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Research Article

Monitoring Pollution in Smart Cities Based on Arduino and IoT

Sura Ali Hobi[1,*], Davood Akbari Bangar [1]

[1] *Faculty of Mechanical, Electrical and Computer Engineering Department, Islamic Azad University, Iran.*

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ABSTRACT

This study offerings an innovative solution for checking pollution in smart cities using the Internet of Things (IoT) and Arduino-based sensors. As urban areas face increasing air pollution levels, the need for effective monitoring systems becomes necessary. This paper focuses on creating a scalable, secure IoT architecture to collect, analyze, and manage air quality data in real-time. The system utilizes MQTT for secure data transmission, and machine learning algorithms for predictive analysis. A model is developed using Arduino sensors to measure carbon dioxide, butane gas, temperature, and humidity. The outcomes indicate the system's ability to effectively monitor pollution, notify users through mobile applications, and provide actionable insights for pollution management. Future work will improve the system's abilities, including expanded scalability and additional environmental parameters.

1. INTRODUCTION

Air contamination is a important supplier to global warming, affecting millions of people worldwide, especially in urban areas. Smart cities goal to usage information technology and communication technologies to mitigate environmental pollution, including air pollution. This study proposes an Internet of Things (IoT) based solution to monitor and manage pollution in cities by integrating sensors, IoT gateways, and cloud infrastructures. The system's primary focus is security, ensuring safe and secure data transmission from IoT devices to cloud storage [1].

Rendering to the World Health Organization, air contamination levels in urban zones exceed acceptable standards in more than 80% of cities globally, causing millions of deaths annually due to diseases linked to polluted air [2]. To report this issue, cities can adopt IoT solutions to continuously monitor pollution levels and implement countermeasures, such as rerouting traffic to lower vehicle emissions. The innovation of this research lies in the safety-focused design of an IoT substructure, ensuring data reliability and protection from cyber threats [3].

This study aims to develop a pollution checking system using IoT devices to achieve real-time air quality monitoring and secure data management. The scheme will help identify highly polluted areas to implement preventive actions and provide public awareness through air quality reports [4]. The key objectives include:

1. Design of accessible IoT architecture for pollution metric collection.
2. Advance of a secure proof-of-conception (PoC) using IoT technologies.
3. Use of prognostic analytics to interpret collected data for pollution control.

Smart cities use various sensors to collect data for management resources efficiently. The system designed in this study collects pollution data, processes it, and sends it to cloud platforms via secure, low-power protocols. A key novelty of this paper is the integration of Message Queuing Telemetry Transfer (MQTT) for secure communication and the use of artificial intelligence (AI) for data analysis [5]. The scheme can animatedly reduce pollution by rerouting traffic when certain thresholds are exceeded, ensuring safer living conditions in cities [6-8].

- **Data analysis methods and tools:**

Qualitative and quantitative analysis procedures and tools such as Python will be used in this thesis.

*Corresponding author. Email: Akbari.Bengor@gmail.com

- **Design and implementation**

Exhausting Arduino MQ-2 gas sensors and Arduino DHT22 hotness and humidity sensors, the air pollution checking system is designed for an Internet of Things (IoT) application. The air pollution monitoring system exclusively monitors temperature, humidity, carbon dioxide gas, and butane gas.
All parameters are tested in indoor conditions. Figure 1 shows the complete circuit prototype designed to alert users who monitor air pollution. This prototype is designed to meet all objectives where temperature, humidity and hazardous gases are measured. It is very valuable to recommend building the environment of the region with the reliability of the Internet of Things system [9].

