that behaves in accordance with the known laws of physics. These systems are not steady state; instead, they are made up of thousands of mechanical and electrical phenomena that are always changing. A system's ability to operate correctly is contingent upon specific temporal events and variable parameters. Most variables need to be measured using a tool, like a visual display, that transforms the phenomenon into a form that humans can understand. Effective vehicle data collection is crucial for improving safety, efficiency, and overall performance in the automotive industry. It also plays a role in the development and implementation of emerging technologies such as autonomous vehicles and smart transportation systems (Oladimeji *et al.*, 2023). Sensors in cars help drivers find problems with their car and prevent damage from happening. It can also display alerts for drivers and a reporting feature for remote diagnosis (Abdelhamid, Hassanein, & Takahara, 2014). They are essential for maintaining optimal engine performance, improving fuel efficiency, and addressing potential problems before they lead to more significant issues. Diagnostic tools and technologies continue to play a crucial role in modern automotive maintenance and repair. To overcome the limitations of existing communication technologies and create an efficient cooperative network for large-scale vehicular networks, alternative solutions need to be explored.

This may involve developing communication protocols specifically designed to handle the strong mobility impact and implementing cost-effective solutions that are suitable for vehicular environments. The in-vehicle controller area network (CAN) bus is a standardized serial communication protocol widely used in automobile internal control systems (Johansson, Törngren, & Nielsen, 2005). The integration of electronic devices in automobiles has significantly enhanced the driving experience by providing convenience, safety, and entertainment features. These advanced driving aids ensure better control over the vehicle and improved connectivity with external devices (Miller & Vasalek, 2013). The original point-to-point interconnection method was initially used, but the number of sensors and controllers in the vehicle has rapidly increased, making installation and maintenance more expensive.

To optimize fuel efficiency and reduce greenhouse gas emissions, drivers can adopt several strategies by driving at a steady speed, avoiding unnecessary idling. By maintaining an optimal temperature range, the turbocharger compressor can function efficiently, enhancing overall engine performance (Olabi, Maizak, & Wilberforce, 2020). Under the anticipated Euro 7/VII standards, vehicle emissions are deemed to be generated by a singular, integrated system, with tailpipe emissions generally understood to be below the limit, irrespective of the technology package the powertrain comprises (Müller *et al.*, 2022).

In order to find out the operation of the applied systems and the role of sensors in it, as well as to identify the characteristic problems for the further experimental research, the compilation of the results of different studies was carried out.

Materials and Methods

The study gathers existing literature to gain insights into vehicle sensor data acquisition technology in the automotive industry. By analysing the information available, the study will help identify gaps in current knowledge and provide a conceptual framework for researchers to explore new directions and opportunities in this field. The information that was published between 2005 and 2024 consisted of 40 full-text research articles and databases. Several keywords such as data acquisition systems, intelligent vehicle technologies, engine data collection were used.

Results and Discussion

Selecting the parameters to monitor is a crucial decision in any research related to vehicle engine performance, as it directly influences the quality and relevance of the data collected. Parameters includes selected vehicle engine sensors, data acquisition hardware such as an OBD dongle, low-power devices, cloud-based data transfer and displaying all information on a smartphone application for easy access and monitoring. Parameters during the operation of a vehicle engine allows for data collection, analysis, and optimization.

Sensors

Oxygen proportion in exhaust gases. Maintaining the ideal ratio is essential as it affects various aspects such as engine performance, emissions, consumption, and the lifespan of the catalytic converter. By preventing issues like engine pinging and knocking ideal ratio ensures optimal engine functioning and reduces harmful emissions.

Engine coolant temperature is measured by the Engine Coolant Temperature (ECT) sensor. It sends a signal to the engine control module, which activates other components to maintain proper operating temperature. The lambda sensor, on the other hand, takes over and measures the oxygen in the exhaust gases to help regulate the fuel mixture for ideal combustion once the engine reaches operating temperature. This is important because the engine`s temperature plays a crucial role in preventing overheating, which can negatively impact the engine`s lifespan and increase of emissions.

