Journal of Applied Information Science
11 (1) 2023, 37-44
http://www.publishingindia.com/jais

Design and Implementation of a Self-Contained Device for Monitoring and Alerting Emission: Sensor Based Approach

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Abstract: The goal of this project is to create a device that can measure the pollution emitted by a vehicle by analyzing its exhaust gases. The device is designed to be self-contained and does not require external instruments or certification. It utilizes a gas sensor that detects the level of carbon monoxide in the exhaust and a microcontroller that controls an LCD display to display this information. The system consists of two parts: a sensor node and a server node. The sensor in the sensor node detects the gases, and the data is processed by the microcontroller. Additionally, the device aims to convert the heat produced by the engine into electricity. The server node of the system is responsible for checking the pollutant levels. If the gas pollutant levels exceed a predetermined threshold or safe range, the server node sends two alert messages to the users. The system is also connected to the engine's on/off circuit, and if the user ignores the warnings and continues to operate the vehicle without repairing it, the engine's on/off circuit will be cut and the vehicle will stop moving. The user will only be able to use the vehicle again once they have repaired the pollution in the engine.

Keywords: Microcontroller, Monitoring, Peltier, Pollution, Sensor.

I. Introduction

The large amount of air pollution in cities, which is largely caused by vehicle traffic, requires constant and accurate monitoring if we hope to reduce vehicle emissions. Road transportation is the main contributor to harmful gas emissions in India, accounting for one fifth of total carbon monoxide and nitrous oxide emissions in the air. To address pollution in cities, it is necessary to monitor vehicle emissions and develop strategies to reduce them in the short and long term. The health consequences of vehicle air pollution, including asthma, eye irritation, lung problems, and reproductive issues, can be severe and long-lasting. People living in rapidly growing cities are particularly at risk for poor health.

India's Air (Prevention and Control of Pollution) Act was passed in 1981 and updated in 1987 to address the prevention, control, and reduction of air pollution. The government has established current emission standards for monitoring air pollution, and the information collected helps to mitigate the negative impacts on the environment. In urban areas, taxis, buses, and trucks are responsible for 72% of carbon monoxide and nitrous oxide emissions. Given these concerning circumstances, the Central Pollution Control Board has made it mandatory for large transport vehicles to renew their fuel efficiency (FC) certificate every year, and for light motor vehicles every five years. According to the legislation, every vehicle must also be inspected every three months to receive a Pollution Under Control certificate. Vehicle pollution can be monitored using the Air Quality Index with appropriate sensors. The transmission and communication of data from the sensors is facilitated through innovative approaches such as the Internet of Things and Wireless Sensor Networks, which allow for real-time and reliable data on a large scale.

Although electric vehicles may have lower long-term cost implications, the expense of introducing a new technology to the market is significant. In contrast, developing countries like India and South Africa rely heavily on petrol and diesel for vehicle and home use. When a new car is purchased in these countries, emission certifications are provided, but many people do not renew them. This project focuses on creating field devices to increase individual awareness. The prototype uses a microcontroller and a sensor to analyze vehicle emissions, communicate through GSM, and alert the vehicle user when it is time to service the vehicle.

II. Literature Review

The goal of Abdul-Rahman and Graves (2016) [1] is to use the online development platform Thing Speak to analyze sensor data, including temperature, sound, and potentiometer readings. This data will be displayed in both graphical and excel sheet formats. Ansari and Alam (2022) [2] the researchers analyzed air quality data collected from IoT enabled devices and stored on cloud infrastructure, which was publicly available on the Indian government website. They examined the data for various states in India and used visualization techniques to understand the impact of air pollution on human life in society. They also used correlation and heat map analysis to examine the relationship between air pollution and certain conditions and found a significant relation. Chaitanya and Kumar (2015) [3] examined the properties of gas sensors for monitoring air pollution and the various gases that contribute to it. They demonstrated how these sensors can be used to detect and measure the concentration of different gases in the air. In the literature survey conducted, there are different approaches developed for monitoring vehicular pollution.

