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AIR POLLUTION MONITORING AND ALERT SYSTEM BASED ON THE ARDUINO MICROCONTROLLER

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Abstract: *In today's world, air pollution stands out as a paramount global concern. Air pollution can originate from either human-made (anthropogenic) or natural sources. Atmospheric pollutants such as carbon monoxide (CO), carbon dioxide (CO2), sulphur dioxide (SO2), nitrogen dioxide (NO2), ozone (O3), suspended particulate matter (SPM), respirable suspended particulate matter (RSPM), and volatile organic compounds (VOCs) have a profound impact on human health. This issue is pervasive, affecting most major cities in both developing and developed countries.*

Given the urgency of the situation, the development of a real-time air quality and pollution monitoring system is imperative. We have engineered an Arduino-based air pollution detector that pairs a compact, cost-effective sensor with an Arduino microcontroller unit. This detector offers several advantages, including reliable stability, swift response and recovery times, and has a long operational lifespan. Furthermore, it is a budget-friendly, user-friendly, low-power hardware solution suitable for mobile measurement and straightforward data collection. The accompanying processing software can meticulously analyze the collected data with exceptional precision, making it an essential tool for understanding and addressing the critical issue of air pollution.

Key words: *Air Quality, Microcontroller, Sensors, IoT*

Introduction

Air pollution is a pressing global issue that has led governments and citizens worldwide to invest billions in policies and solutions. It arises from various sources

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like industries, vehicles, and household activities, emitting harmful pollutants such as heavy metals, carbon monoxide, ozone, carbon dioxide, and more. The World Health Organization (WHO) estimated that outdoor air pollution alone is responsible for 4.2 million premature deaths each year [1].

Air pollution not only affects human health, but also impacts animals, food crops, and the environment. Long-term exposure to these pollutants can lead to respiratory infections and even cancer. For instance, carbon monoxide can be fatal through prolonged exposure. In 2014, WHO reported that 7 million deaths globally were attributed to air pollution, a statistic echoed by the International Energy Agency.

Air pollution also contributes to environmental disasters such as acid rain and ozone layer depletion [2], underscoring the urgency of establishing control. Fortunately, advancements in technology have led to the development of compact and affordable air quality sensors, capable of detecting common pollutants like nitrous oxide, carbon monoxide, ozone, sulphur dioxide, and particulate matter. These sensors are versatile, usable indoors and outdoors, making them essential for monitoring the air quality impact on human health.

Air quality sensors play a vital role in assessing and enhancing indoor air quality, making them particularly valuable for home use. They can identify indoor pollutants, alerting residents to the need for proper ventilation. This is especially important because indoor air quality can sometimes be worse than outdoor air due to activities like cooking and the use of household products.

By continuously monitoring indoor air quality, these sensors empower residents to take action, like opening windows or using air purifiers. This proactive approach not only improves the well-being, but also reduces the risk of respiratory problems and allergies associated with poor indoor air quality. These sensors, thus, serve as indispensable tools for creating safer and healthier living environments, ensuring that people can enjoy clean, fresh air in their homes.

In summary, air pollution is a global challenge with severe consequences for both human health and the environment. The development of affordable and portable air quality sensors is a critical step in addressing this issue, allowing individuals to monitor and take action to improve the air they breathe, both indoors and outdoors. This proactive approach to air quality management is essential for safeguarding public health and the planet.

Material and methods

We have used the Arduino Mega 2560, digital sensor for temperature and humidity (DHT22, Fig 1a), flame sensor module (KY-026, Fig 1b), CO sensor for carbon monoxide (ZE16B-CO, Fig 1c), sensor for carbon dioxide (MH-Z19B, Fig. 1d), breadboard, jumper wires, and Arduino shields (Fig.2) to develop an arduino based air pollution detector which combined a small-sized, minimum-cost sensor to an arduino microcontroller unit. The device is linked to a computer through a serial connection.

The Arduino microcontroller is used to collect data from the sensor. It will then be transmitted to the computer software, where it becomes documented and plotted in real-time. It is very small in size, and can be a hand-held measurement system that can detect numerous gases in real-time.