The vehicle speed is measured by Vehicle Speed sensor (VSS). Usually, it is installed on the output shaft of the gearbox. It measures the speed of the vehicle and sends this information to the engine control unit (ECU), where the gathered data on the speed of the vehicle is calculated to parameters like fuel injection timing, transmission shift points, and ABS activation. This information helps optimize fuel consumption and reduce emissions by determining the relationship between vehicle speed and fuel consumption.

The *air flow* is measured by the Mass Air Flow (MAF) sensor. A malfunctioning MAF sensor can lead to a decrease in engine efficiency and performance. It can cause the engine to run rich at idle, meaning it will use more fuel than necessary. This can result in poor fuel efficiency and increased emissions.

The *ignition pickup* sensor plays a vital role in the ignition system by accurately detecting the distributor's shaftposition, allowing the engine control module to effectively manage ignition timing for optimal engine performance. Failing to address issues with this sensor can result in significant problems like engine misfires, stalling, and difficulty starting. Regular maintenance and timely replacement of faulty sensors are essential for smooth engine performance.

The *throttle position sensor* measuring the angle of the throttle plate or lever and transmitting this data to the ECU. By adjusting the throttle, the driver can control the speed and power output of the engine by regulating the amount of air and fuel mixture entering the combustion chambers. This mechanism is crucial for maintaining fuel efficiency and performance in gasoline engines. The proper air/fuel mixture is essential to the combustion process, which places strict demands on the accuracy of the throttle position sensor.

The *knock sensor* purpose is to detect engine knocking or pinging caused by improper combustion in the engine cylinder, which can lead to damage. By monitoring these vibrations and sending signals to the engine control unit, the knock sensor helps adjust ignition timing to prevent knocking and ensure smoother engine operation. Its placement on the engine block, cylinder head, or intake manifold allows it to effectively detect these vibrations and contribute to overall engine performance and longevity.

The *Manifold Absolute Pressure (MAP) Sensor* helps the engine control unit adjust the fuel injection volume based on the changing intake manifold vacuum levels at different engine speeds and loads. The engine control module uses this pressure reading to calculate the amount of fuel that needs to be fed to each cylinder and the timing of the ignition. By converting these vacuum variations into voltage signals, the MAP sensor ensures the correct fuel-air mixture for optimal engine performance.

The *Exhaust Gas Recirculation* (*EGR) position sensor* play crucial role in monitoring and controlling the exhaust gas recirculation process in a vehicle's engine and helps in determining the exact position of the EGR valve pintle. By accurately controlling the opening time and duty ratio of the valve, the system can efficiently manage the recirculation process to minimize emissions and enhance the engine's performance (Rimpas, Papadakis, & Samarakou, 2020).

Data collection and processing technologies

Many researchers have made significant efforts to analyze and collect various aspects of vehicular data. Some have focused on gathering data related to vehicle performance, such as fuel consumption and emissions (Olabi *et al.*, 2020). Some scientists from Israel and Australia (Grimberg, Botzer, & Musicant, 2020) reported a review on prospective technological advancements that could have more effects on the use of smartphones to research and improve road safety, while Guardiola *et al.* (2021) states that Determining in-service emissions at the vehicle and fleet levels appears to be a significant advancement for the upcoming

