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ASSESSMENT OF HARMFUL EMISSIONS RELEASED INTO THE ATMOSPHERE FROM MOTOR VEHICLE TRAFFIC IN BAKU AND THE DEVELOPMENT OF PURIFICATION METHODS

N.N. HEYDAROV[1], M.M. MUTALLIMOV[2], T.A. MUSTAFAZADA[3]

Abstract. This study explores the feasibility of installing air filtration systems on building facades to monitor vehicle-induced pollution and mitigate its effects in urban environments. Additionally, the study addresses the optimal placement of sensor-equipped air filtration systems to maximize their effectiveness. This proposed approach not only curtails the spread of polluted air throughout urban spaces but also facilitates its immediate purification.

Keywords: motor vehicles, harmful gases, air quality, air filtering systems, regression model, air pollution, optimal placement, filtering systems, carbon dioxide, global warming.

AMS Subject Classification: 62J05, 76N15.

1. Introduction

The operation of vehicles powered by internal combustion engines leads to the release of various harmful gases into the atmosphere, including Carbon Dioxide (CO_2), Carbon Monoxide (CO), Nitrogen Oxides (NO_x), Hydrocarbons (HC), and Particulate Matter (PM), among others. These pollutants pose significant risks to both the environment and human health, contributing to respiratory illnesses and accelerating global warming. In order to reduce the emission of these harmful gases, a range of mitigation strategies must be implemented, including:

(1) The development of public transportation systems with different fuel sources;
(2) The promotion of electric vehicles;
(3) The advancement and adoption of Hydrogen Fuel-Cell Vehicles ($HFCV_s$) as a promising renewable energy alternative for future transportation;
(4) The enforcement of rigorous technical inspections for vehicles;
(5) The expansion of bicycle lanes and pedestrian pathways;
(6) The implementation of large-scale tree-planting initiatives;
(7) The implementation of policies to protect ocean health, recognizing that marine algae produce approximately 80% of the Earth's oxygen.

Despite the aforementioned measures, traffic congestion remains an unavoidable challenge in densely populated areas of capital cities and major urban centers, particularly during peak commuting hours. The traffic jams are typically concentrated along specific streets and avenues, where vehicles are forced to operate at reduced speeds. Under these conditions, fuel combustion

[1]Institute of Radiation Problems of the Ministry of Science and Education of the Republic of Azerbaijan, Baku, Azerbaijan
[2]Baku State University, Institute of Applied Mathematics, Baku, Azerbaijan
[3]The International School of Azerbaijan, Baku, Azerbaijan
e-mail: mutallim@mail.ru
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becomes inefficient, leading to an increased release of toxic emissions into the surrounding atmosphere. While the complete elimination of harmful gas emissions is unattainable, it is possible to explore and develop various air purification techniques aimed at reducing the concentration of these pollutants in urban environments.

In addition to the aforementioned measures aimed at reducing the number of vehicles contributing to air pollution in various countries, in addition to the above-mentioned measures, various innovative methods are being applied to purify polluted air. For instance, Germany has introduced the “Green Roof” initiative, which involves transforming building rooftops into green spaces capable of absorbing carbon dioxide. Similarly, air filtration towers have been installed in China and Japan to lower the concentration of harmful airborne particles and gases [10]. Meanwhile, environmentally sustainable technologies are increasingly being integrated into urban development projects in countries such as the Netherlands and Sweden.

Although these methods address various aspects of air pollution, they are not without limitations. For example, the “Green Roof” initiative primarily targets the reduction of carbon dioxide levels and does not address other pollutants. Likewise, the air filtration towers deployed in China and Japan are only effective within a limited area and require substantial urban space for installation. Moreover, the construction and maintenance of these systems demand significant financial investment [1, 3, 5, 8, 9, 11].

