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Design and Manufacturing of Pollution Monitoring System

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Abstract- This study shows the construction of a compact pollution monitoring system designed to measure the percentage of the gases that escape from the cylinder, like oxygen (O_2) and carbon dioxide (CO_2). These are harmful to the environment, so to reduce the percentage of pollution of air through the escape gases, a custom-built filter/catalytic converter chamber is used. In this system, for interpreting exhaust gas data, the Arduino Nano microprocessor was used to display the gas proportion in real time on the 16 x 2 LCD screen. When the level of exhaust gases exceeds the predetermined safety threshold value level, an audible siren notifies the operator, and a 10-minute countdown timer starts as a warning. If the excessive CO_2 condition persists beyond this duration, the system automatically disconnects electricity to terminate operation, thereby preventing potential risks. This prototype demonstrates useful applications in environmental safety and emission regulation by providing an affordable, real-time solution for monitoring and managing emissions from small engines or laboratory exhaust.

Keywords— Exhaust Gas Monitoring, Arduino Nano, Emission Control, Automatic Safety Cutoff, Real-Time Sensing, and Analysis,

I. INTRODUCTION

Air pollution from internal combustion engines has become a major global concern due to the continuous increase in vehicular population, industrialization, and reliance on fossil fuels. Exhaust gases emitted from engines contain several harmful components such as carbon monoxide (CO), carbon dioxide (CO_2), unburned hydrocarbons (HC), nitrogen oxides (NO_x), and particulate matter (PM) [1]. Among these, carbon dioxide (CO_2) is a key greenhouse gas contributing directly to global warming, while oxygen (O_2) concentration in exhaust gases provides valuable insights into the combustion efficiency and the performance of emission control systems [2-5]. Therefore, monitoring exhaust gas composition is environmental protection and engine optimization.

Modern automotive systems use complex and expensive sensors integrated into the engine control unit (ECU) to continuously monitor and regulate exhaust emissions [6,7]. However, small engines, laboratory combustion setups, and educational prototypes often lack access to such advanced systems due to cost and complexity. The need for a low-cost, real-time exhaust monitoring and control system is thus highly relevant for small-scale applications, academic research, and environmental demonstration projects [8-10]. This project addresses that gap by developing a compact Arduino-based exhaust gas monitoring system capable of detecting and responding to elevated CO_2 levels in real time [11].

II. PROBLEM STATEMENT

Vehicular and small-engine emissions cause harmful air pollution. A portable monitoring system that both displays emissions and performs an automated safety response when pollutant levels exceed safe limits can aid in diagnostics, lab testing, and education. This project aims to produce such a prototype capable of measuring O_2 and CO_2 downstream of a filter/catalytic module and performing automated actions when levels are unsafe.

III. LITERATURE REVIEW

S. Kumar et al., "Low-cost CO_2 and O_2 sensing for small engine exhaust," 2019.
Kumar et al. present a compact sensing system aimed at low-displacement engines and laboratory benches. The study evaluates the performance of electrochemical O_2 sensors and nondispersive infrared (NDIR) CO_2 sensors under transient exhaust conditions and compares them against reference bench analyzers. They emphasize sensor selection trade-offs for small systems: electrochemical sensors are low-power and accurate for O_2 in the 0–25% range, yet need periodic calibration and are temperature sensitive; NDIR CO_2 sensors provide good selectivity and stability but are bulkier and costlier. Their experimental setup includes a small catalytic chamber and tests consisting of varied air–fuel ratios and throttle conditions. Results show that, with appropriate temperature compensation and filtering, low-cost sensors can track trends and trigger safety actions (alerts / shutdown), though absolute accuracy lags high-end analyzers.

