ONLINE EXHAUST MONITORING SYSTEMS IN IC ENGINES

[1]Dr.S.P. Venkatesan, [2]K L V Prasad, [3]P Siddardha raj
[1]Associate professor, [2]Student, [3]Student
1School of Mechanical engineering,

Abstract: The rapid growth in the usage of two-wheeled vehicles in urban metropolises has necessitated the need for highly efficient emission monitoring systems to address increasing environmental concerns and regulatory standards. This has led to the development of portable, self-contained exhaust monitoring systems that are capable of running on their own with minimum dependency on external infrastructure or cloud services. This extensive review presents the state of the art in portable exhaust monitoring systems for motorcycles, scooters, and other two-wheeled motorbikes that incorporate present advancements in embedded sensing technologies, local data processing architectures, direct wireless communication protocols, and integrated user interface design through the systematic review of peer-reviewed publications, technical reports, and industry standards in the period**.**

I. INTRODUCTION

1.1 Background and Context

The global transport industry is a major cause of air pollution, responsible for about “24% “of CO2 emissions from energy use. This makes cities less sustainable. Motorcycles, scooters and mopeds are two-wheeled vehicles that have grown quickly, especially in developing areas like Asia, Africa and Latin America. This is because they are cheap, use less gas and are easy to use in crowded cities. Urbanisation and economic growth drove the industry from 58 million units in 2015 to more than 132 million in 2024, with predictions of 155 million by 2030.

Two-wheelers have higher emissions per unit of fuel than cars, even though their engines are smaller. This is because their controls are less advanced and the rules are less strict. The EPA has found that motorcycles emit hydrocarbons 16 times, nitrogen oxides 3.1 times, and carbon monoxide 10 times more per kilometer than newer passenger cars. Two-stroke engines emit particles 20 to 50 times more. In places with a lot of people where two-wheelers make up 70–80% of all vehicles, they make the air and public health much worse.

II. LITERATURE REVIEW

2.1 Search Strategy

A thorough search of the literature was done in major academic and technical databases like IEEE Xplore, ScienceDirect, Scopus, Web of Science, Google Scholar, SAE International, and JSAE. Additional searches included government and regulatory databases like the US EPA's Office of Transportation and Air Quality, the European Commission Joint Research Centre, ARAI (India), NILIM (Japan), and NTIS.

The strategy used a combination of Boolean operators and controlled vocabulary to find studies that were relevant to portable exhaust monitoring for two-wheelers. Some of the main keywords were "portable emission* monitor*," "two-wheeler pollution," and "PEMS." Some of the secondary keywords were "electrochemical gas sensor*," "MOS sensor*," and "Bluetooth automotive." Som

the tertiary searches looked for rules using phrases like "BS-VI emission standard*," "OBD-II protocol*," and "real driving emission*."

III. BASICS OF MONITORING EXHAUST EMISSIONS

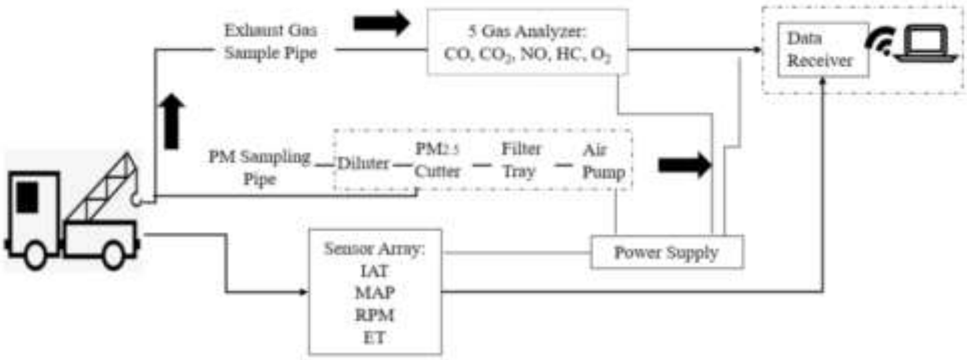

fig.1

3.1 Emission Traits of Two-Wheelers

Different kinds of pollutants "(CO, HC, NOx, PM)" Two-wheeled vehicles are widely used globally, especially in urban areas, and their exhaust is a significant source of air pollution. They let out carbon monoxide ("CO"), hydrocarbons ("HC"), nitrogen oxides ("Nox"), and particulate matter ('PM").

When fuel doesn't burn all the way, it makes carbon monoxide, a colorless, odorless, poisonous gas that binds to hemoglobin and makes it harder for oxygen to get to the body. This can cause headaches, dizziness, and even death. Hydrocarbons are parts of fuel that haven't burned or have only burned partially. They help make ozone at ground level, which makes breathing problems like asthma worse. When nitrogen and oxygen react at high temperatures, they make nitrogen oxides. These gases are reactive and make smog, acid rain, and lower the amount of ozone in the atmosphere. Particulate matter is made up of tiny solid or liquid particles in exhaust. "PM2.5" (particles smaller than "2.5" micrometers) are especially bad for you because they get deep into your lungs and bloodstream and cause heart and lung diseases.