Cordova *et al.* (2007) [4] it is the use of RFID technology to solve transport problems such as accident risk management, traffic rule violations, and vehicle theft identification. In this approach, an RFID tag is placed on each vehicle and its identification is sent to a traffic information database via RFID readers located at toll gates, parking areas, and traffic signal areas. This technology can also be used to monitor the environment and alert authorities to any potential issues. Hassan *et al.* (2022) [5] the study proposes a system in which a private blockchain network is run on a separate board and paired with a microcontroller for use with smart devices. The system utilizes blockchain technology to address challenges such as lightweight, evaporation, storage, and transportation time. Their study aimed to demonstrate how blockchain technology can be used in conjunction with machine learning for food traceability. Additionally, their study highlights how accurate data can be used to prolong shelf life in a supply chain.

Hunshal *et al.* (2017) [6] focused on the issue of both human safety and air pollution in vehicles. They explored ways to address these issues through the use of various technologies or methods. Khedo *et al.* (2010) [7] suggests using wireless sensor networks to monitor air pollution in Mauritius. The proposed system, called the Wireless Sensor Network Air Pollution Monitoring System, would utilize a large number of wireless sensors placed around the island to collect data on air quality. The system would also incorporate a new data aggregation algorithm to combine data, remove duplicates, and filter out invalid readings.

Li and Shimamoto (2012) [8] CO_2 emission reduction system for vehicles can be achieved using an ETC (electronic toll collection) device. These devices are placed at intersections and use signals to communicate with one another and determine traffic flow at each junction. By implementing this system, CO_2 emissions can be reduced. Malhotra *et al.* (2022) [9] their study examines how several well-known brands of virtual assistants are perceived by their users through correspondence analysis. Their results suggest that in addition to fulfilling their basic functions, these devices also create emotional connections with users, such as being perceived as partners, friends, or family members. Their research found differences among the brands studied, with Google Assistant and Alexa standing out as the only ones capable of forming these types of relationships with their users. The findings of their study can inform the development and design of future virtual assistants to enhance the user experience.

In paper Manna *et al.* (2014) [10] used RFID technology to monitor pollution levels in high traffic areas. RFID tags were placed at short intervals along with sensor nodes on the roadside. When the sensor level exceeded a certain threshold, an RFID reader would identify the tag number of the vehicle and send a message to the owner. This approach was implemented to help reduce pollution levels in areas with heavy vehicle traffic. Considering Pavani and Rao (2016) [11] describe the use of the TGS4161 electrolyte carbon dioxide sensor for monitoring pollution levels. This sensor must be calibrated by exposing it to different concentrations of gas, and the sensor output is plotted based on the results. This allows the sensor to accurately measure pollution levels.

For instance, in paper Rushikesh and Sivappagari (2015) [12] discussed a system for monitoring and controlling pollution levels in vehicles using MQ sensors, RFID technology, and Arduino. If the pollution level exceeds a certain threshold, the authorities will be alerted. Vong *et al.* (2014) [13] developed a pollution control system that uses radio-frequency identification (RFID) and lambda sensors. The lambda sensor is mounted on the exhaust pipe and measures the air-fuel ratio in the exhaust gas. When the air-fuel ratio is less than one, it results in increased emissions of carbon monoxide and hydrocarbons. On the other hand, if the air-fuel ratio is greater than one, it leads to an increase in nitrogen oxide emissions. The RFID is connected to the lambda sensor to help identify and monitor the emissions of the vehicle.

III. Description

A. Microcontroller

The ATmega328-based Arduino Uno is a microcontroller board. It features a 16 MHz ceramic resonator, 14 digital input/output pins (6 of which can be used as PWM outputs), 6 analog inputs, a USB connection, a power jack, an ICSP header, and a reset button. This board is user-friendly and easy to use; all the necessary components to support the microcontroller are included on the board. To get started, simply connect it to a computer via a USB cable and power it using an AC-to-DC adapter or a battery. One notable difference between the Arduino Uno and other boards is that it does not use the FTDI USB-to-serial driver chip. Instead, it has the ATmega16U2 (or ATmega8U2 on version R2) programmed as a USB-to-serial converter. The ATmega328 microcontroller is an 8-bit, highperformance device from Atmel with low power consumption. It is based on an advanced RISC architecture with 131 powerful instructions, most of which can be executed in a single clock cycle. The ATmega328 has a total of 28 pins and can operate at a maximum frequency of 20 MHz. It has 32 KB of programmable flash memory, 2 KB of static RAM, and 1 KB of EEPROM. It also has various built-in peripherals such as an ADC, USART, and analog comparator. The microcontroller has 23 I/O lines which are divided into three ports: PORT B, PORT C, and PORT D.