Figure 1: Sensors used in research

a) Digital moisture and temperature sensor DHT 22 [3]; b) Flame sensor module KY-026 [4]; c) Carbon monoxide sensor ZE16B-CO [5];
d) Carbon dioxide sensor MH-Z19B Infrared CO2 Sensor Module [6];

a) **b)**

Figure 2: Shields used in the model

a) SIM 808 GPRS/GSM shield with GSM antenna [7];

b) ESP 32 CAM-MB module [8];

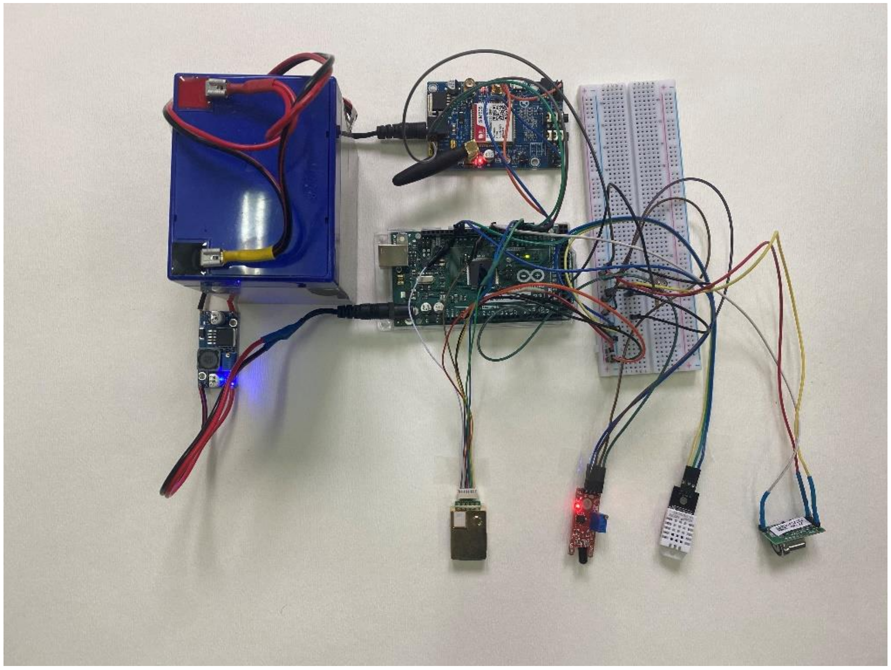

Figure 3. Display of a connected system

The purpose of sensors for the Arduino Mega 2560 is to enable interaction with physical signals from the environment and convert those signals into an electrical signal suitable for electronic circuits. Sensors are electronic devices that measure physical quantities such as light, temperature, humidity, and convert them into voltage-based measurement units (Figure 3).

Software

The software implementation of this project was conducted using the Arduino IDE and *Thingspeak IoT analytics platform* [9]. The former provides an enabling environment for the microprocessor configuration, whereas the latter is responsible for the real-time implementation of the IoT of the project[3].

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[3] The code itself is written in the integrated development environment Arduino IDE, in the C/C++ programming language. The code consists of over 560 lines and it is given in the appendix to the doctoral dissertation of Dr. sc. Ljupco Shosholovski (2022). Defining a system

Conditions and design of the research

Before commencing measurements with the equipment described in the system model (Arduino Mega 2560 board, sensors, camera, platforms), it was necessary to define the circumstances under which the measurements would be performed and to interpret the obtained results to determine the thresholds for activating the camera. The conditions under which the measurements were conducted are as follows:

Step 1: Preparation of the measuring instruments. The controller with sensors for temperature, humidity, flame, CO, and CO2 is placed in an open space, connected to the SIM 808 GPRS/GSM module and a camera, positioned at a height of 1 meter.

Step 2: The channel (interface) from the Thingspeak platform is located in the control center and is connected to the Internet to monitor the data.

Step 3: Checking and synchronizing the channel from the Thingspeak platform with the microcontroller and verifying the viewing time.

Step 4: Verifying the system configuration:

- ✓ Online status
- ✓ Data transfer (temperature, humidity, CO, and CO2) to the platform at 1-minute intervals (an option that can be set during compilation, but not shorter than 2 seconds).

Step 5: Obtaining weather forecast data from www.accuweather.com for the experimental time period and comparing the data.

Step 6: Recording data on the microcontroller at different time intervals throughout the day (24 hours) and noting differences in the measured parameters.

Research and results

After connecting the sensors to the Arduino Mega 2560 single-board computer and creating a dedicated channel on the Thingspeak platform through the ESP32 and GSM modules connected to the board, data transfer to the channel became possible. Following preliminary tests in controlled laboratory conditions (in a closed space) for each sensor individually and in combination, a 24-hour test of the system under real atmospheric conditions was conducted to assess its stability, accuracy, efficiency, resistance to atmospheric influences, and measurement of standard atmospheric parameters.