L. Martinez and H. Cho, "Microcontroller-based emission monitoring and control for generator sets," 2020. Martinez and Cho describe a microcontroller-driven monitor for small generator sets (1–5 kW) that measures CO_2, O_2, and temperature downstream of an oxidation catalyst. The system integrates a mid-range microcontroller, TFT display, wireless logging, and a relay to disconnect the generator under dangerous emissions or overheating. They place strong emphasis on software strategies: moving-average filtering to smooth sensor noise, hysteresis to avoid chattering in control outputs, and staged alarms (warning then cutoff) to allow operator intervention. Field trials demonstrate effective early warning of fuel-lean or fuel-rich burn conditions; importantly, the paper documents safe cutoff sequences to avoid abrupt engine stalling that might cause mechanical damage.

A. Pérez et al., "Evaluation of catalytic converter performance using downstream O_2 and CO_2 measurements," 2018. Pérez and colleagues investigate how downstream O_2 and CO_2 concentration profiles can quantify catalytic converter efficiency and degradation. They present a controlled lab protocol where known concentrations of CO and HC are fed through a small catalytic sample and downstream gas composition is measured continuously. Their analysis shows that an increase in CO_2 combined with a drop in free O_2 typically signals effective oxidation of CO/HC; conversely, elevated O_2 with suppressed CO_2 generation points to converter fouling or insufficient catalyst temperature. The authors also model diffusion and residence time effects inside small converter housings, showing that residence time and catalyst surface area scale strongly influence conversion efficiency. They recommend periodic dynamic testing (varying load and inlet composition) rather than static single-point tests, because catalysts show load-dependent behavior.

M. Hossain and R. Lee, "NDIR CO_2 sensors in harsh exhaust environments: conditioning and compensation," 2021. Hossain and Lee focus on practical challenges of using NDIR CO_2 sensors in exhaust sampling: particulates, temperature swings, water vapor, and interfering gases. They propose a compact sample-conditioning module that includes a particulate filter, a thermoelectric cooler to condense moisture, and a length of sampling tubing sized to dampen pressure pulses.

R. B. Singh et al., "Arduino-based gas monitoring and alert system for indoor air quality," 2017. Singh et al. developed an Arduino-based indoor air-quality monitor that combines CO_2 NDIR sensors, O_2 electrochemical modules, and particulate sensors with a local display and buzzer alerts. While the application targets indoor air quality, many architectural elements translate directly to exhaust monitoring: sensor interfacing (I2C/SPI/analog), LCD display routines, buzzer/warning logic, and timed alarm behavior. The paper provides source code snippets (PID-free, event-driven loops) and hardware schematics for integrating multiple sensors into a single-node monitor.

IV. METHODOLOGY

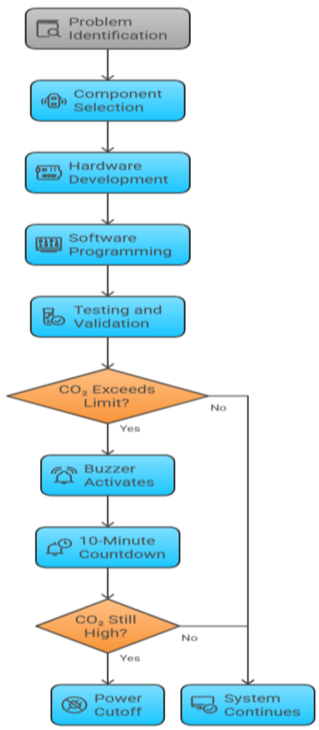

Fig. 1 Flow chart for Methodology

Design

The system consists of an inlet pipe connected to a catalytic converter-type cylinder containing the filter medium. Sensors are mounted at the outlet end of the box. The Arduino Nano receives the signals from O_2 and CO_2 sensors, processes them, and displays real-time readings on a 16×2 LCD. When CO_2 concentration exceeds the limit, the buzzer activates and a countdown timer is displayed. After 10 minutes, the system cuts power automatically using a relay. This setup helps monitor exhaust quality and automate shutdowns under unsafe conditions.