- Arduino ATmega328 Microcontroller

The Arduino ATmega328 microcontroller has been programmed for a variety of applications. It can be programmed using the power jack cable, and the execution of the program takes place once it is connected. There are several different types of Arduino boards available on the market. In this project, we will be focusing on the Arduino UNO ATmega328 microcontroller in detail. The Arduino software must be installed on a computer in order to edit and upload programs for specific applications. This software mainly supports the C and C++ programming languages. The Arduino board has various inputs and outputs, and up to 8 input and output ports can be used simultaneously for various applications. Some examples of applications that can be implemented using the Arduino board include controlling a general motor, a stepper motor, or a valve. There are approximately 700,000 Arduino boards in circulation, and the Arduino ATmega328 microcontroller has 14 input and output analog and digital pins (6 of which are PWM pins), 6 analog inputs, and the remaining digital inputs. The power jack cable is used to connect the Arduino board to a computer.

An external battery is used to supply power to the Arduino microcontroller. The Arduino is an open-source microcontroller that does not have any built-in feedback. It has an I2C bus that can transfer data from the Arduino board to output devices. The Arduino board can be programmed over RS232 serial interface connections with Atmega Arduino microcontrollers. The operating voltage range is 5V, and the recommended input voltage for the Arduino microcontroller is 7V to 12V. The DC input current for the Arduino board is in the range of 40 mA. It has different types of memory, including flash memory, EEPROM, and SRAM. The length of the Arduino board is approximately 68.64 mm and the width is about 53.4 mm. There are various types of microcontrollers that can be used, such as 8-bit AVL Atmel microcontrollers and 32-bit Atmel ARM microprocessors. These processors can be used for various engineering projects and industrial applications, such as controlling actuators and sensors.

The ATmega328 microcontroller is the processor for the Arduino board and has 28 pins. These pins can be used to control inputs by transmitting and receiving data to and from external devices. The ATmega328 also has pulse width modulation (PWM) capability, which is used to transmit signals in pulse modulation. It requires an input power supply such as Vcc and Gnd. The IC has both analog and digital inputs, which can be used in various applications.

B. Power Supply

The Arduino microcontroller also has an additional power supply source located at one corner of the board. This power supply port can be used to connect the microcontroller to an external power supply, such as an AC or DC power source. These power supplies provide active power to the Arduino microcontroller. It can accept a range of power supply voltages, but if the voltage exceeds the recommended range, the microcontroller can be damaged. Therefore, it is important to only provide the appropriate range of power supply to the Arduino microcontroller. To ensure proper operation, it is necessary to make sure all connections, including the power supply connection, are properly made. The output pins of the microcontroller can be connected to external devices as needed for various applications. Programs for these applications can be created and edited using the Arduino software, which supports the C and C++ programming languages. These languages are high-level languages.

By using appropriate conditions, we can create a program to carry out specific applications. This program can then be uploaded to the Arduino microcontroller using the power jack cable. Once the program is uploaded to the ATmega328 microcontroller, it can save the program and act as a processor to carry out the process without any errors. By providing analog or digital input to the system, we can control the process of the application. If we need to make changes to the program, we can edit it using the Arduino software and re-upload it to the microcontroller via the power jack cable. There is also a reset button that allows us to reset the program, which means that any previous programs are deleted and the Arduino can be used for other applications. In this way, the Arduino ATmega328 microcontroller can be used for a wide range of applications. These microcontrollers are widely used in the automation industry to control processes and operate systems in an automated mode.

C. Charging Circuit

The charging circuit is used to charge a battery by regulating and stepping down the input current to the desired output. It also prevents current flow from the battery back to the charging circuit by using a diode. To charge a battery from AC power, a step-down transformer, rectifier, filtering circuit, and regulator are needed to maintain a constant voltage, which is then applied to the battery. If only DC voltage is available to charge a lead-acid battery, a DC-DC voltage regulator and additional circuitry can be used. Car batteries are also lead-acid batteries.