3.2 Guidelines and Standards for Measurement

International Ways to Test Emissions International testing protocols use chassis dynamometers to measure vehicle emissions under controlled conditions. They do this by running two-wheelers through driving cycles that are like real traffic, such as city and highway driving. These cycles are set by standards like "NEDC", "WMTC", and "IDC". The pollutants that are tracked include "CO", "HC", "Nox", and "PM", as well as fuel use and "CO2" emissions. This gives a complete picture of how the environment is affected.

Standard Measurement Protocols Measurement protocols keep data consistent and comparable by controlling factors that affect emissions, such as temperature, humidity, and altitude. Constant volume sampling "(CVS)" collects exhaust gases in real time, which stops errors from happening when they are mixed. To keep accuracy, you need to calibrate regularly against standards that can be traced. International standards, such as "ISO 8178", make measurement practices the same all over the world.

IV. **MATERIALS AND METHODS**

4.1 Sensors that use chemicals and electricity

Table 1

Sensor Type	**Target Gases**	**Accuracy**	**Power Use**	**Cost**	**Lifespan**	**Calibration Needs**
Electrochemical	CO, NO_2, O_2	High	Low	Low	1–5 yrs	Frequent
NDIR	CO_2, CH_4	Very High	Medium	Medium	5–10 yrs	Minimal
MOS	NH_3, VOCs	Moderate	Medium	Low	2–3 yrs	Moderate
Optical (UV-VIS)	NOx, SO_2	Very High	High	High	5+ yrs	Complex

How They Work and How They Work

Electrochemical sensors find gases by using chemical reactions at electrodes in an electrolyte. Gas molecules go through a selective membrane to get to the working electrode. There, oxidation or reduction makes an electric current that is directly related to the amount of gas present. The materials used for electrodes and electrolytes determine how selective they are for gases like CO, NO_2, and O_2.

4.2 Sensors that don't spread infrared light (NDIR)

A Look at the Technology and How It Works

NDIR sensors find gases by measuring how much IR light is absorbed at certain wavelengths. IR goes through gas in a chamber to a filtered detector. The Beer-Lambert law says that absorption is related to concentration. This is true for CO_2, CO, and CH_4.

Issues with Selectivity and Interference

Cross-sensitivity happens when two absorption bands, like CO_2 and water vapour, overlap. Particulates scatter IR, which makes noise. Filtering out moisture, detecting multiple wavelengths, and making algorithmic corrections all help to cut down on interference.

V. SYSTEMS FOR GETTING AND PROCESSING DATA

Table 2

Platform	Processing Power	Power Efficiency	Sensor Compatibility	Cost	Use Case
Arduino	Low	Very High	High	Low	Prototyping
Raspberry Pi	High	Medium	Very High	Medium	Research/Cloud
ARM Cortex-M	Medium	High	High	Medium	Real-Time Embedded

5.1 Platforms for Microcontrollers and Processors

Systems Based on Arduino boards are popular for small data acquisition because they are easy to use, have a large user community, and work with a wide range of sensors. Arduinos process analogue signals with Atmel "AVR" chips that have "ADCs". They also support quick prototyping through open-source "IDEs". Their small size and low cost make them good for monitoring the exhaust of portable two-wheelers, but their limited memory and processing power make it hard to do complex real-time or machine learning tasks.

VI. COMMUNICATION AND USER INTERFACE TECHNOLOGIES

6.1 Systems for Showing Dashboards

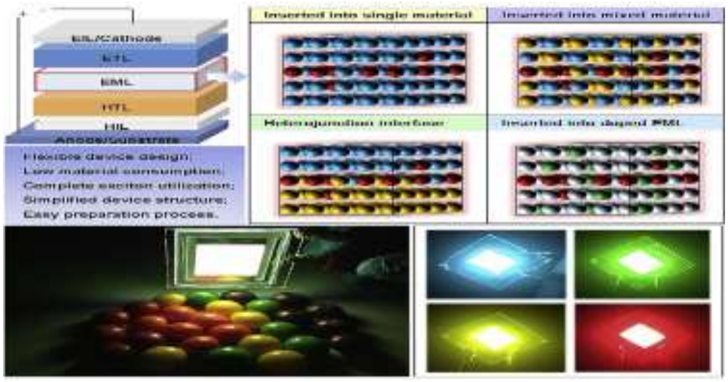

fig.2

Systems with LED Lights

LED (Light Emitting Diode) lights are one of the easiest and cheapest ways to let riders know what's going on with the engine or exhaust at a glance on the dashboard. LEDs use colors to show different states, such as normal operation (green), warnings (yellow), and critical alerts (red). They don't use much power, last a long time, and are very bright, so you can see them in many different lighting conditions. LED indicators aren't very good at showing small or detailed information, so they're better for simple alert systems than for showing detailed emission data.