Upon verifying steps 1 to 5 of the data collection and survey design, we proceeded to the 24-hour system testing, during which atmospheric parameter measurements were taken under changing meteorological conditions over the course of 24 hours.

(integrated model) for forest fire prevention, early warning and management. Military academy “General Mihailo Apostolski”-Skopje.

In Table 1, a portion of the digitally recorded data is presented, with an associated channel ID of 1677242 titled ***„PreventForestFire”.*** This data is accessible for download in CSV format from the platform and can be processed at any time.

Table 1: Part of the CSV format exported from the Thingspeak platform channel

created_at	entry_id	T	H	CO	CO_2	IR
2022-03-30T16:00:23+02:00	1880	23.3	29.1	0	430	1
2022-03-30T16:01:25+02:00	1881	23	29	0	404	1
2022-03-30T16:02:26+02:00	1882	22.9	29	0	425	1
2022-03-30T16:03:28+02:00	1883	22.8	29.2	0	404	1
2022-03-30T16:04:29+02:00	1884	22.8	30.4	0	404	1
2022-03-30T16:05:30+02:00	1885	23	30	0	485	1
2022-03-30T16:06:32+02:00	1886	23.2	30.4	0	401	1
2022-03-30T16:07:33+02:00	1887	23.2	29.7	0	456	1
2022-03-30T16:08:34+02:00	1888	23.2	29.9	0	459	1
2022-03-30T16:09:36+02:00	1889	23.2	29.5	0	413	1

Throughout the 24-hour monitoring period, we collected 1,415 lines of data for various atmospheric parameters, including temperature, humidity, carbon monoxide, and carbon dioxide. To provide a clearer representation of the data, we displayed every 30th data point in the graphical presentation, resulting in 48 data lines. However, the entire dataset was used for the interpretation of results. As a result, you may notice certain peaks in the diagrams. Notably, the system demonstrated uninterrupted data transmission to the channel at all times, showcasing its stability, reliability, and efficiency when operating in real atmospheric conditions.

Regarding temperature measurements, the highest recorded temperature reached 30.9°C, coinciding with a relative humidity of 22.2%, which also marked the lowest recorded humidity level during the day and night. Conversely, the lowest temperature observed was 13.7°C, accompanied by a measured relative humidity of 70.7%. The highest relative humidity recorded was 77.9%, occurring at a temperature of 13.9°C (as shown in Fig. 4).

In the course of our experiment in real atmospheric conditions, short-term rain showers occurred when the relative air humidity exceeded 50%. These rain showers intensified in the early morning as relative humidity exceeded 70%. This observation clearly demonstrates that when relative humidity surpasses the 50% threshold, conditions favorable for rain are created, and the risk of fire occurrence is minimal. In the event of a fire, for any reason, the saturated air with moisture would inhibit its spread.

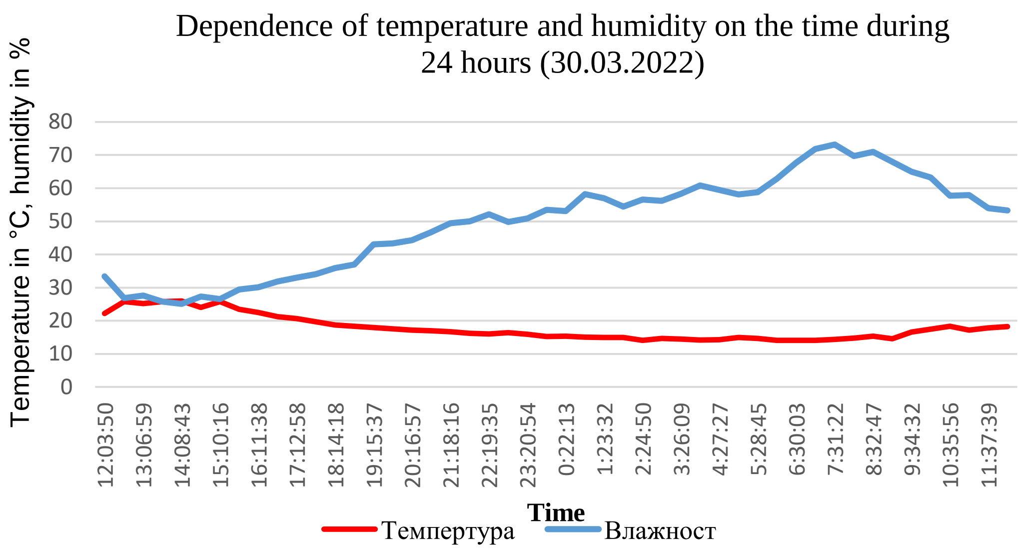

Figure 4: Temperature and humidity value during 24 hours measured with the DHT 22 sensor

In Figure 5, the temperature and humidity changes in the air, recorded by the channel on the platform, are displayed for the period between 18:30 and 19:00.