The DC voltage is supplied to a DC voltage regulator, such as the LM317. The regulated DC output voltage is then applied to the battery. There is also a trickle charge mode circuit that reduces the current when the battery is fully charged. The LM317 is a voltage regulator invented in 1970 by Robert C. Dobkin and Robert J. Widlar. Its main function is to regulate voltage and provide a constant voltage without noise interference. For example, if we have a 42 V input and want a 10 V output, we can use the LM317 to get the desired output. The LM317 does not have a maximum voltage, as long as the difference between the input and output voltages does not exceed the maximum differential voltage, which is around 40 V. It can also provide an output current of up to 1.5A for a voltage range of 1.2 V to 37 V. The minimum input voltage for the LM317 is 18 V.

Lead-acid batteries were invented in 1857 by Gaston Planté and have several advantages. They dissipate very little energy, making them efficient and able to work for long periods of time. They also have a low energy-to-weight ratio, are able to deliver high currents, and have a low cost.

D. Battery

An electric battery is a device that stores and supplies electrical energy through one or more electrochemical cells. It is used to power a variety of devices such as flashlights, smartphones, and electric cars. When a battery is supplying electrical power, the positive terminal is called the cathode and the negative terminal is called the anode. The negative terminal is the source of electrons that flow through an external circuit and provide energy to an external device when the battery is connected. The movement of ions within the battery allows for chemical reactions to take place at the separate terminals, which allows for the flow of current out of the battery to perform work. Historically, the term “battery” referred specifically to a device with multiple cells, but it has also come to include devices with a single cell.

E. Clock and Reset Circuit

In digital electronics, the clock and reset circuit play a crucial role in the functioning of a microcontroller. It is important to pay careful attention to these elements from the early stages of design. The clock and reset circuit provide the necessary clock signals to the microcontroller to enable it to function properly.

F. Relay

A relay is an electrical switch that can be controlled by an electrical signal. It is used to connect or disconnect two circuits. Instead of being operated manually, a relay uses an electromagnet to activate the switch. The electromagnet consists of a coil of wire wrapped around a metal core, with the ends of the coil connected to two pins. These pins are used as the supply connections. There are typically two additional contacts called switching points that are used to connect high-amperage loads. There is also a common contact that connects the switching points. These contacts are typically labeled as normally open (NO), normally closed (NC), and common (COM).

G. Fuel Exhaust

Exhaust gas, also known as flue gas, is emitted as a result of burning fuels like natural gas, gasoline, and coal in engines. The type of engine determines how the gas is released into the atmosphere, whether through an exhaust pipe, flue gas stack, or propelling nozzle. Exhaust gas can spread in the air, forming a plume. Motor vehicle emissions, including exhaust gas, contribute significantly to air pollution and can create smog in urban areas. Vehicle emissions can also include crankcase blow-by, which is the escape of gases from the crankcase of an internal combustion engine, and evaporation of unused gasoline. These emissions have been linked to negative health effects and premature deaths.

Emissions from motor vehicles contribute to air pollution and can contribute to the formation of smog in cities. A study by the Massachusetts Institute of Technology (MIT) found that vehicle emissions are responsible for 53,000 premature deaths each year in the United States. Another study by MIT found that traffic fumes cause the deaths of 5,000 people annually in the United Kingdom.

H. Heat

The heat generated during the combustion of fuels in an engine can be quite high, especially in the engine and exhaust parts. Currently, this heat energy is typically not utilized and is considered waste. However, it would be beneficial to find ways to transform this heat energy into a useful form.

I. Thermo Electric Peltier

A thermocouple is a device that can measure temperature by using the thermoelectric effect, which is the direct conversion of temperature differences to an electric voltage. The device consists of two dissimilar conductors forming electrical junctions at different temperatures. It is made up of two unique semiconductors, one n-type and one p-type, and is connected to a thermally conducting plate on each side. When a voltage is applied to the ends of the semiconductors, there is a flow of DC current across the junction, creating a temperature difference. The side with the cooling plate absorbs heat, which is then transferred to the other side with the heat sink. Thermoelectric coolers (TECs) are typically connected side by side and sandwiched between two ceramic plates, with the cooling ability proportional to the number of TECs. The term “thermoelectric effect” includes the Seebeck, Peltier, and Thomson effects.