The method and device proposed in this study offer a more efficient solution for urban air purification by installing air filtration systems directly onto the facades of buildings situated along high-traffic streets. This approach aims to protect the ecological balance within the urban environment while significantly enhancing air quality. Furthermore, the proposed system is designed to be powered by solar panels, ensuring both environmental sustainability and energy efficiency. The system operates autonomously: during periods of heavy traffic, sensors continuously monitor the concentration of carbon and other harmful gases in the air. When pollutant levels exceed established safety thresholds, the filtration system is automatically activated. Contaminated air is drawn into the device, where harmful gases and particulate matter are captured by a series of specialized filters. The purified air is then slightly cooled before being released back into residential zones. Owing to its lower temperature, the clean air descends naturally, ensuring that the population breathes fresher, safer air. Additionally, the system is designed to incorporate an ultraviolet (UV) light source at its outlet, which can be activated when necessary to neutralize harmful bacteria and viruses.

2. The statement of the problem

Research conducted across various countries has consistently shown that air pollution- particularly emissions from motor vehicles-is a major contributor to a wide range of serious health conditions. The rapid growth in the number of vehicles, coupled with the comparatively slower pace of road infrastructure development, has led to reduced average traffic speeds. This, in turn, results in incomplete fuel combustion and an increase in the volume of harmful gases emitted by vehicle engines [10]. Accurately assessing the concentration of these pollutants is of critical importance. Air pollution caused by motor vehicles can be analyzed using both macroscopic and microscopic modeling approaches [2]. A detailed evaluation based on these methods has been presented in [4].

3. Regression model

As highlighted in [6], the regression analysis offers one of the most straightforward and effective approaches among mathematical modeling techniques for evaluating environmental phenomena. This model is designed to quantify the influence of one or more independent factors on a dependent variable. In the context of this study, the following parameters are considered as independent variable factors: air temperature (T), wind speed (V), air humidity (R), the height of surrounding buildings (H), distance from the roadway (S), and traffic intensity (I). The harmful substances to be evaluated are Carbon Dioxide $(C_{O2}) - C_{O2}$, Carbon Monoxide $(C_O) - C_O$, Nitrogen Oxide $(NO) - N_O$, Hydrocarbon $(HC) - H_C$, and Particulate Matter $(PM) - P_M$. Let us summarize these and denote them by y. In this case, the regression equation will be as follows:

$$\mathrm{y} = \mathrm{b} + \mathrm{b_T}T + b_V V + b_R R + b_H H + b_S S + b_I I + b_{TV}TV + b_{TR}TR$$

$$+b_{TH}TH + b_{TS}TS + b_{TI}TI + b_{VR}VR + b_{VH}VH + b_{VS}VS + b_{VI}VI$$

$$+ b_{RH}RH + b_{RS}RS + b_{RI}RI + b_{HS}HS + b_{HI}HI + b_{SI}SI. \tag{1}$$

Using this equation, a regression analysis was performed, and based on experimental data. This process involved determining the coefficients on a full factorial experiment of the regression model presented in equation (1). All coefficients were calculated within a dimensionless coordinate system. Once these coefficients have been established, the resulting mathematical model can reliably predict the emission levels of harmful gases without the need for additional experimental measurements.

Note that if a regression model is constructed based on the values $(x_1, y_i), \overline{1, n}$, obtained from n number of measurements, its determination coefficient can be calculated using the following formula:

$$R^2 = \frac{RSS}{TTS}.$$

Here, RSS refers to the Residual Sum of Squares, and TTS denotes the Total Sum of Squares. They are defined by the following formulas:

$$RSS = \sum_{i=1}^{n} (y_i - f(x_i))^2, \; TSS = \sum_{i=1}^{n} (y_i - \overline{y})^2.$$

Here, $f(x_i)$ is the predicted value of y_i in the regression formula, $\overline{y} = \frac{\sum_{i=1}^{n} y_i}{n}$ is the mean value of a sample. If there are k number of independent variables, then the adjusted coefficient of determination. If there are k number of independent variables, the adjusted determination coefficient is calculated using the following formula:

$$\overline{R}^2 = 1 - (1 - R^2)\frac{(n-1)}{(n-k)} \leq R^2.$$

It can be observed that the adjusted coefficient of determination may decrease.