The graphical representation clearly illustrates that as night approaches, the temperature significantly decreases, indicating a cooling of the air, while relative humidity increases. This process results in the moistening of the fuel material, as it absorbs moisture from the air. These conditions create a more favorable environment for extinguishing a fire, if one were to exist. The most effective conditions for fire suppression are typically between 18:00 and 06:00 when temperatures are at their lowest, and air humidity is at its highest during both day and night.

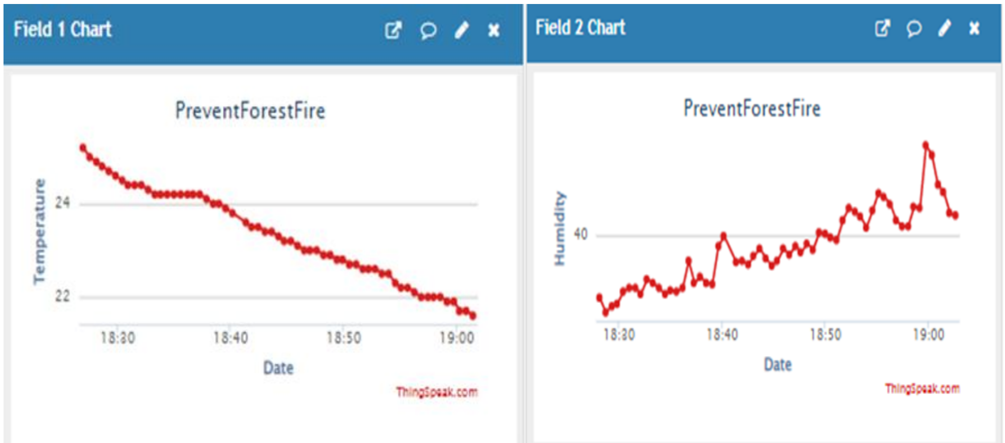

Figure 5: Graphical representation of the temperature and humidity values of the channel on the Thingspeak platform

Throughout the day and night measurements, an average temperature of 17.85°C and a relative humidity of 49.4% were recorded. The most significant temperature change between two consecutive measurements occurred at 12:31:37, dropping from 29.3°C to 26.4°C, a difference of 2.9°C. During this same interval, relative humidity changed from 23.6% to 26%, a change of 2.4%.

The most substantial relative humidity change happened at 10:59:32, shifting from 56.9% to 51.9%, representing a 5% change, while the temperature remained constant. These data are further analyzed to define the phases of the logic controller and establish the conditions for determining the presence of a fire.

In regard to carbon monoxide measurements, the highest value, 0.32 ppm, was recorded at 7:31:22 a.m. on the same day, while the lowest value, 0.13 ppm, was recorded at 1:37:47 p.m. Throughout the day and night, the recorded values never exceeded 1 ppm, which aligns with the sensor's precision (as shown in Fig. 6).

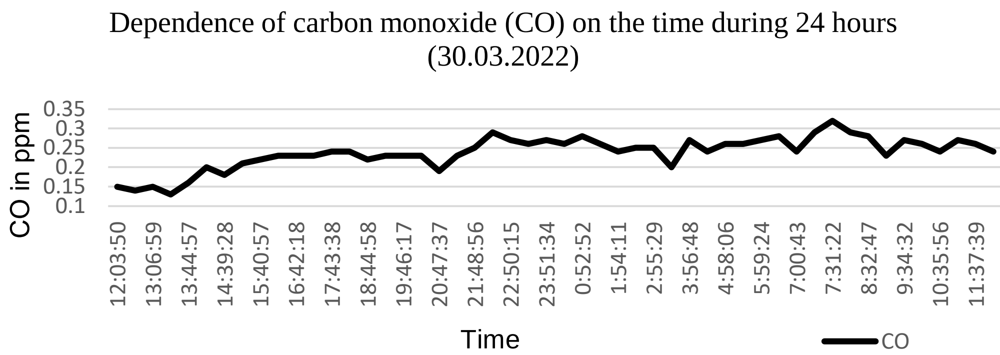

Figure 6: Carbon monoxide (CO) value measured overnight with the ZE16B-CO sensor

Carbon dioxide (CO_2) concentrations observed during the measured day ranged from 400 ppm to 1,518 ppm, with the highest measurement recorded at 12:51:08. The average concentration of CO2 throughout the day and night was 423.74 ppm, consistent with ambient air quality standards (as shown in Fig. 7).