The Seebeck effect is a phenomenon in which electricity is generated at the junction of two different types of wire when there is a temperature difference between them. This process, which is an example of electromotive force (EMF), produces measurable currents or voltages similar to other EMFs. The Seebeck effect can also modify Ohm's law by creating currents in the absence of a voltage difference.

J. Carbon Monoxide Sensor MQ-7

The MQ-7 gas sensor is made up of micro aluminum oxide ceramic tube, a layer of Tin Dioxide (SnO_2) that is sensitive to gases, measuring electrodes, and a heater all contained in a plastic and stainless steel casing. The heater is used to maintain the necessary conditions for the sensor to function properly. The MQ-7 has six pins, four of which are used to detect signals and the other two to provide heating current. The sensor's surface resistance, Rs, is determined by the voltage signal output of the load resistance, RL, in a series circuit. The relationship between them is described as Rs/RL = (Vc-VRL)/VRL. The SnO_2 layer of the MQ-7 is stable and has excellent long-term stability, allowing the sensor to have a service life of up to 5 years under normal use conditions.

K. Liquid Crystal Display

An LCD (Liquid Crystal Display) screen is a widely used electronic display module. A 16x2 LCD display is a basic module that is often used in various devices and circuits. These modules are preferred over seven-segment displays and other multi-segment LEDs because they can display 16 characters per line on 2 lines. Each character on the LCD is displayed in a 5x7 pixel matrix. The LCD has two registers for commands and data. Some advantages of using an LCD include cost-effectiveness, easy programming, and the ability to display custom characters, animations, and more.

L. Soldering

Soldering is a technique used to join two or more metal components together by melting and flowing a filler metal, known as solder, into the joint. The filler metal has a lower melting point than the base metals being joined, and is typically made up of a combination of tin and lead (Sn and Pb). Soldering is commonly used in the fabrication of printed circuit boards (PCBs), where various electronic components are arranged on the PCB and then soldered in place. Adhesive forces, or surface tension, between the solder and the base metals allow the joint to solidify and create a strong bond. The tools and materials needed for soldering include soldering iron, nose pliers, solder, flux, and a blade or knife. It is important to ensure that the melting point of the solder is lower than the base metals being joined to prevent melting the base metals during the soldering process.

- Soldering Fluxes

In order to make the surfaces ready for soldering, it is necessary to remove any oxides or other obstructing films from the surface of the metal using a flux. The leads should be cleaned chemically or by scraping with a blade or knife, and then coated with a small amount of lead and a bit of the soldering iron. This is known as tinning. Commonly used fluxes include zinc chloride, ammonium chloride, and rosin.

- Solder

Soldering is the process of joining two or more metal surfaces using an alloy with a low melting point. A common example of this is a mixture of tin and lead, which melts at a temperature of 370 °F and solidifies upon cooling. Soldering is often used to connect electronic components on a circuit board. To prepare the surfaces for soldering, a flux is often used to remove any oxide or film that may obstruct the process. The soldering process can be aided by tinning, which involves coating the surfaces to be joined with a thin layer of solder. Solder wires, which often contain flux within the core, can be used for this purpose and may not require additional flux.

The procedure that is involved in soldering process is as follows:

- ■ Create a diagram of the component placement in the circuit. Connect the cord of the soldering iron to the power source to heat it up.
- ■ Clean the leads of the components with a blade or knife and bend them as needed. Apply some flux to the leads, and then use the soldering iron to apply a small amount of molten solder to each lead. It is important to be careful not to overheat the components during this process.
- ■ Mount the components on the PCB, apply flux to the joints, and solder the joints quickly to prevent dry soldering and excessive heating of the components and Wash the residues.
- ■ To remove excess soldering material from a circuit, a de-soldering tool such as a de-solder pump can be used.

- De-Soldering

De-soldering is the process of removing solder from previously soldered connections. One tool commonly used for this purpose is a de-soldering pump, which uses a vacuum to suck the melted solder into a tube when its trigger is activated. To ensure a successful de-soldering process, it is important to use the appropriate soldering iron for the task, coat the soldering iron tip with solder before beginning, keep the tinned parts clean of oxide, and avoid overheating the PCB and devices.