4. Assessment of harmful gases emitted by motor vehicles

Before initiating the purification of harmful gases released into the atmosphere by motor vehicles and improving air quality, it is essential to accurately measure and assess their concentrations. For this purpose, various types of sensors will be used in the design and development of the device. Thus, the concentration of each gas will be determined separately, and a dedicated filter will be installed for each type of harmful gas.

An initial prototype was developed under laboratory conditions using the Arduino Nano platform for the purpose of monitoring and purifying polluted air. Arduino Nano is a compact, low-power, and multifunctional microcontroller board. It is built on the ATmega 328P microcontroller chip and is easily programmable via a USB interface. The Arduino Nano features a $16MHz$ clock frequency, 14 digital input/output pins, 8 analog input pins, $32KB$ of Flash memory, and $2KB$ of SRAM.

The electrical circuit of the developed prototype is shown in Fig. 1. As illustrated in Fig. 1, the system is equipped with an $MQ-135$ Air Quality Sensor. This sensor is primarily used to measure the levels of Ammonia ((NH_3), Carbon Dioxide (CO_2), Benzene (C_6H_6), alcohol, smoke, and other air pollutants. The output voltage (analog signal) varries depending on the concentration of gas detected by the sensor. Based on these changes, the concentration of harmful gases in the air (in PPM) is determined through mathematical calculations and algorithms programmed on the Arduino Nano platform.

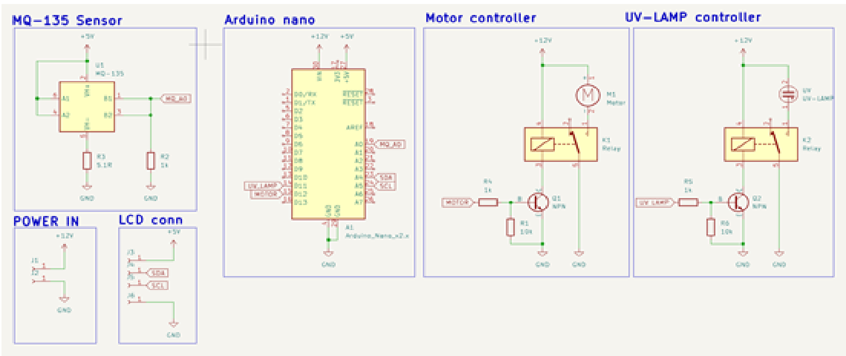

Figure 1. Electrical schematic layout of the prototype system designed for monitoring and purifying polluted air.

The electrical circuit is powered by an external 12V constant voltage source. The input voltage is converted to a 5V constant voltage using a voltage converter block integrated into the Arduino platform. The gas sensor, the circuit elements on the Arduino and the LCD screen are powered by a $5V$ voltage. As shown in the circuit, the gas sensor is connected to the A0 pin of the Arduino. Since the Arduino's analog-to-digital converter is 10-bit, the analog input from this pin records the information as values between 0 and $1023(2^10)$, respectively. This implies that the sensor readings are captured with an accuracy of $5/1023 = 0.0048 \approx 5mV$. The calculation of PPM based on the recorded values for ammonia gas is performed using the following program:

- float Vout = analogRead(A0)×(5.0/1023.0);
- float $R_s = (5.0 - Vout) \times R_2/Vout$;
- float ratio = R_s/R_0;
- float PPM = $116.6020682 \times pow(ratio, -2.769034857)$.

Here, the analog signal from the $MQ-135$ sensor is read as Vout. Based on this voltage, the internal sensor resistance R_s is calculated. This resistance is then compared to the resistance in clean air (R_0) and the ratio R_s/R_0 is calculated. This ratio is used to calculate the concentration of ammonia gas (PPM) and finally the amount of PPM is determined based on the formula shown [7, 8, 9].

The final value obtained is visualized on the LCD monitor connected to the Arduino via the I2C protocol. If the measured value exceeds the predefined pollution threshold, the Arduino sets its digital pin $D12$ (designated as the MOTOR pin) to a high logic level 1 (i.e., $5V$ voltage is supplied to the output). This action activates the NPN-type transistor in the motor controller block, which powers the electromagnetic switch. The switch then supplies power to the motor, which blows the polluted air toward the filters. When pollution levels drop below the threshold, the $D12$ pin is set to $0V$, cutting power to the motor. Thus, the system automatically responds to air pollution levels by activating or deactivating the filtration system. Additionally, an ultraviolet (UV) lamp can be activated via the "UV LAMP controller" block to neutralize airborne bacteria.