Technologies for LCD and OLED Screens Liquid Crystal Displays (LCDs) and Organic Light Emitting Diode (OLED) displays are now common in dashboard systems because they can show a lot of visual information clearly. LCDs are cheaper, use less energy, and are easy to read in different kinds of light, especially when they are backlit. OLED displays are usually more expensive, but they have better contrast, wider viewing angles, faster response times, and deeper blacks. This makes them easier to see in both bright sunlight and darkness. These screens can show riders complicated graphical data like emission levels, real-time diagnostics, and historical trends, which keeps them informed. Some LCD and OLED modules can also have touch capabilities, which let users change settings and get alerts through the user interface.

Putting together the Heads-Up Display (HUD)

6.2 Rules for Wireless Communication

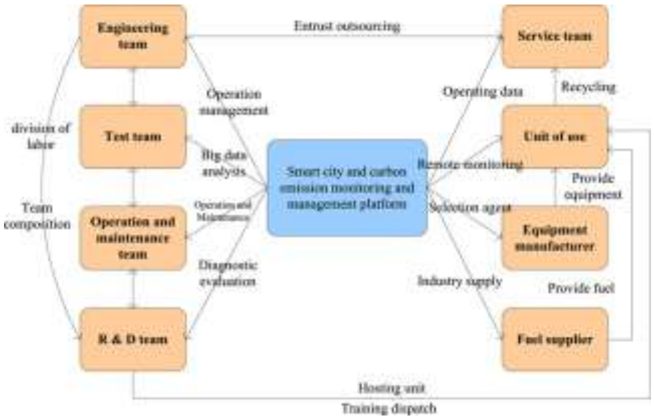

fig.3

Bluetooth technology lets exhaust monitoring sensors send data wirelessly to user interfaces like smartphones or displays built into cars. Bluetooth Classic (BR/EDR) has a higher bandwidth, which means it can send a lot of data all at once and in real time. However, it also uses more power. It works well for programs that need a lot of data quickly, but not so well for small devices that run on batteries and don't have a lot of power. This makes it great for portable exhaust monitoring systems that only need to send data updates every once in a while. BLE makes it simple to find devices, connect to them, and use a lot of different kinds of devices. The choice of protocol depends on the needs of the system design and the trade-offs between data rate, energy use, and range.

Table 3

Protocol	Range	Bandwidth	Power Use	Ideal Use Case
BLE	~10 m	Low	Very Low	Mobile App Sync
Wi-Fi	~50 m	High	High	Cloud Upload
Cellular	Global	High	Medium	Fleet Monitoring

Issues with Wi-Fi Setup

Wi-Fi is great for exhaust monitoring systems because it can send a lot of data quickly and connect to the internet. But it has some problems, like needing more power, taking up more space on hardware, and needing a stable network. Wi-Fi might not always be available or work well on two-wheelers, especially in remote areas. This can make data less reliable. Security concerns necessitate robust encryption and authentication methods to safeguard sensitive emission data. Also, Wi-Fi might not be used as much in setups that care about costs or power because it is hard to set up and costs a lot.

VII. PROTOTYPE

7.1 3D Modeling and Printing

The initial prototype design was done using computer-aided design software. In this software, all the parts were designed with specific dimensions. After completion of the design, it was fabricated using 3D printing technology with PLA material. PLA is used because it is easy to print with and is cost-effective. In addition, it has enough strength for a prototype. This printing technology enabled the actualization of the designed prototype with precision. This allowed for quick production

fig.4

7.2 Assembly of Components

After the fabrication, the individual parts were assembled to form the final prototype. Proper alignment and fastening techniques were used to ensure the stability of the structure and the integration of the functions. The design also enabled the direct fastening of the parts by the use of screws, thus avoiding the need for fastening parts such as nuts and bolts in the assembly process.

fig.5

VIII. RESULTS

8.1 Experimental Setup

The developed prototype was tested on a two-wheeler at controlled conditions of operation. The exhaust monitoring system was placed near the exhaust outlet to collect data regarding exhaust emissions in real time. Data was collected at different states of operation of the engine, namely idle state, moderate acceleration state, and high acceleration state.

