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AIR QUALITY MONITORING SYSTEM IN A CAR USING ML AND IOT

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ABSTRACT

In today's urban settings, most vehicles remain idle for long periods due to traffic congestion and changing travel behaviors. Extended idleness of cars can lead to the accumulation of hazardous gases such as CNG, CO, and CO_2 from leaks or inadequate ventilation, creating fire risks and health hazards. This project presents an IoT-based Air Quality Monitoring System that employs Machine Learning to evaluate in-car air safety. A Random Forest model, which is trained on gas concentration data, determines air quality as normal or abnormal. The system combines gas sensors (MQ-4, MQ-7, MQ-135) with a microcontroller for real-time data acquisition and analysis. Immediate alerts are offered through an LCD unit and necessary suggestions are provided in the user-interface, allowing for timely action. The IoT platform provides for continuous monitoring, improving vehicle safety by avoiding gas-related accidents. The method incorporates real-time sensing and predictive analytics to enhance the safety of urban transportation.

Keywords:
Air Quality Monitoring, IoT, Machine Learning, Random Forest, Vehicle Safety, Gas Sensors, CNG Detection, CO Monitoring, CO_2 Levels.

INTRODUCTION

In cities, vehicles are frequently under idling for longer durations due to traffic conditions and changing traveling patterns. Such idling will result in the build-up of dangerous gases within the vehicle compartment, like Compressed Natural Gas (CNG) in vehicles that run on CNG, Carbon Monoxide (CO) in petroleum-burning vehicles, and Carbon Dioxide (CO_2) resulting from fuel burning as well as from human respiration. These gases present serious health hazards and the risks of fires when a car is driven without good ventilation.

To solve this problem, this project suggests a Machine Learning-powered Air Quality Monitoring System to evaluate in-car air safety. A Random Forest classifier, which is trained on gas concentration data, identifies air quality as normal or dangerous with great accuracy. The system checks for CNG leaks, CO due to incomplete combustion, and CO_2 due to vehicle emissions and human actions.

The hardware configuration consists of gas sensors (MQ-4 for CNG, MQ-7 for CO, MQ-135 for CO_2) and a microcontroller for real-time data acquisition. Sensor data is processed and passed to the Random Forest classifier, and outputs are shown on an LCD display for notification to the user. Through timely notifications and preventive analysis, this system provides improved vehicle safety and reduces risks from gas leaks and toxic air exposure.

RELATED WORK

Title: **"IoT-Based Air Quality Monitoring System with Machine Learning for Accurate and Real-time Data Analysis"**
Authors: Hemanth Karnati
Publication: arXiv: 2 Jul 2023

DESCRIPTION:
Air pollution in urban areas has severe consequences for both human health and the environment, predominantly caused by exhaust emissions from vehicles. To address the issue of air pollution awareness, Air Pollution Monitoring systems are used to measure the concentration of gases like CO2, smoke, alcohol, benzene, and NH3 present in the air. However, current mobile applications are unable to provide users with real-time data specific to their location.
The study proposes a portable air quality detection device that leverages IoT and machine learning for real-time data analysis. The system employs MQ135 and MQ3 sensors to detect harmful gases and measures air quality in parts per

million (PPM). Collected data is stored and visualized using the cloud-based web app ThingSpeak, and machine learning analysis is applied to enhance data accuracy and provide real-time insights.

EXISTING SYSTEMS

Some studies have developed air quality monitoring systems using IoT and machine learning for detecting and predicting pollution. There is limited research carried out for outdoor air pollution monitoring, with less for in-vehicle air quality monitoring with other Machine Learning models.
Few Existing are:

IoT-Based Smart Air Quality Monitoring in Vehicles

This paper presents a system utilizing Node MCU, gas sensors, and actuators to detect undesirable gases in vehicles and automatically open windows for ventilation.

Real-Time In-Vehicle Air Quality Monitoring System Using Machine Learning

This study develops a cloud-based system with sensors measuring CO_2, particulate matter, and other parameters, employing machine learning algorithms to predict cabin air quality and assess driver drowsiness.
Machine learning algorithms, such as Random Forest, Support Vector Machines (SVM), and Deep Learning, have been applied in air quality forecasting.