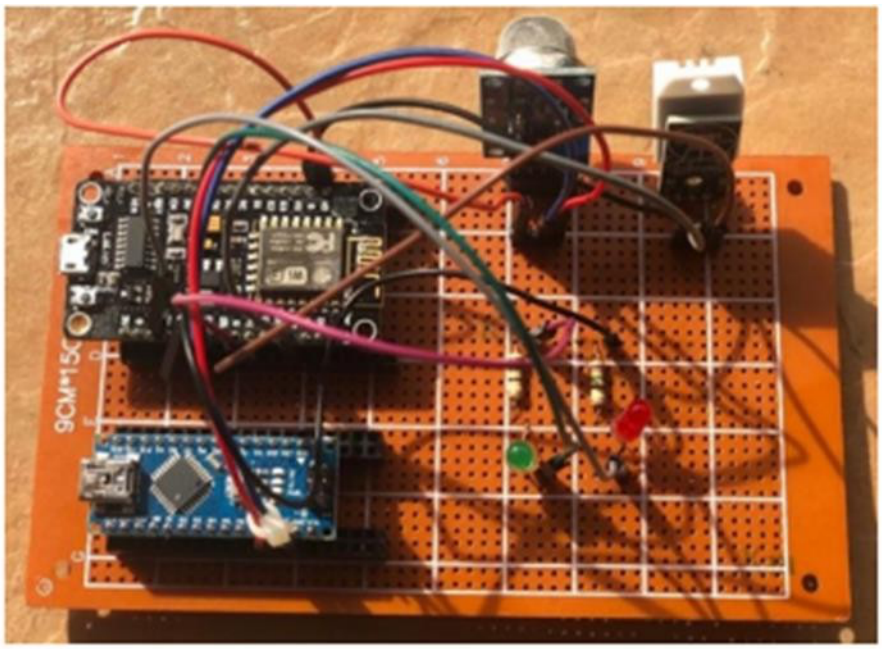

Fig .1. Prototype diagrams

Different hazardous gas level detection is tested by sacrificing the gas sensor to analyze the amount of gas level in different forms. The alarm system and app alert are designed to notify through the Blynk app when hazardous gas is detected and appear on the mobile screen [10,11].

1.1 Measurement

The IoT-based GPS bus tracker with automatic passenger counting system has been successfully designed and tested. Blynk is used to monitor bus location and passenger count through mobile app. The bus tracker system continuously tracks and updates the exact location of the bus. In this project, there are two independent variable parameters for testing, which are carbon dioxide gas and butane gas (refer to figure 2). Therefore, it is very important to monitor and quickly detect this smoke

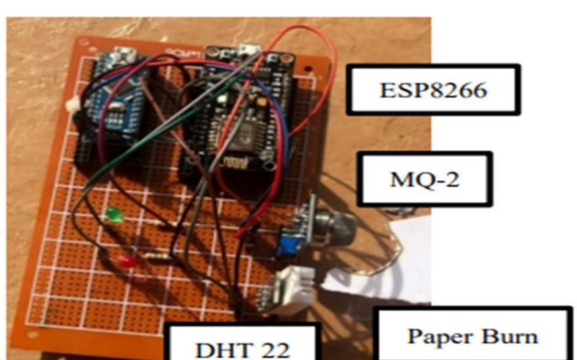

Fig .2. Carbon dioxide gas test

In this process, the oxygen in the air combines with the carbon and hydrogen when the paper burns, turning it into the carbon dioxide gas found in the smoke. It leaves the unconsumed solid ash lighter than the original paper. Figure 3 shows the butane gas measurement experiment around. Butane exposure should always be minimized. Combustion of butane can also lead to hazards because it releases harmful substances such as nitrogen dioxide. Butane is a gas that is usually used in lighters and as a propellant in aerosol sprays.

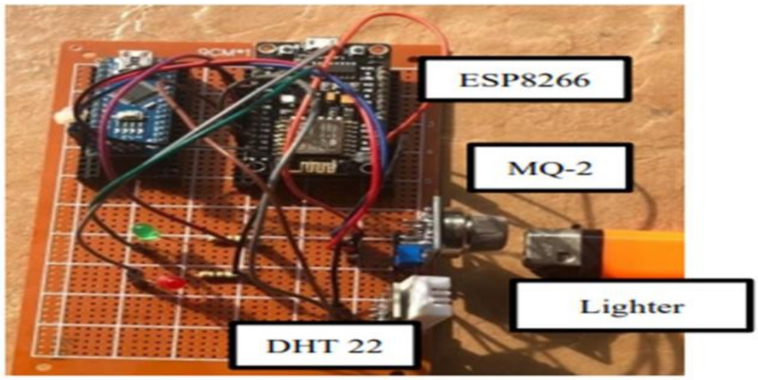

Fig .3. The butane gas measurement experiment around

The AQI-based air quality results are indicative of a satisfactory ambient air quality level below 100, as determined by experiments conducted in the building environment. The Arduino IDE software simulation establishes all conditions within the range if the reading exceeds 200 AQI, which indicates hazardous air quality. All sensors functioned flawlessly, as evidenced by the precise measurements that were obtained and the rapid response time of the air pollution monitoring system. It evaluates the air quality in both the safe and hazardous environments when gases or pollutants are discharged into the air and cause significant damage to both humans and the environment. The green LED is illuminated in Figure 4, which suggests that the air quality is satisfactory. The range was established to indicate that no hazardous gases were detected in the vicinity. The air pollution system can be continuously monitored by users through real-time notifications on their mobile devices via the Internet of Things (IoT). The crimson LED would illuminate if carbon dioxide or butane gas were not detected.