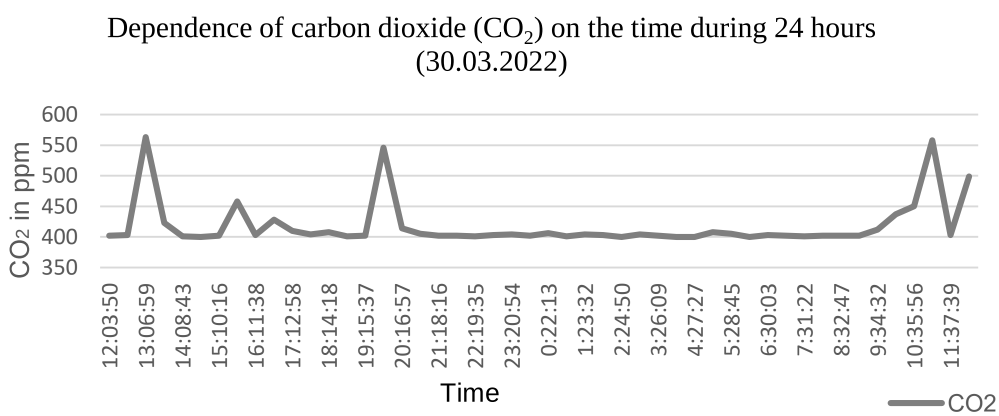

Figure 7: Carbon dioxide (CO2) value measured overnight with the MH-Z19B sensor

In Figure 7, certain peaks are noticeable. These peaks are a result of displaying every 30^{th} data point from the 24-hour measurement dataset and are associated with the movement of air masses carrying CO2 particles. The sensor registers these particles as they move, and their concentrations range from 400 to 560 ppm. It's important to note that these peaks fall within the normal limits for carbon dioxide in the ambient air in Skopje.

Additionally, correlation coefficients were computed for the dataset of registered parameters, using values collected at one-minute intervals. This analysis encompasses a total of 1,415 data points (refer to Table 2).

Table 2: Correlation coefficient between parameters

	T	**H**	**CO**	**CO_2**
T	1	-0,87681	-0,7789	0,326898
H	-0,87681	1	0,7603	-0,23847
CO	-0,7789	0,7603	1	-0,316
CO_2	0,326898	-0,23847	-0,316	1

From Table 2, according to the results of the Pearson correlation, it can be concluded that there is a significantly strong positive correlation between relative humidity and carbon monoxide, with a value of 0.7603 ($r(1415) = 0.7603$, $p < 0.001$, p-value 0.4794). Additionally, the Pearson correlation shows a significantly strong negative correlation between temperature and carbon monoxide, with a value of -0.7789, and between temperature and relative humidity, with a value of -0.87681. Carbon dioxide does not exhibit a significant correlation with any other parameter.

Conclusion

The development of an Arduino-based air pollution detector represents a significant advancement in air quality monitoring technology. This system has demonstrated its effectiveness, ease of use, and comparable functionality to expensive existing air pollution detectors. It is a portable, microcontroller-based solution that offers efficiency and user-friendliness. Through a series of tests conducted under atmospheric operating conditions, the system has proven to be reliable, accurate, and precise in line with its technical specifications. Moreover, its ability to provide real-time data access via the Internet adds a layer of convenience and accessibility.

The growing concern over air quality, particularly in densely populated urban areas like Skopje, underscores the importance of such innovative solutions. Harmful gases are pervasive in both indoor and outdoor environments, impacting human health. With the use of an Arduino-based detection system, individuals can gain insight into gas

levels in these environments, which is a critical step toward improving public health. The real-time data transmission feature empowers users to take prompt and informed actions based on the readings.
Given the promising performance and practicality of this Arduino-based air pollution detector, it is highly recommended for wider adoption, especially in urban areas facing air quality challenges. Implementing this system can help individuals and authorities make data-driven decisions to mitigate air pollution's adverse effects on health and well-being. Additionally, further development and refinement of the technology could expand its applications and enhance its impact on environmental and public health management.

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