Arduino Nano Microcontroller

Fig. 2 Arduino Nano

The Arduino Nano is the central processing unit of the exhaust monitoring system. It is a compact, breadboard-friendly microcontroller based on the ATmega328P chip as shown in fig. 2. The Nano is selected for its small size, low power consumption, and versatility in sensor interfacing. It operates at 5V with 32KB of flash memory and 14 digital input/output pins, of which six can function as PWM outputs. In this project, the Arduino Nano processes the analog and digital signals from the CO_2 and O_2 sensors, performs threshold comparisons, and drives the display, buzzer, and relay module. Its serial communication capability allows easy debugging and data logging. The open-source Arduino IDE simplifies coding, calibration, and modification of system logic. The microcontroller ensures that if CO_2 levels exceed the set limit, the alarm and countdown functions are executed reliably.

CO_2 Sensor (NDIR Type)

Fig. 3 CO2 Sensor Module

The Non-Dispersive Infrared (NDIR) CO_2 sensor is used to detect and measure the concentration of carbon dioxide in the exhaust gas as shown in the fig. 3. It operates on the principle that CO_2 molecules absorb specific wavelengths of infrared light. Inside the sensor, an infrared lamp emits light through the gas sample chamber, and a detector measures the amount of light absorbed at the CO_2 absorption wavelength (typically around 4.26 μm). The absorption is proportional to the CO_2 concentration. NDIR sensors are highly accurate, have long operational life, and provide selective detection without interference from other gases. They are well-suited for exhaust applications because of their resistance to high humidity and stable calibration over time.

O_2 Sensor (Electrochemical or Zirconia Type)

The oxygen (O_2) sensor measures the residual oxygen concentration in the exhaust stream, which reflects combustion efficiency. Two common types are used: electrochemical and zirconia-based sensors. Electrochemical sensors produce a current proportional to oxygen concentration through a redox reaction, while zirconia sensors generate a voltage based on oxygen partial pressure differences across a heated ceramic membrane. In this system, the O_2 sensor provides critical feedback on the effectiveness of the catalytic or filter section, as low O_2 and high CO_2 indicate efficient combustion and filtration. The sensor's analog signal is processed by the Arduino Nano and displayed on the LCD. O_2 readings also help identify potential faults like incomplete combustion, blocked filters, or insufficient air supply.

16×2 LCD with I²C Adapter

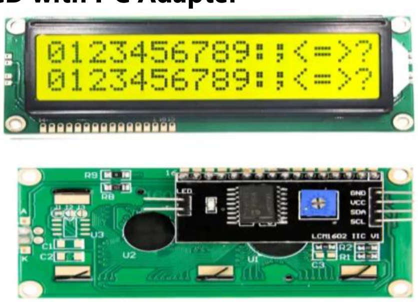

Fig. 4 16×2 LCD with I²C Adapter

A 16×2 Liquid Crystal Display (LCD) module with an I²C adapter is used to show real-time readings of O_2 and CO_2 concentrations shown in the fig. 4. The 16×2 LCD can display two lines of text with 16 characters per line, sufficient to show both gas values and system status messages like "Normal," "Warning," or "Shutdown." The I²C (Inter-Integrated Circuit) adapter simplifies wiring by reducing the connection from 16 pins to just four (VCC, GND, SDA, SCL). This allows the Arduino Nano to easily communicate with the display using the I²C protocol. The LCD provides clear, direct feedback to the user, essential for quick visual assessment during testing.

Buzzer (Active Piezo Type)

Fig. 5 Buzzer

The active piezo buzzer serves as an audible alarm that activates when the CO_2 concentration exceeds the predefined limit. Unlike passive buzzers, active types have built-in oscillators and only require a DC voltage (typically 5V) to generate sound shown in the fig. 5. The Arduino Nano controls the buzzer using a digital output pin that toggles ON during warning and shutdown conditions. The sound alerts the operator to take corrective action before the system automatically cuts power after the countdown. In this project, the buzzer's tone and duration are programmed to differentiate between alert stages—continuous beeps for warning and steady tone for shutdown.