DRAWBACKS

Although there are various air quality monitoring systems available, they are not equipped with essential features for real-time and accurate in-vehicle air quality monitoring. Following are the significant limitations of currently available systems in comparison to our IoT-based Machine Learning- Air Quality Monitoring System for Vehicles:

1. Shortage of Predictive Analysis
Most current systems are based on threshold-based alarms, in which an alarm is sounded only when gas levels go beyond a predetermined level. They do not forecast possible hazards on the basis of past trend sand Cannot distinguish between small fluctuations and real dangerous conditions.
2. Limited Real-Time Monitoring and Integration
Most air quality monitoring solutions employ elementary sensor modules that simply detect air pollution levels without providing data analysis or cloud-based monitoring system integration in real-time. There is no live data visualization and interactive monitoring created or even often need manual data fetching for further examination.
3. Lacking Gas Detection Functionality
Current air quality monitoring solutions tend to be targeting outdoor air quality and do not cater to confined vehicle spaces and the inability to monitor multiple gases at once.
4. Ineffective Machine Learning Models or No AI Integration
There are air quality monitoring systems that try to incorporate basic AI models, but the models they implement are simple regression models that cannot capture intricate gas interaction trends. And lack responsiveness to real-time sensor inputs.
5. Inadequate User Interaction and Alert Mechanisms
The majority of conventional systems incorporate LED indicators or buzzer warnings, which offer minimal information regarding the real gas levels and Do not provide users with suggestions for the situation.

PROPOSED SOLUTION

In order to overcome the limitations of current air quality monitoring systems, we suggest an IoT-based, machine learning-driven air quality monitoring system that can detect and forecast dangerous gas buildup within parked vehicles. The system provides real-time monitoring, predictive assessment, and timely notifications to avoid potential hazards.
The system utilizes gas sensors to continuously monitor the PPM of critical gases. Sensor outputs are in real-time processed and forwarded to the microcontroller, which sends the data to further analyse.
A pre-trained Random Forest model is used to predict gas concentration patterns and classify air quality normal and abnormal. In contrast to conventional systems that rely on fixed threshold values, our model forecasts possible risks based on past trends, lessening false alarms. The model improves over time through occasional updates, promising increased compatibility with real-world conditions.
A web application is created to offer users the live gas concentration reading in PPM. Predicted air quality status on ML analysis. Resulting in an interactive real-time monitoring dashboard. In case of detection of hazardous gas levels, the system gives actionable recommendations based on Reliable Sources, which provides recommendations for remedial actions on the basis of gas concentration levels by consulting credible environmental health resources.

MERITS

- Predictive ML Model – Forecasts risks rather than just detecting threshold breaches.
- Multi-Gas Detection – Monitors CNG, CO, and CO_2 simultaneously.
- Smart Alert System – Provides real-time LCD and web-based alerts.
- Actionable Insights – Offers expert-recommended safety measures.
- IoT-Enabled – Ensures real-time data logging and cloud access.
- User-Friendly Interface – Displays readings through an HTML-based dashboard.

MODULE DESCRIPTION

The proposed IoT-Based Air Quality Monitoring System in Vehicles is implemented employing several interacting modules, each performing a significant function of real-time gas sensing, machine learning-driven prediction, and user interaction. The system includes the following essential modules:

SENSOR MODULE:

The Sensor Module is the primary data collection unit responsible for detecting air pollutants, temperature, and humidity levels in the environment. It gathers real-time data, which is then processed by other modules.

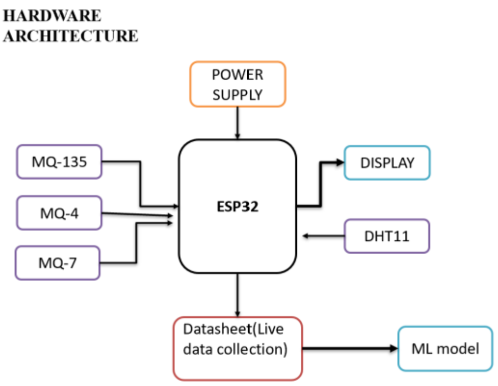

Fig.1. Hardware Architecture

Components and sensors used:

- **MQ-135 Sensor**:

  The MQ-135 Gas sensor can sense gases such as CO_2, Ammonia (NH_3), and other toxic gases and smoke. Like other MQ series gas sensor, this sensor also provides a digital and analogue output pin.

Fig.2. MQ-135 Sensor

- **MQ-4 Sensor**:

  An MQ4 sensor is a gas sensor specifically designed to detect methane (CH_4), which is the primary component of Compressed Natural Gas (CNG), making it essentially a "CNG sensor" that can detect the presence of natural gas leaks in the air; it outputs an analog signal proportional to the concentration of methane gas detected.