8.2 Observed emission readings in 2 stroke petrol engines

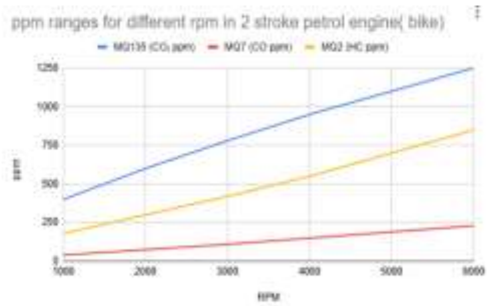

fig.6

The graph represents the variation of exhaust emissions (in ppm) with respect to engine speed (RPM) in a **2-stroke petrol engine**. The sensors used include "**MQ135" ("CO" detection), "MQ7" ("CO" detection), and "MQ2" ("HC" detection)**.

As the engine speed increases from **1000 RPM to 6000 RPM**, a significant rise in emission levels is observed:

- **"MQ135" ("CO" ppm):**
  - 1000 RPM → ~400 ppm
  - 2000 RPM → ~600 ppm
  - 4000 RPM → ~950 ppm
  - 6000 RPM → ~1250 ppm
- **"MQ7" ("CO" ppm):**
  - 1000 RPM → ~40 ppm
  - 2000 RPM → ~70 ppm
  - 4000 RPM → ~140 ppm
  - 6000 RPM → ~220 ppm
- **"MQ2"("HC" ppm):**
  - 1000 RPM → ~150 ppm
  - 2000 RPM → ~300 ppm
  - 4000 RPM → ~550 ppm

- 6000 RPM → ~850 ppm
-

8.3 Observed emission readings in 4 stroke petrol engines

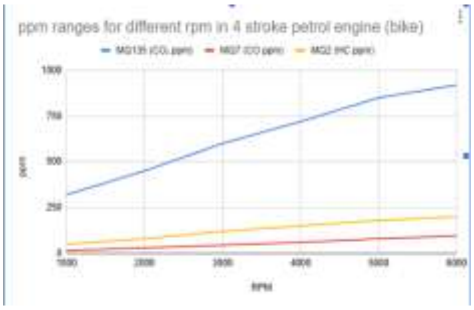

fig.7

The graph illustrates emission behaviour for a **4-stroke petrol engine**, analysed using the same sensors "(**MQ135, MQ7, MQ2**)" across varying RPM conditions.

As the engine speed increases from **1000 RPM to 6000 RPM**, emissions also increase, but at a comparatively lower rate:

- **"MQ135" ("CO" ppm):**
  - 1000 RPM → ~300 ppm
  - 2000 RPM → ~450 ppm
  - 4000 RPM → ~700 ppm
  - 6000 RPM → ~920 ppm
- **"MQ7" ("CO" ppm):**
  - 1000 RPM → ~20 ppm
  - 2000 RPM → ~35 ppm
  - 4000 RPM → ~65 ppm
  - 6000 RPM → ~95 ppm
- **"MQ2" ("HC" ppm):**
  - 1000 RPM → ~50 ppm
  - 2000 RPM → ~80 ppm
  - 4000 RPM → ~150 ppm
  - 6000 RPM → ~200 ppm

ACKNOWLEDGMENT

The authors sincerely thank **Sathyabama Institute of Science and Technology, Chennai**, for providing the academic environment and resources necessary to carry out this review work. We express our deep gratitude to **Dr. S. P. Venkatesan** for his constant guidance, technical insights, and encouragement throughout the preparation of this paper. We also acknowledge the contributions of researchers, institutions, and regulatory bodies whose published literature and standards formed the foundation of this review. Their work has been invaluable in understanding and analyzing advancements in portable exhaust monitoring systems

REFERENCES

[1] Bharat Stage (BS6) Emission Norms – Central Pollution Control Board (CPCB)
[2] Pollution Under Control (PUC) Guidelines – Regional Transport Office (RTO) rules
[3] MQ-7 Sensor Datasheet – For CO gas detection (Hanwei Electronics)
[4] MQ-135 Sensor Datasheet – For general air quality detection (Hanwei Electronics)
[5] Arduino UNO Documentation – For interfacing sensors and coding (www.arduino.cc)
[6] "Design and Development of Emission Monitoring System in Automobiles" – IJERT, 2019
[7] "Real-time Vehicle Emission Monitoring and Control Using IoT" – IEEE Xplore, 2021
[8] "Low-Cost Exhaust Gas Monitoring Using MQ Sensors" – IRJET, 2022
[9] "Vehicle Pollution Monitoring Using Arduino" – IJSER, 2020
[10] "Comparative Study of Gas Sensors for Vehicle Emissions" – Materials Today: Proceedings, 2021

[11] *Automotive Emission Control* – William B. Ribbens
[12] *Embedded Systems: Introduction to ARM Cortex-M Microcontrollers* – Jonathan W. Valvano
[13] Circuit Digest – "Air Pollution Monitoring System using Arduino"
[14] Electronics Hub – MQ sensor interfacing tutorials
[15] Instructibles – Step-by-step guides on Arduino sensor projects