MICRO-SENSORS USE FOR INDOOR AIR QUALITY MONITORING IN PRIVATE VEHICLE CABINS

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Indoor pollution in cars and vehicles include volatile organic compounds, particulate matter, carbon monoxide, carbon dioxide, nitrogen oxides, formaldehyde, cigarette smoke, airborne bacteria etc. This paper presents the development and implementation of a system based on a microprocessor, to which specialized miniature and pre-calibrated sensors are connected. The purpose of these sensors is to measure in real time indoor air quality parameters inside vehicle cabins. The study demonstrated the effectiveness of an integrated vehicle cabin air quality monitoring system, based on microprocessors and pre-calibrated sensors, capable of measuring relevant pollution parameters. The collected data provide opportunities for optimizing ventilation strategies and improving the efficiency of air filtration, while also opening the way to the integration of artificial intelligence algorithms for air quality forecasting in vehicles. The data obtained are stored in a database, allowing later their optimization.

Keywords: air, comfort, data, health, microprocessor, monitoring.

1. Introduction

This paper presents the design and implementation of a real-time vehicle indoor air quality monitoring system. Its purpose is to provide a detailed picture of polluting elements to better understand the degree of people exposure and mode of transport. In the framework of the current study, micro-sensors were selected as the technical answer over the traditional, gravimetric method for measuring pollution levels to create an overview of the air quality inside automobiles. To estimate the mass of particles in the air, Particulate Matter (PM) is collected on a filter and weighed both before and after sampling. This process is known as the gravimetric

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method. The gravimetric approach to air PM monitoring has the primary disadvantage of being labor- and time-intensive.

The proposed system is based on a microprocessor from the ESP family, to which are connected the specialized miniature and pre-calibrated sensors (SPG40, PMS5003, MICS5524 and SCD30), which measure various air parameters, including temperature, humidity, concentration of volatile organic compounds (VOC), fine particles (PM2.5, PM10), carbon monoxide (CO) and carbon dioxide (CO_2). The data achieved by using the proposed system is stored in a database, allowing further analysis with a role in optimizing the environmental conditions inside the vehicle and can be used in the development of local, national or global policies with the aim of reducing the people exposure to indoor air pollution inside of their cars [1].

The way transport develops in society reflects our changing world. With mobility data acquired from urban environments from all continents, one can capture how people, goods and ideas move globally [2], [3]. Thus, information from data interpretation support the transportation sector to become day by day more viable, sustainable and efficient [4], [5].

The current research describes a study that was undertaken to monitor the air quality inside cars by employing an integrated system with microprocessors.

2. Development of the real-time vehicle air quality monitoring system

In the framework of the development of the real-time vehicle indoor air quality monitoring system, the realisation of three main components was foreseen:

- the development of an integrated system that uses a microprocessor from the Expressif System Processor;
- integration of miniature and pre-calibrated sensors (SPG40, PMS5003, MICS5524 and SCD30) for measuring different air quality parameters;
- implementation of a data storage mechanism in a database.

Each component is described in the following paragraphs.

2.1. *Development of the integrated system*

The integrated system is a high-performance microprocessor with Wi-Fi module interconnection capabilities, ideal for Internet of Things (IoT) applications, that uses a microprocessor from the Expressif System Processor (ESP) family [6] for monitoring the indoor air quality of the vehicles.

This microprocessor was selected for this investigation because of its adaptability to a range of communication protocols. This microprocessor has a robust and reliable design and is capable of operating in industrial area, with an operating temperature (between –40°C and +125°C). The internal power supply is made by advanced calibration circuits, able to dynamically eliminate external circuit imperfections and adapt to changes in external conditions. The microprocessor also includes state-of-the-art features such as high-precision clocking, various internal power modes, and dynamic power scaling.

2.2. *Pre-calibrated sensors*

The sensors that were integrated are SPG40 [7], PMS5003 [8], MICS5524 [9] and SCD30 [10], these sensors being used for measuring volatile organic compounds, fine particles, temperature, humidity, carbon monoxide and carbon dioxide, colorless and odorless hazardous gas resulting from incomplete combustion of fuels, mechanical, magnetic or even chemical changes.