generation of vehicles thanks to a clever integration of embedded and cloud components. Also, there have been efforts to collect data on traffic patterns and congestion (Celesti *et al.*, 2018), data related to autonomous vehicles and their interactions with other vehicles and infrastructure (Zhou, Li, & Shen, 2019). Mesenger *et al*. (2017) presents the architecture, which adopts data mining techniques and neural networks.
Table 1 shows Kumar & Jain (2023) suggested approach which classifies driver behavior using machine learning techniques based on ten categories: fuel usage, braking patterns, steering stability, and velocity stability. Also, contrasted with commercial driver and automobile tracking programs Campos-Ferreira *et al*. (2023) is based on basic algorithms and makes use of traditional sensor measurements.
In 'Figure 1', Malekian *et al*. (2017) developed a comprehensive system for monitoring and analysing land vehicle fleets.
There are several different devices based on OBD-II and paired with adapters, allow users to access and monitor engine data directly from their connected software. It is important to carefully evaluate pros and cons, determine which one best fit the specific needs. These systems typically consist of hardware components for signal conditioning and analog-to-digital conversion, as well as software for data processing and visualization. The specific choice of system will depend on factors such as the number of sensors, type of data being collected, and required level of precision, speed, cost, scalability, ease of use, and integration capabilities. Examples of a data acquisition systems for acquiring data from a sensor array are described below.

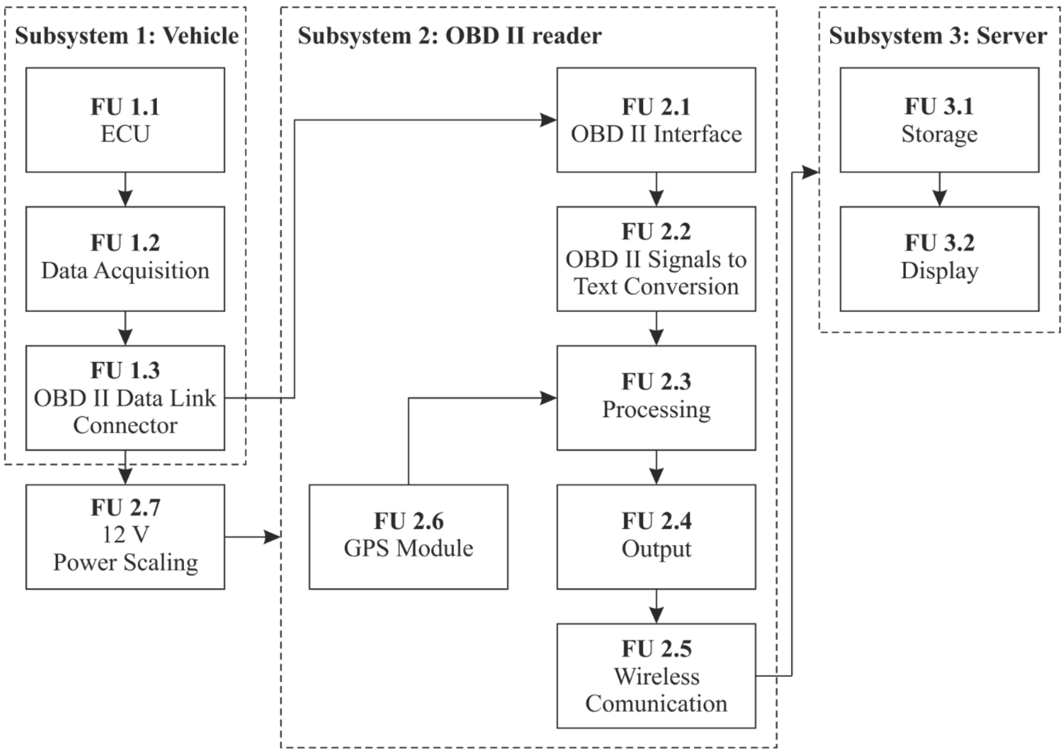

Figure 1. The subsystem functional units.