The system's use of solar power not only highlights its environmentally sustainable design but also minimizes operating costs by utilizing renewable energy sources. This approach serves to reduce the carbon footprint and allows for long-term operation without creating additional burden on the environment.

The developed prototype allows for air pollution measurements across different city locations and times of day, enabling the collection of statistical data. Using a regression model based on measured values, the concentration of harmful gases can be estimated by considering the following independent variables: air temperature, wind speed, air humidity, the height of surrounding buildings, distance from the road, and the intensity of vehicular traffic. Since the hardware and installation costs of building-mounted systems are high, the actual devices should be installed in limited numbers and in locations where they yield the most effective results. To achieve this, statistical data should be collected in a prototype model of the city, and a pollution map should be generated. Based on this map, the optimal placement of the devices can then be determined.

5. Filtration systems and their optimal placement

The optimal placement of air filtration systems is crucial for maximizing the purification of harmful gases emitted by motor vehicles into the atmosphere. Let us consider the three-dimensional area affected by vehicular pollution, is denoted by D. $(x, y, z) \in D$ is a given point in the Cartesian coordinate system. At time $t = t_0$, the degree of air pollution can be denoted by $p_0(x, y, z) = p(x, y, z, t_0)$. Here, the function $p(x, y, z, t)$ represents the level of pollution at point $(x, y, z) \in D$ at time t. It is evident that additional pollution occurs as a result of the mixing of harmful gases emitted by vehicles into the atmosphere after time t_0, and the harmful gases will change by $p(x, y, z, t)$. In this case, the pollution level at point $(x, y, z) \in D$ at time t can be expressed as:

$$p(x, y, z, t) = p(x, y, z, t_0) + p(x, y, z, t). \tag{2}$$

Then, the problem is about the optimal placement of n number of filtration systems in a three-dimensional area D that is polluted by vehicle emissions, so that at time $t = t_1$, the total air pollution in area D is given by:

$$P = \oint_D p(x, y, z, t_1) dxdydz - \sum_{i=1}^{n} S(x_i,\, y_i,\, z_i), \tag{3}$$

is minimized. Here, the quantity $S(x_i, y_i, z_i)$ represents the amount of air purified by the filtration system located at point (x_i, y_i, z_i). In other words, it is required to determine n number $(x_i, y_i, z_i) \in D,\ i = 1, 2, \ldots, n$, points where filtration systems are located in the region D, so that P, calculated by formula (3), takes a minimum value.

6. Algorithm for the assessment of hazardous waste and its effective treatment

Based on the methods outlined previously, the following algorithm is proposed for assessing hazardous waste and its treatment:

Algorithm.

(1) The measurement of independent variables such as air temperature (T), wind speed (V), air humidity (R), height of surrounding buildings (H), distance from the road (S), traffic intensity (I);
(2) Experimental determination of harmful substances such as Carbon Dioxide $(CO_2) - C_{O2}$, Carbon Monoxide $(CO) - C_O$, Nitrogen Oxide $(NO) - N_O$, Hydrocarbon $(HC) - H_C$, Suspended Particulate Matter $(PM) - P_M$, which are intended to be evaluated at the required number of different values for regression analysis of independent variables;
(3) Determination of coefficients in the regression Eqn. (1) based on a full factor experiment;
(4) Determination of the concentration of harmful gases by means of independent variables based on the regression model using the determined coefficients;
(5) Purification of harmful gases by means of filtration systems;
(6) When the concentration of harmful gases falls below a predetermined threshold, the filtration system ceases operation, otherwise the system remains active;
(7) While the filtration system is inactive, Step 4 is performed to monitor the concentration of harmful gases. Once the concentration surpasses the threshold, the system will activate and perform Step 5.