These sensors are offering accurate and stable monitoring of indoor air quality [11], [12]. The power module can supply the system with the voltages necessary for its operation using the 12V or 24V source of the car in which the air quality monitoring is carried out. Thus, it is integrated on the main board of the system ensuring the working voltages of 3.3V and 5V necessary for the operation of the equipment. This device is available with fixed outputs with voltages of 3.3 V, 5 V, 12 V or adjustable output variant [13].

The electronic design of the whole system was done using the program EAGLE [14] which is a scriptable electronic design automation application with schematic capture, printed circuit board layout, automatic router and computer-aided manufacturing features.

The power supply module designed in EAGLE was physically integrated on the same printed circuit board as the ESP microprocessor module (Figure 1) and the sensor connections, becoming the main board of the whole equipment.

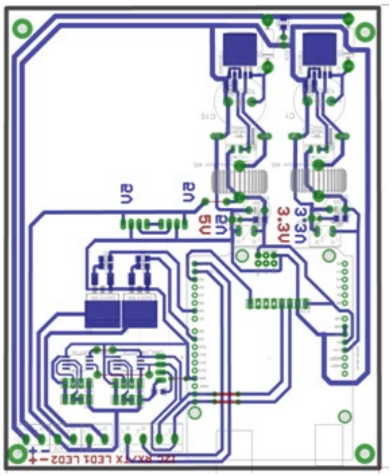

Fig. 1. The printed circuit board of the system

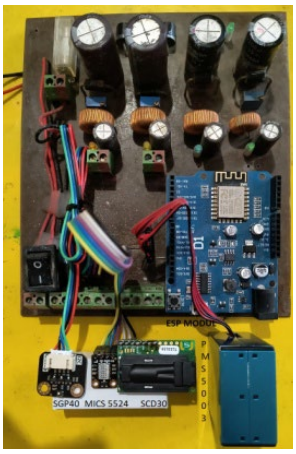

Fig. 2. Final configuration ESP module motherboard and sensors

2.3. *Implementation of a data storage mechanism in a database*

The system was designed to integrate all these sensors with the microprocessor of the ESP family, which manages the collection of data, their processing and their transmission to a centralized database. In this way, further analysis of the measured parameters is allowed. Communication between the sensors and the microprocessor is carried out through the two protocols (I_2C-Inter-Integrated Circuit is a communication protocol which uses clock signals to help synchronize the data being read or transmitted by the devices and UART- for implementing asynchronous serial data streams for point to point connection and includes no clock signal), thus ensuring an efficient and reliable interfacing (Figure 2).

The software developed for it was written in C/C++ using the Arduino IDE platform, being facilitated in this way the access to a vast library of resources, examples and libraries specific to each sensor. The code is structured on modules that manage the initialization of the sensors, the collection of data, as well as their storage in a database on an internal memory. For data storage, memory was used, which allows efficient storage of large volumes of data and quick access for further analysis. The database structure was designed to store information about each measured parameter, synchronized with the collection times.

Data collection can also be done through the serial communication of the microprocessor preset at 9600 baud (where baud rate is the measure of the number of changes to the signal/per second that propagate through a transmission medium) [15], through the program CoolTermWin64Bit (Figure 3) [16].