On OBD-II based data acquisition
On-board computers in modern cars only provide the driver with specific information. Most of the data is only accessible from specialized service stations. This highlights the complexity of decoding the messages sent by vehicles, as manufacturers often utilize their own unique encoding schemes that may differ between vehicle models. This variability adds an extra layer of challenge for those looking to interpret and understand the data transmitted by vehicles (Balakrishna, Thirumaran, & Solanki, 2018).
OBD-II modules are commonly used in monitoring tools to access data from the ECU of vehicles. By tapping into the vehicle's onboard computer system, these modules can provide real-time information on various vehicle parameters like speed, engine RPM, fuel consumption. This technology allows for consistent and reliable collection of information for analysis and diagnostics. The OBD interface acts as a crucial point to accessing vehicle sensor data by offering a standardized means of communication and discovery for various sensor readings. By providing a common platform for accessing information in a uniform format, it streamlines the process of extracting specific data points and facilitates compatibility across different vehicle models (Silva *et al*., 2018).
Overall, OBD-II system serves as a gateway to the Controller Area Network (CAN) within a vehicle, providing access to limited data from various sensors. These sensors transmit messages with their current measurements over the CAN, but the information is often encoded in a manufacturer-specific format that may differ

between vehicle models (Matesanz *et al*., 2021).

Reininger *et al*. (2015) was one of the first who introduced a vehicle data collection system using an OBD-II dongle. Aljaafreh *et al*. (2011) presents a system that collects information about cars and uses OBD, GPS, and Wi-Fi to manage them automatically. Moreover, researchers present to optimize route planning for taxi drivers using OBD-II that would minimize fuel consumption and decrease vehicle emissions (Ding *et al*., 2017). Higher level combinations of various data sources can also be achieved by combining data from smartphones and current telematics systems (Rehrl *et al*., 2018).

Matesanz *et al*. (2021) showcased the potential for modern mainstream cars to be transformed into a global sensor network through the deployment of software. Having sensors supplied from different producers with varying data-access channels can complicate data collection and integration processes. This achievement not only highlights the capabilities of current automotive technologies, but also suggests the scalability and adaptability for other automakers or operators with large sensor networks to take advantage of this technology.

Arduino data acquisition system

It`s an electronic platform that allows users to create projects by connecting various inputs and outputs. It offers a wide range of possibilities, from recording data to controlling motors or LEDs, and even connecting to the internet. The hardware and software are easy to use, making it accessible for both beginners and experienced users. Data acquisition is comparatively inexpensive, the software is open source, and programmers find it easy to work with the abundance of freely available online libraries. It also boasts excellent durability and dependability (Fuentes *et al*., 2014) even when used in harsh environments such as that of the vehicle. Additionally, Arduino boards provide an affordable and accurate means for users to learn measurement procedures, making it an excellent tool for training purposes (Vidal-Pardo & Pindado, 2018).

Authors of another study used Arduino to create an affordable, high-performing data acquisition system for dual-fuel engine research (Sinaga *et al*., 2019).

The Internet of Things (IoT) data acquisition system

It enables the connection between virtual and physical objects through intelligent devices, allowing for communication and actuation capabilities (Paudel & Neupane, 2021). The IoT consists of various objects that offer specific information, data, or services: from basic devices like digital cameras to more comprehensive entities like our homes, offices, daily surroundings, or vehicles (Kim, Oh, & Kang, 2017).

The utilization of data collected in real time from various electronic devices within vehicles and infrastructures has become crucial in analysing and understanding the dynamics of traffic, infrastructure operation, and overall system performance. By tapping into this data through advanced information and expert systems, organizations can make informed decisions, optimize operations, and improve safety and efficiency in the transportation sector (Ang *et al*., 2019).

Pourrahmani *et al*. (2022) states that each object within the IoT ecosystem serves to provide its unique set of functionalities and capabilities In order to help the car navigate more quickly, the developed IoT system can gather a variety of data using the most precise sensor devices (Prinsloo & Malekian, 2016), traffic monitoring (Celesti *et al*., 2018), but Brous *et al*. (2020) approaches the issue of IoT adoption in different domains, namely water management and road management.