Fig.3. MQ-4 Sensor

- **MQ-7 Sensor**:

  An MQ7 sensor is a gas sensor specifically designed to detect the presence of Carbon Monoxide (CO), often referred to as "coal gas"

Fig.4. MQ-7 Sensor

- **DHT11: Temperature and humidity sensor:**

  A DHT11 sensor is a digital device that measures the temperature and humidity of the air. It is a low-cost option that can be used in many applications.

Fig.5.DHT11 Sensor

- **ESP8266-based microcontroller with Wi-Fi capabilities:**

  An ESP8266 is a microcontroller: Low-power, highly-integrated Wi-Fi solution. A minimum of 7 external components. Wide temperature range: -40°C to +125°C. ESP8285 — 8 Mbit flash embedded.

  The NodeMCU (Node Micro Controller Unit) is an open-source software and hardware development environment built around an inexpensive System-on-a-Chip (SoC) called the ESP8266.

Fig.6. Microcontroller

- **Power Supply**: Provides required voltage and current to the circuit.

- **I2C LCD: Display module with I2C interface for easy communication.**

An I2C LCD is a liquid crystal display (LCD) that uses the I2C protocol to communicate with a microcontroller. I2C stands for Inter-Integrated Circuit.

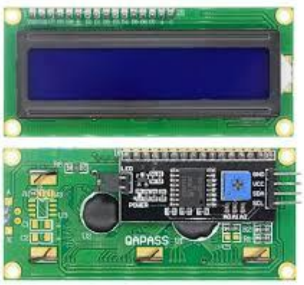

Fig.7. 12C LCD Display

Working:

- Real-time air monitoring: The sensors continuously collect air quality data, including gas concentrations and environmental conditions.
- Signal Processing: The sensor outputs are converted into electrical signals.
- Data Transmission: The collected sensor data is sent to the Data Transmission Module for further processing.

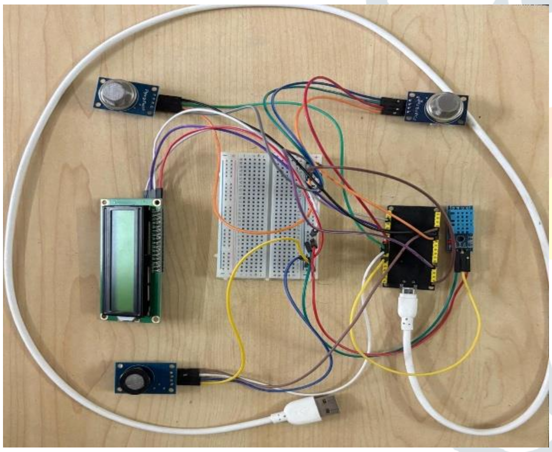

Fig.8. Hardware Setup

DATA PROCESSING MODULE:

This module is responsible for transmitting and pre-processing the sensor data before sending it to machine learning algorithms.
Functions:

- Filtering & Cleaning: Removes noise or incorrect readings from sensor outputs.
- Formatting Data: Converts raw sensor values into structured datasets.
- Transmitting Processed Data: Sends the cleaned and structured data to the Machine Learning Module for analysis.
- Storing Raw Data: Sends a copy of raw sensor data to the Database for logging and future use.

MACHINE LEARNING MODULE:

This module uses Machine learning technique (ML) to analyses sensor data, classify air quality levels, and predict future pollution trends.
Algorithms Used:

- Random forest is a machine learning algorithm, that combines the output of multiple decision trees to reach a single result.
- Its ease of use and flexibility have fuelled its adoption, as it handles both classification and regression problems.

Working:

- Pre-Trained Model: The system is trained on datasets containing historical gas readings.
- Classification Output: Categorizes air quality into normal and abnormal based on the ppm values
- Continuous Learning: The model can be refurbished from time to time for improved accuracy.

COMPUTATION MODULE:

This module analyses the Air Quality using standard air quality levels.

Working Mechanism:

- Receives Processed Data: Takes sensor data & ML model outputs as inputs.
- Uses Random Forest for Forecasting: Models analyses past Air-quality trends, and predicts air quality for the live data based on past patterns.
- Computes Using Standard air quality levels: Uses government-approved air quality levels to analyses the present air quality condition.
- Identifies Trends: Analyses historical data to detect pollution trends over time.
- Stores Processed Data: Saves computed air-quality values in the Database.

SUGGESTION MODULE:

CO2 Component:

- According Environmental Protection Agency, Increase Ventilation, Open windows and doors to allow fresh air in.