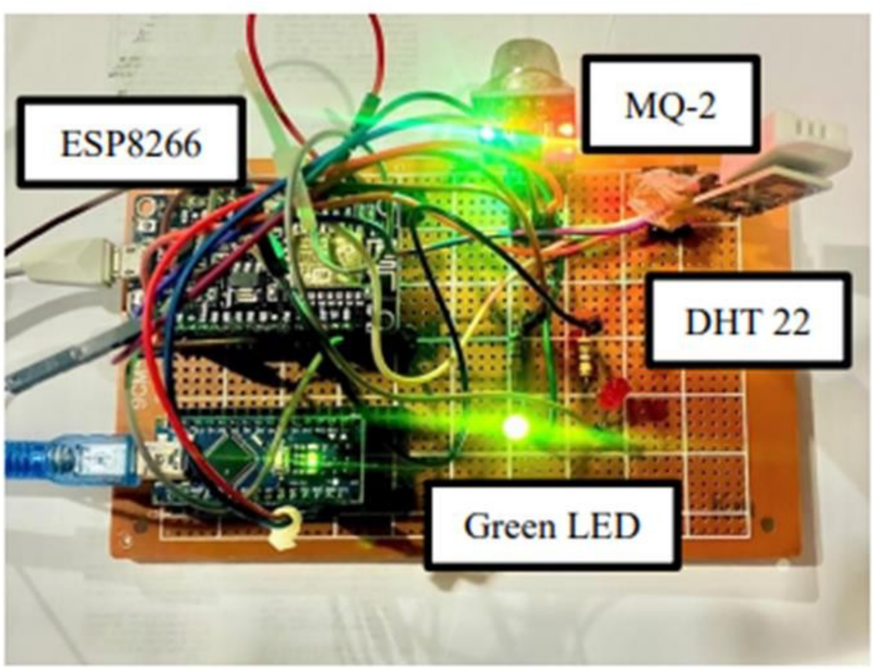

Fig .4. Green LED lights up in good environment

The measurement of carbon dioxide gas is illustrated in Figure 4. The red LED was illuminated, indicating that the air quality was hazardous. This was due to the fact that the AQI reading exceeded 200. It was established within a range that would suggest the presence of hazardous substances in the vicinity. Suffocation, loss of consciousness, and an elevated respiratory rate may result from exposure to hazardous gases. Consequently, it poses a significant threat to the safety of individuals, particularly students and patients in the environment.
The green LED illuminates when carbon dioxide or butane gas is detected. The red LED was illuminated, indicating that the air quality was hazardous. This was due to the fact that the AQI reading exceeded 200. In the range established to signify the presence of hazardous gases in the vicinity

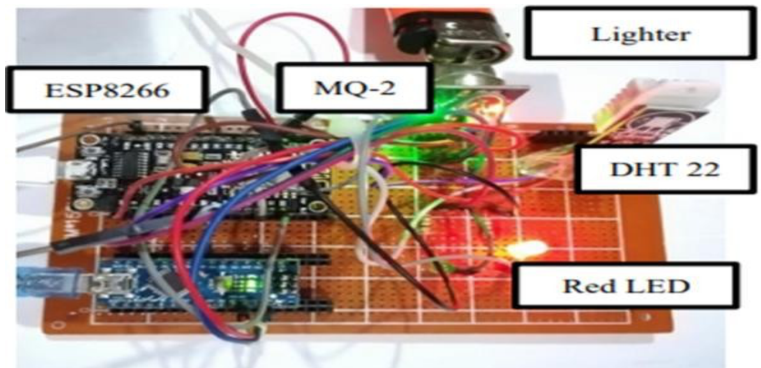

Fig .5. Butane gas detected from the lighter.

Thing Speak program monitoring results All parameters of carbon dioxide gas and butane gas (AQI), temperature (Celsius) and humidity (percentage) were displayed through Thing Speak program. It is important for users to ensure that the air quality in the environment is always good.
These three charts show humidity, hazardous gases and temperature. The gas level reading was 86 AQI in the environment with good air quality. Figure 5 shows the results of the air pollution monitoring system displayed and monitored through the Thing Speak program in hazardous air quality environments. When carbon dioxide and butane gases were detected by the MQ-2 gas sensor, the hazardous gas level was 405 AQI. The red indicator started from 200 to 500. The yellow index started from 100 to 200, which indicates unhealthy air quality for the sensitive group.