Rasberry Pi data acquisition system

The Raspberry Pi is a single-board computer and runs on the Linux operating system. It serves as a central controller for various data sources, collecting data from sensors through a Python script. The results confirm that the performance of developed system is comparable to some higher-priced and less portable data acquisition systems (Ambrož, 2017). Also, data can be stored in a MySQL database, reducing memory usage, and improving reliability (Andria *et al*., 2016). Aciti *et al*. (2018) described as a prototype vehicle data capture and monitoring system that enables the user to observe the on-board system and get the vehicle`s geolocation via GPS-enabled satellite monitoring. It appears that the system integrates a software component with a vehicle platform to collect sensor readings, which can be transmitted in real-time or as trip records with specific consistency guarantees in recorded files. This setup allows for access to acquired data through a cloud platform, enabling efficient data management and analysis for various automotive applications.

Influencing factors and future perspectives

Cyberattacks on the in-car network and dongle exploitation pose a threat to OBD-II ports. As they permit the gathering of diagnostic data, access to the in-car network, and the installation of malware, OBD-II ports are vulnerable points in automotive security. El-Rewini *et al*. (2020) review a valuable insight into the various attacks and threats targeting the communication layer, along with effective countermeasures to mitigate these risks.

Additionally, the scanners or applications can access a wealth of information, ranging from engine performance metrics to emission levels. In the case of a vehicle, locating and modifying a dependable power source can present challenges (Aciti, Urraco, & Todorovich, 2018).

Sensors presents a significant challenge as it leads to limited power availability from energy sources. This constraint requires a careful balance between sensor size, energy consumption, and overall system efficiency. To successfully overcome this challenge, researchers and developers need to explore innovative approaches to power management and energy harvesting techniques to ensure effective and sustainable operation of these sensors in various applications (Raj & Steingard, 2018).

Table 1

Summary of selected studies with data acquisition type, the indices, results

Authors	The goal	Applications/Devices/Techniques	Indices	Results obtained
(Kumar & Jain, 2023)	To assess the performance of a platform that was receiving actual data streams from moving vehicles	Machine learning techniques (SVM, AdaBoost, Random Forest)	• Fuel consumption • Steering balance • Velocity balance • Breaking archetypes	99%, 99%, and 100% of 3 different models with associated learning algorithms
(Reininger *et al.*, 2015)	To create a prototype for a mobile computing platform that enables users of smartphones and tablets to access vehicle sensors	ELM327 WiFi Smartphone Sensor	• Fuel consumption • Engine RPM • GPS location • Speed	Driving behaviour analysis can benefit from the use of data collection and visualization tools
(Osman & Massoud, 2013)	To construct a customizable, low-cost DAS with sensors, an analog to digital card, and an acquisition and processing software package	A/D boards and RS232 devices	• Pressure of the cylinder • Cylinder block vibration • Temperature of oil, inlet and outlet water • Crank angle • Engine`s RPM	After processing the collected data, the system calculates the average cycle over the course of the four strokes as a function of a synchronized crank angle
(Andria *et al.*, 2016)	To make a low-cost acquisition platform to gather information about vehicles that can be used for things like tracking drivers, managing vehicles, and finding problems.	Raspberry Pi, IMU, ELM327 device, GPS receiver	• Vehicle speed • Engine RPM • Vehicle acceleration	Showed two clearly distinct behaviours, which can influence fuel consumption, car reliability and more generally, driving security
(Malekian *et al.*, 2017)	To track and analyze vehicles by measuring their distance traveled, speed, and fuel consumption	ELM327 integrated circuit Interface protocols (CAN, ISO) Wireless communication module GPS tracking	• Speed • Mass air flow (MAF) • Distance • Fuel consumption	The system can successfully process, send, and display the readings in addition to reading a variety of parameters
(Campos-Ferreira *et al.*, 2023)	To display in real time the relationships between fuel consumption, exhaust-gas emissions, driving style, and driver health	A biometric wristband, a smartphone, and an on-board diagnostic connector	• Polluting emissions • Fuel economy • Driving behaviour • The health of the driver	The index of fuel consumption 84%, the emissions of pollutants 89%, and the driving style 89%; there are findings about the relationship between the driver`s heart and traffic conditions
(Bedretchuk *et al.*, 2023)	To develop an intelligent, low-cost, IoT-based system for gathering vehicle data while conducting on-road testing	A low-cost acquisition hardware with an IoT server artificial intelligence (AI) algorithms	• Uploaded data • Update rate • Engine speed • Vehicle speed • Vehicle consumption	System delivers data performance rate at 13 times cheaper; hardware processes and updates the server with all collected data at a rate of 330 kB s^{-1}