M. EAGLE

EAGLE is a software tool that allows users to design and create electronic circuits and PCBs (printed circuit boards). It has a range of features including a schematic capture editor, a PCB layout editor, an auto-router, and CAM and BOM tools. EAGLE is known for its ease of use, even for those new to PCB design, as well as its open design resources and the ability to expand its capabilities through extensions (ULPs) and compatibility with various workflows. It is developed by CadSoft Computer GmbH.

The three important modules of EAGLE are:

- Schematic Editor

EAGLE, or Easily Applicable Graphical Layout Editor, is a comprehensive electronic design automation software with capabilities including schematic capture, PCB layout design, auto-routing, and manufacturing tools. It is known for its user-friendly interface and extensive library of components, as well as its ability to be customized and extended with various extensions. The schematic editor feature in EAGLE allows users to create a symbolic representation of their design and provide documentation for others to understand the design intent. The software also includes an electrical rule check (ERC) function to verify that all connections are properly defined.

- Layout Editor

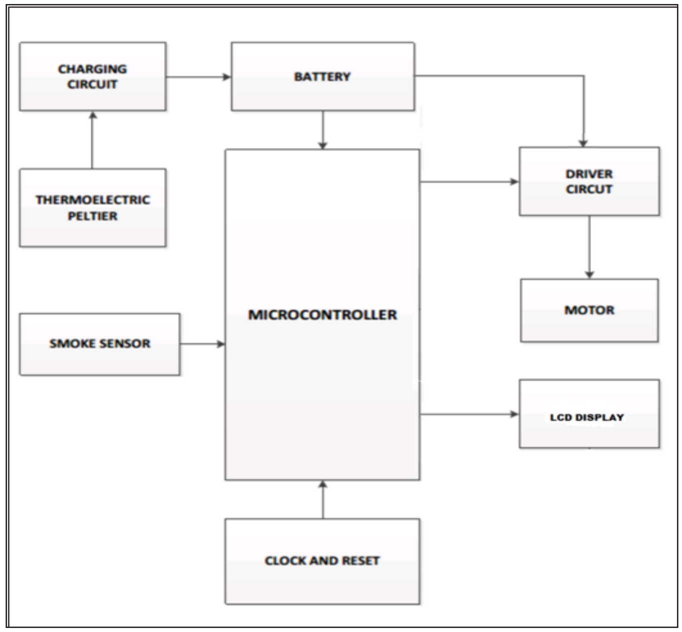
The layout editor in EAGLE is used to create the physical representation of your design, including the placement of components and routing of copper connections between them. It includes advanced features such as the ability to handle different assembly variations and specialized routing for differential pairs. The board created in the layout editor represents the final physical product.

- Autorouter

Paraphrase without plagiarism: "The autorouter function in EAGLE can assist in placing copper traces between components on a circuit board. It can be customized using cost factors to influence its routing behavior and quickly produce effective results. The autorouter operates as a multi-threaded program, allowing for the exploration of multiple routing options and the selection of the most suitable one for the design. It also protects previously routed traces and allows users to decide which nets should be manually routed and which can be handled automatically.

IV. Block Diagram

Fig. 1, shows the block diagram of the model setup.

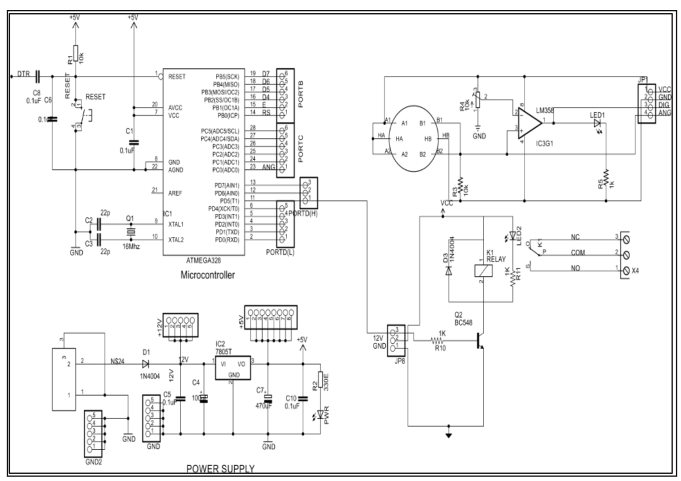


(Source: Primary)