Compressed-Natural-Gas (CNG):

- IOAGPL, discusses the safety of CNG vehicles, highlighting the importance of using certified kits and regular inspections to prevent leaks. Which gives out suggestions like "Turn Off the Ignition" and "Ventilate the Vehicle Immediately"

CO Component:

- To mitigate CO hazards, OSHA recommends ensuring adequate ventilation

USER-INTERFACE MODULE:

User-Interface (UI) Shows real-time air quality status to the users and offers safety advice.

Key Features:

- The Live Dashboard Shows PPM levels of CO, CO_2, and CNG.
- Preventive Action like the immediate alerts and suggestions are given in the user-interface enable users to take preventive measures prior to using the vehicle, and avoiding health hazards and fire risks.
- Historical data is present to know the previous trends and levels of ppm accordingly.

The system works on interconnected modules that provide real-time monitoring, machine learning-based forecasts, and user-friendly notifications. The combination of IoT, ML, and real-time sensors which makes the proposed solution reliable.

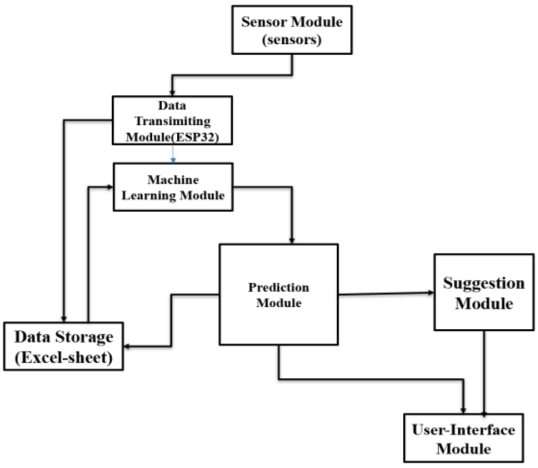

Fig.9. Block Diagram

SOFTWARE TOOLS/LIBRARIES:

Machine -Learning Module Libraries:

- **Pandas**-Handling the data
- **Numpy**-Numerical computation
- **Scikit-Learn**-Machine learning modules for Random Forest
- **Joblib**-Saving/loading the trained ML model(model.pkl)
- **Pickel**-Handling .sav model files
- **Flask**-Web framework for API communications
- **Requests**- Sending /receving data from ESP32
- **Json**-Handling JSON response
- **Matplotlib**-Data Visualization used in the user-interface

Arduino/ESP32 Libraries:

- WiFi.h-Connecting ESP32 to wifi
- HTTPClient.h-Sending HTTP requests to Flask API
- ArduinoJson.h-Formatting sensor data as JSON
- SPI.h- Communication Protocol for MCP3008
- Adafruit_MCP3008.h-Reading analog data from MCP3008

RESULT

The suggested Air Quality Monitoring System using IOT & ML accurately identifies and forecasts dangerous gas levels inside vehicles with the help of real-time data and machine learning algorithms. The system utilizes PPM levels of CO, CO_2, and CNG to analyse sensor data via a Random Forest model in order to classify air quality as normal or abnormal. The combination of IOT and ML will enable the users to obtain real-time warnings and take corresponding precautions, guaranteeing a proactive solution to vehicle safety. The system effectively gives immediate response, enabling car owners to avoid risks that come with gas leaks or polluted air before their cars are ignited. This system serves an important purpose in hindering fire threats, health threats, and gas-induced suffocation within parked cars.
This automated system improves speed, accuracy, and reliability compared to the conventional manual methods, which require human action. The capability of analysing air quality and giving data-based advice makes this system a highly desirable component of urban security measures.

Fig.10. Response I

Fig.10. Response II

CONCLUSION AND FUTURE WORK

The IoT Air Quality Monitoring System proposed in this work effectively counters the threat of dangerous gas buildup within stationary vehicles. By collecting real-time sensor readings with a Machine Learning model-based prediction system, the system gives reliable air quality measurements and warns users against impending risks. The Random Forest algorithm allows for accurate classification of gas levels, ensuring safe monitoring. In contrast to traditional air quality detection systems, this system is automated, improving both efficiency and safety. The findings prove that this strategy is able to avoid fire risks, health problems, and accidents, and therefore constitute a contribution to urban air quality management and vehicle safety.

Future Work:

To better improve the system, future work can incorporate:

- Mobile App Development: Enhancing accessibility through real-time air quality alerts and suggestions through a mobile app.
- Increased Sensor Capabilities: Adding more pollutant sensors to track a broader spectrum of dangerous gases.
- Battery-Powered IoT Devices: Using low-power solutions to allow continuous monitoring without complete dependence on vehicle power sources.

Through the incorporation of these developments, the system can develop into a more complete and expandable solution, further aiding in automated air quality monitoring and car safety.

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