2. INTERNET OF THINGS (IOT)

The term “Internet of Things” (IoT) refers to a collection of ubiquitous things that can interact by exchanging information to achieve common goals. The Internet of Things is defined as a network infrastructure that connects uniquely identifiable objects to the Internet, allowing information about them to be collected and their state changed at any time and from anywhere. The Internet of Things is considered the future of the Internet, where billions of smart devices can be automatically connected. The IoT model contributes to increased monitoring of air pollution and understanding of its impact on human health and the environment. Air quality monitoring systems rely on electronic sensing and microprocessor technologies to analyze data. Big data strategies are used to analyze information from sensors. Figure 6 shows the four-layer architecture of IoT systems, where the upper layers provide additional data processing and end-user interfaces. The choice of technologies is influenced by the application and impacts the cost, complexity, and performance of IoT deployments.

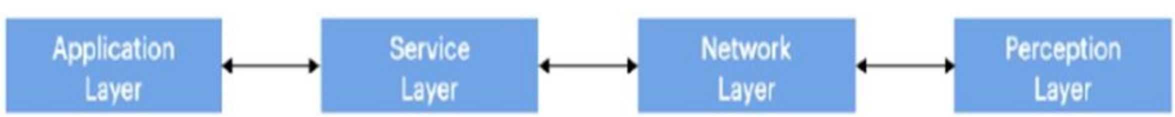

Fig .6. Multi-layer architecture of the Internet of Things

2.1 Air pollutants

Air pollution includes particles and substances in the air that cause harm to human health and the environment, and also affect atmospheric conditions. Major pollutants include fine particulate matter (PM) that originates from human activities, carbon monoxide, carbon dioxide, and nitrogen oxides that may cause acid rain, methane from the decomposition of organic matter, and ozone, which protects from solar radiation but becomes a pollutant in low conditions. This air pollution is a threat to human health and negatively affects the environment.

2.2 Study method

Systematic mapping is a method that is well-organized and serves to summarize the most recent technology in a particular research area. In order to identify and analyze studies concerning IoT-based air pollution monitoring systems for smart cities, five stages were established. Planning the research questions is the initial stage, which involves defining a set of questions that will be addressed in accordance with the primary research topic. In this phase, a "search query" is established for academic databases. The third stage involves the establishment of a set of principles that encompasses the selection criteria.

Our objective is to conduct a comprehensive review of the research literature regarding the most prevalent environmental variables and sensors, communication technologies, data processing analysis, and interaction with other applications (e.g., smart cities), as well as software and hardware architectures in air quality solutions.

Then, we generated the search strings in accordance with the modifications of these terms. Specifically, we identified the primary keywords (in bold) and linked them to the corresponding modifications using the ORlogical operator. The keyword groups that were obtained were connected using the AND logical operator. In January 2020, the search was conducted in five of the most significant electronic databases, including IEEEXplore, ACM Digital Library, Science Direct, SCOPUS, and ISI Web of Science. Fourteen. We executed the task.

the search is conducted by comparing the search term with the title, abstract, and keywords of the published studies. This search yielded a total of 152 studies.

Key words group1:	internet of things. iot
Key words group2:	air poiiution.air quality environmental variables Key
words group3:	monitoring sensing, drlecting
Key words group4:	smart cities, smart city

Objects to monitor the pollution of smart cities (IOTP4mSCp solution)

Objects for smart city pollution monitoring (IOTP4mSCp) include the following components:

- Wire and beam sensors for different measurements.
- IoT gateway(s) / node(s) for data collection - Currently, development boards are used for proof of concept.
- Iran Eshahi middleware with security features to send data to Internet of Things clouds.
- Employing Internet of Things (IoT), Statistics and Artificial Intelligence (AI) for data analysis or data science; The authors are still working on these models.
- IoTP4mSCp architecture and data flow

A data flow diagram shows the logical flow of data processing and transfer functions through the current architecture.
The architecture has the following components:
*Edge devices of the Internet of Things
Internet of Things wired sensors (integrated circuit (I2C), serial peripheral interface (SPI) and universal asynchronous receiver / transmitter (UART)) and wireless sensors (ZigBee / Z-Wave)
Temperature (C), pressure (hPa), altitude (m), relative humidity level (%), carbon dioxide (ppm CO_2), carbon monoxide (ppm CO), ammonium (NH_4 ppm), methane (CH_4 parts per million) Detected - WiFi networks and their signal strength in dB
-Smart objects of the Internet of Things
Internet of Things - for prototyping and proof of concepts, using ESP8266, but in the production of industrial / external MCUs (Micro Computing Unit) should be used. Refer to figure 7.