Relay Module (5V)

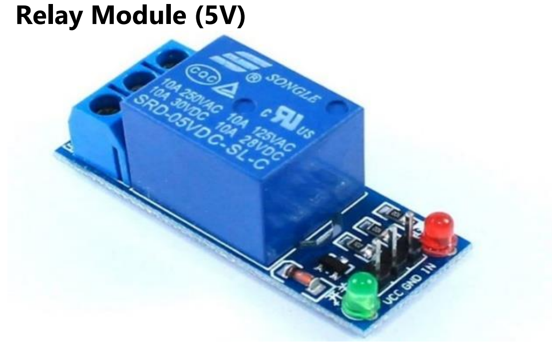

Fig. 6 Relay Module (5V)

The relay module acts as an electromechanical switch that isolates the low-power Arduino control circuit from the high-power load (such as the exhaust fan or engine circuit). It typically operates on 5V control signals and can handle 230V AC or 12V DC loads as shown in the fig. 6. The relay coil is activated by an output pin from the Arduino Nano through a transistor driver circuit. When CO_2 levels remain above the threshold for more than 10 minutes, the Arduino energizes the relay to cut off power, effectively stopping the operation of the connected device.

Temperature Sensor

The temperature sensor (such as DS18B20 or LM35) is an optional but valuable addition to monitor the exhaust or sensor chamber temperature. Gas sensor readings, especially CO_2 and O_2, can be affected by temperature variations. By measuring temperature, the Arduino can apply compensation algorithms or use the value for diagnostic purposes (e.g., verifying catalytic chamber heating). The sensor provides an analog or digital signal corresponding to temperature, typically in degrees Celsius. In this project, it ensures that gas readings remain accurate under varying exhaust conditions.

Power Supply and Wiring Accessories

Fig. 7 Power Supply

The system operates on a 12V DC power supply, stepped down to 5V using a voltage regulator or DC converter for the Arduino and sensors as shown in the fig. 7. A stable, noise-free power supply is essential for accurate sensor readings and reliable microcontroller performance. The power circuit includes protective components such as fuses, diodes, and capacitors to ensure safe and smooth operation. Wiring accessories include connectors, jumper wires, and breadboards that facilitate clean and secure assembly.

Metallic Box with Inlet and Outlet Pipes Containing the Filter Section

The metallic chamber houses shown in the fig. 8, the self-designed filter or catalytic converter section where gas sampling and monitoring take place. It is constructed from stainless steel or aluminum to withstand exhaust temperatures and prevent corrosion. The chamber contains inlet and outlet pipes to allow smooth exhaust gas flow through the filtering medium or catalyst. Inside, the filter material (such as ceramic honeycomb or activated carbon) reduces particulate and harmful gas concentrations. The O_2 and CO_2 sensors are positioned downstream of this chamber to measure post-filtration gas composition, providing data for evaluating filter efficiency. The box also ensures operator safety by preventing gas leaks and maintaining structural integrity during testing. Its modular design allows easy replacement of filter media or catalytic elements. This mechanical unit is critical for demonstrating real-world exhaust treatment and forms the physical testing base for the electronic monitoring and control system.

V. CONCLUSION

The Exhaust Gas Monitoring and Control System was developed to measure and control CO_2 and O_2 concentrations in small engine exhaust or laboratory setups.. When CO_2 exceeds the preset threshold, the system activates a buzzer alarm and starts a 10-minute countdown, after which a relay cuts power to stop operation, ensuring safety and emission control. The prototype demonstrates a low-cost, compact, and efficient method for real-time exhaust monitoring and automatic intervention. Around 60% of the work is completed, including design, component selection, and partial testing. Initial results show reliable sensor response and stable performance, confirming the system's potential as a useful educational and research tool for emission analysis and control.

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