This process continues periodically. The future of the project development aims to integrate a specialized sensor system and individual filters for each gas type. The filtration system will be designed with an automatic replacement mechanism, and the algorithm will be updated to control this process. Based on real-time data from the sensors, the system will select the appropriate filter for the gas with the highest concentration, thereby optimizing purification efficiency.

7. Laboratory testing of the prototype and evaluation of the efficiency of the filtration process

To assess the functional capabilities of the prototype and validate its operational principles, the device was tested in laboratory conditions. The experiments took place within a transparent, hermetically sealed plastic container. The prototype was placed inside the container, and gas concentrations were continuously monitored using an $MQ-135$ air quality sensor.

During the testing phase, the concentrations of ammonia and carbon dioxide within the container's internal environment were deliberately elevated. Carbon dioxide levels were increased by burning paper, while ammonia levels were raised through the evaporation of a 10% medical-grade ammonia solution. Using these methods, the measurement range of the $MQ-135$ sensor was tested and the initial pollution level was recorded.

Subsequently, the fan (cooler) installed within the container was activated, directing the polluted air through the activated carbon filter. To evaluate the effectiveness of the filtration process, gas concentration levels were recorded at regular intervals over time. The measurements indicated a gradual decline in gas concentration following the initiation of filtration, eventually stabilizing at a consistently low level. The results are presented in the table below:

Table 1.

Time (minutes)	Ammonia concentration (ppm)	CO_2 concentration (ppm)
0	38	1200
2	30	956
5	21	652
10	13	423
15	8	359
20	6	342

The results obtained showed that the activated carbon filter significantly reduced gas concentrations over time. This confirms the feasibility of applying the proposed system as a potential air purification device.

8. Conclusion

The article presents the development of a device equipped with sensors to more effectively purify harmful gases emitted into the atmosphere as a result of vehicle operation and the construction of a mathematical model that ensures the optimal placement of these devices in the urban area. Laboratory tests of the prepared prototype revealed the following results:

(1) The prototype allows for the initial determination of air pollution levels within urban environment;
(2) Establishes conditions for testing the effectiveness of various filter types;
(3) Enables the testing and selection of sensors intended for integration into a real device,
(4) Supports the identification of coefficients of the mathematical model based on experimental data;
(5) Ensures the optimal placement of devices in the urban areas based on the model;
(6) Allows for accurate calculations required for the development of real-scale devices in the future.
(7) The system offers a convenient interface for real-time data collection and processing, enabling prompt and effective responses to pollution events.
(8) Based on a mathematical model, it ensures that the results obtained are more accurate by taking into account factors such as urban topography, wind direction and traffic density in the placement of devices;
(9) The device and model-based system serves as a practical basis for scientific research in the field of environmental monitoring;
(10) The system allows for the preparation of a visual map of high-pollution points, which plays an important role in urban planning;
(11) It has a flexible and modular structure that can be integrated into the Smart City concept.

The proposed mathematical model not only optimizes the number of devices, but also ensures more effective air purification. This significantly reduces the cost of the overall system. The proposed system offers notable advantages in terms of functionality, user-friendliness, cost-effectiveness compared to similar solutions, and long-term reliability

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Namig Heydarov - is currently pursuing his Ph.D. studies and working as a research scientist at the Institute of Control Systems of the Ministry of Science and Education of the Republic of Azerbaijan. He is also the head of the Innovative Research Group at the Institute of Radiation Problems, which is likewise affiliated with the Ministry of Science and Education. His main research interests include UAV stabilization systems, inertial navigation systems (INS), and the application of UAVs in radiation and environmental measurements.

Mutallim M. Mutallimov, for a photograph and biography, see TWMS J. Pure Appl. Math., V.13, N.2, 2022, p.220.

Timur Mustafazade - is a 10th-grade student at the International School of Azerbaijan (TISA). He is a finalist of the Intel ISEF 2025 for his project Urban Fresh, a smart solar-powered air purification system. His academic interests include environmental engineering, air pollution control, and mathematical modeling. He also leads EcoEra, a youth-led environmental initiative focused on sustainability, education, and research. Within this framework, he has explored heavy metal detection in post-war zones using biomonitoring techniques.