The order of the characteristics in Table 1 would affect whether or not data collection methods are appropriate for use as research instruments in various fields. Affiliation with applications (2nd attribute in the table) and indices (e.g., engine parameters and use of data), would be crucial in the researcher`s selection of the effective data acquisition method. Depending on the study, researchers may find many more implications beyond those listed in Table 1, such as cost implications, independent battery, and storage capacity.

However, in terms in ecological solutions, embracing sustainable practices in data analysis and monitoring can lead to significant reductions in carbon emissions and resource consumption, contributing to a greener automotive industry. Implementing extensions such as capturing more metrics of the vehicle engine, like vehicle wear, average fuel consumption, and reduction of exhaust-gas emissions.

At least some storage capacity is essential to ensure that all gathered data is captured and retained for analysis and future reference. Without this capability, valuable information may be lost or inaccessible, potentially impacting the overall success and reliability of the data acquisition process.

The lack of emphasis on the data-collection process in existing papers might be due to researchers prioritizing the application and functionality arising from data acquisition. Consequently, scientists typically choose for logging and uploading data when Wi-Fi is accessible (Pese, Ganesan, & Shin, 2017). To achieve seamless connectivity, it is crucial for technology to make significant advancements in terms of speed and computational capabilities, as well as ensuring a highly reliable connection. This will allow for easy integration of vehicles with any devices, providing users with a smooth and efficient experience (Apostolos Papathanassiou & Khoryaev, 2017).

In general, it is necessary to consider various types of problems in the operation of the previously discussed systems and cooperation with sensors. For example, the system power could shut down during vehicle engine turning based on loss of wireless communication and GPS location tracking.

A primary advantage of remote diagnostics, is that the expert can react immediately to measurement results, conduct additional measurements, modify parameters, and address actuators. By monitoring vehicle engine key metrics and making necessary adjustments, users can ensure that their engine operates at peak performance levels, ultimately saving time and resources. This access capability also illustrates the significant difference between remote diagnostics and the approach of using a logger or on-board tester. By embracing advanced technologies such as cloud storage and data analysis, can gain a competitive edge by harnessing real-time insights from engine data. This proactive approach not only enhances operational efficiency and maintenance practices, but also can be used from private practices to large scale fleet demands for their sensor readings and strengthens customer engagement through the delivery of valuable information using user-friendly smartphone applications. After consolidating these researches, it comes down to development an efficient and user-friendly application for data acquisition that can be easily installed, readable and self-sufficient.

Conclusions

1. Advances in technology over the last decade have made it possible to significantly improve engine control and management, introducing major innovations such as remote diagnostics and cloud storage.
2. The wide range of sensors allows obtaining a valuable amount of information, but there are significant gaps, for instance, it is possible for different manufacturers to supply the sensors themselves with different data-access channels.
3. Data collection and processing technologies still face certain challenges as lack of standardization, data security and storage.
4. During creation of own system, attention should be paid to the analysed engine signals, data transfer to the cloud and creation of smartphone application, which is also confirmed by various researchers in the development and testing of their own systems.
5. Predicting future technology development in the context of the development of your own system, it would be necessary to pay additional attention to enabling real-time remote control capabilities for engine sensors in addition to only monitoring them.

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