Fig. 1: Block Diagram

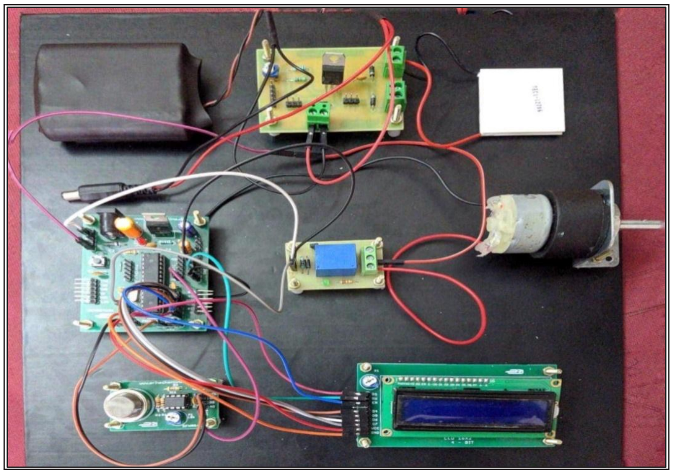
V. Circuit

Fig. 2 and Fig. 3 depict the model's circuit diagram and circuit setup.



(Source: Primary)

Fig. 2: Circuit Diagram



(Source: Primary)

Fig. 3: Circuit Setup

VI. Working

A smoke sensor is installed on the exhaust of a vehicle to measure the level of pollutants in the exhaust gas. The output from the sensor is compared to a predetermined threshold value, which is determined based on the allowed limit of pollutants in a vehicle. If the output from the sensor exceeds this threshold, the microcontroller will stop the vehicle and display a message on an LCD screen indicating that the pollution level is too high.

The thermoelectric Peltier is attached to the exhaust or another heating component of the engine. The Peltier has two surfaces, one of which is attached to the heating component, creating a temperature difference between the two surfaces. This temperature difference generates an electric charge based on the principle of thermocouples, which is used to recharge the battery that powers the microcontroller and other components. A charging circuit is used to recharge the battery because the current produced by the Peltier varies according to the temperature difference.

The vehicle's exhaust gas is monitored by a smoke sensor, which generates an analog output signal proportional to the pollutant concentration. This output is compared to a threshold value set according to the vehicle's allowed limit, and displayed on a 16x2 LCD screen. If the sensor output surpasses the threshold, the microcontroller activates a relay to stop the vehicle and displays a message indicating high pollution.

A thermoelectric Peltier device is attached to a heating component, such as the exhaust, of a vehicle engine. The Peltier has two surfaces, with one in contact with the heat source and the other remaining detached. This creates a temperature difference between the surfaces, causing a thermoelectric current to be generated based on the principle of thermocouples. This current is used to recharge the battery that powers the microcontroller and other components. A charging circuit is utilized due to the fluctuating nature of the current produced by the Peltier, which depends on the temperature difference on its surfaces.

VII. Conclusion

The proposed project is practical and easy to implement. It is also more cost-effective and secure than other available systems. If implemented by vehicle manufacturers, it would be beneficial to consumers. In addition to monitoring pollution, it also continuously tracks CO_2 levels, which can help reduce ozone-damaging chemicals in the atmosphere. This solution has the potential to significantly decrease and control emissions. If implemented on a global scale, it could contribute to the reduction of global warming.

VIII. Applications and Future Scope

The proposed system is a simple and cost-effective solution for monitoring and reducing pollution in vehicles. It can be easily integrated into the manufacturing process by vehicle companies, and eliminates the need for external certification from certified institutions. In addition, the system has the potential to continuously monitor and regulate CO_2 emissions, which can help reduce the amount of ozone-depleting chemicals in the atmosphere and contribute to the reduction of global warming when implemented on a global scale. In the future, the system can be further enhanced and expanded to address other issues and advancements.

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