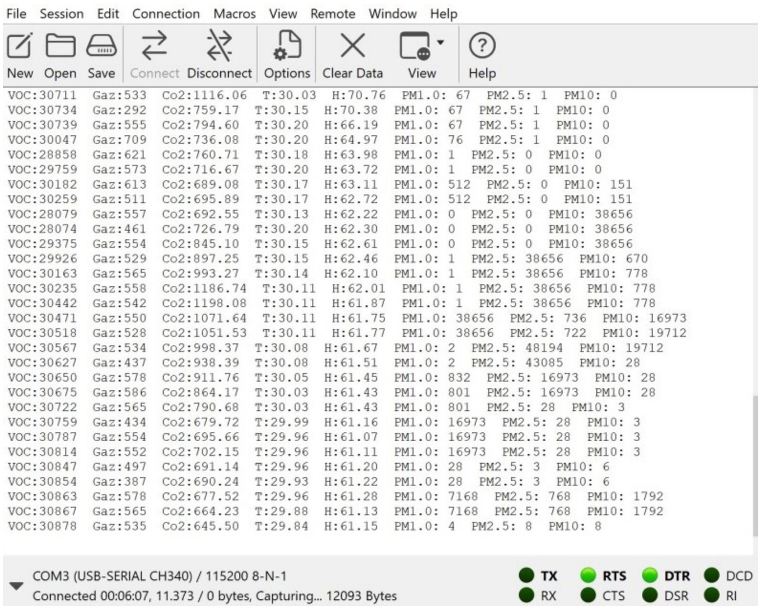

Fig. 3. Screenshot with the obtained data

Data evidencing the values of the monitored parameters can be illustrated as graphs (Figure 4), for a better visualization and interpretation of the achieved information.

Fig. 4. Screenshot of the generated graph

3. Evaluation of the performance of the system in real conditions

For the evaluation of the performance of the system in real conditions and to determine its effectiveness in monitoring the air quality inside vehicles and mode of transport, the system was tested under real conditions. The tests were developed inside a vehicle in daily traffic and demonstrated an excellent ability to monitor air quality variations in real time. The data collected revealed significant fluctuations in VOC, fine particulate and CO concentrations depending on external conditions and activities inside the vehicle. Further analysis of the data allowed the identification of key factors affecting air quality, thus providing opportunities for improving ventilation and air filtration inside the vehicle.

To evaluate the system performance and determine its effectiveness in monitoring indoor air quality and the mode of transport, it was tested under real-world conditions. The tests were conducted inside a vehicle in daily traffic, and the results of the study demonstrated an excellent ability of the proposed system to monitor air quality variations, with data collection focusing on key pollutants such as VOCs, fine particulate matter (PM) and CO concentrations. The validity of the results obtained by the proposed system configuration was further supported by a comparative evaluation against certified standard equipment, as performed in the reference study [17], [18]. This cross-analysis confirmed the reliability of the microprocessor-sensor system, strengthening its applicability in terrestrial, maritime and private vehicle cabin environments. Further analysis of the collected data will allow the identification of major influencing factors on indoor air quality, providing opportunities to improve ventilation strategies and air filtration efficiency inside the vehicle.

4. Results and interpretations

During data collection, there were situations where for no apparent reason, the equipment would freeze, data acquisition being stopped. Everything was back to normal after a simple system reset! Analyzing the situation, everything was attributed to a software programming error, but it turned out not to be the case. After thoroughly studying the documentation of the ESP microprocessor, the internal fuses were set according to the requirements, and the file was loaded into the microprocessor with the ESP tool program after converting it from INO-file to HEX-file. Performing these operations brought everything back to normal.

The continued data collection provided by this system over a longer period of the order of years will allow their integration into an artificial intelligence (AI) system.

The implemented algorithm will consider, in addition to the already existing data, the sequence of seasons, the external atmospheric conditions, thus contributing to the accuracy of the predictions offered by the AI algorithm.

To analyze and forecast the air quality in the vehicle in the future, a hybrid deep learning model combining Convolutional Neural Networks (CNN) with Long Short-Term Memory Networks (LSTM) is to be developed [19]. This model, CNN could be used to extract relevant features from external data provided by an external device, such as outdoor air quality and weather conditions. Simultaneously, LSTM can be used to capture temporal relationships between data, such as the succession of seasons and daily variations in external air quality.

The integration of this information obtained in the management of the HVAC systems of cars and mode of transport will bring a definite improvement in the air quality inside the vehicles, doubled by an efficiency of energy consumption by replacing the control type method by threshold reached, by an intelligent predicted one by the AI algorithm.

5. Conclusions

In the future, it is desired to complete the project by implementing artificial intelligence algorithms with the aim of predicting the air quality, followed by the integration with the automatic ventilation systems of the vehicle with the aim of improving the air quality inside it but also optimizing the energy performance of the system.

This algorithm will consider the number of passengers in the vehicle, the time of year and day, the external atmospheric conditions, the route on which the journey is made, all this data will improve the air quality inside the vehicle.

The results obtained in the framework of the current research require additional costs for their processing in specialized laboratories.

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