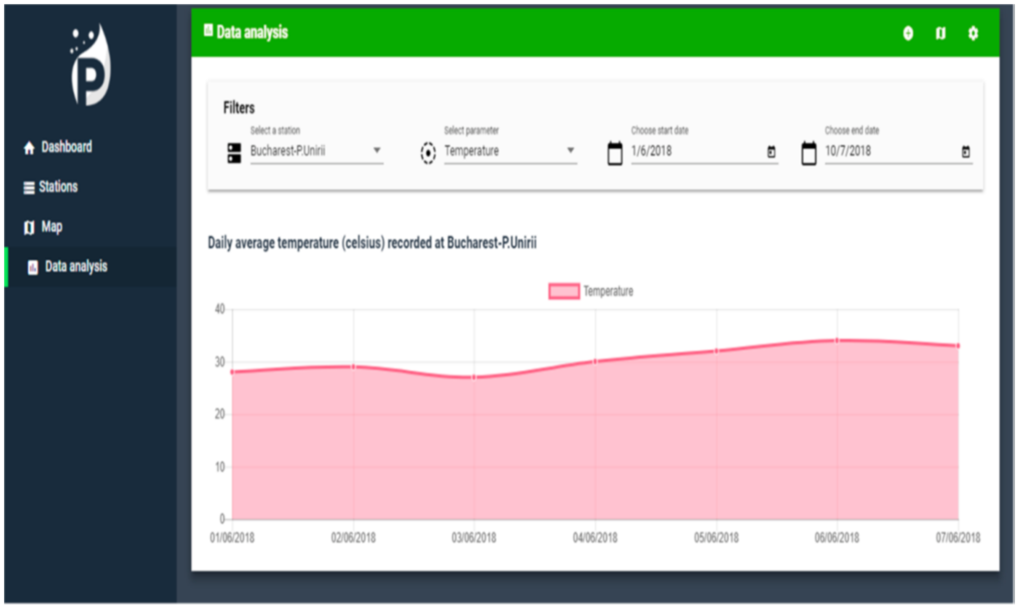

Fig .7. Monitor the Internet of Things station in real time

3. RESEARCH METHODOLOGY

This study follows a systematic approach to define, design, and implement a pollution monitoring solution based on IoT technologies. As shown in figure 8, The steps include system architecture design, comparison with existing solutions, and prototype implementation using Arduino-based sensors. The prototype measures key environmental parameters, such as carbon dioxide and butane gas levels, temperature, and humidity, and triggers alerts when pollution thresholds are exceeded.

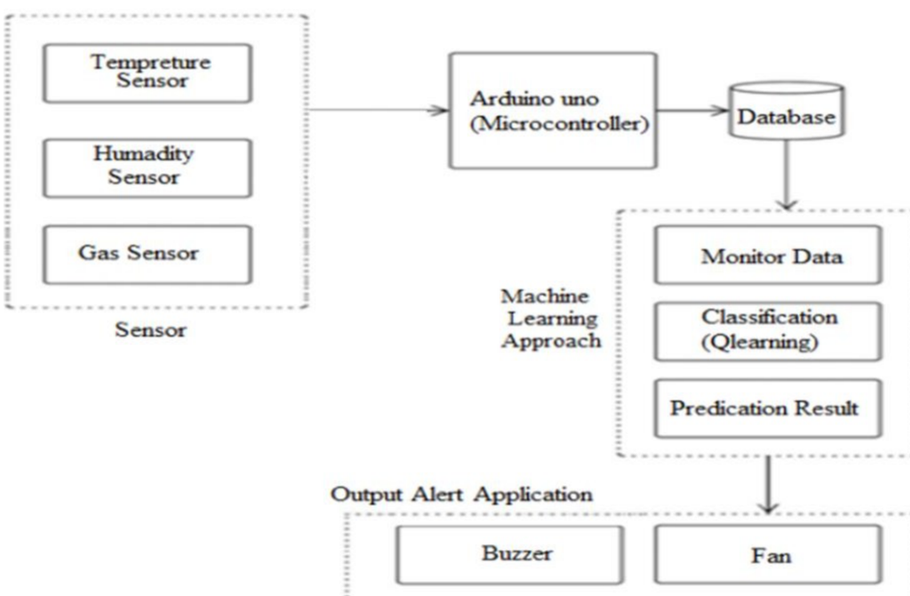

Fig .8. System architecture of the proposed system

Research Hypotheses This research explores whether the IoT can effectively manage air pollution in smart cities. It further investigates if IoT data can be used to predict future pollution levels and suggest timely countermeasures. The hypotheses are:

H1: IoT-based systems can manage air pollution effectively.

H2: IoT data can predict pollution trends and support decision-making in smart cities

TABLE I. STRUCTURES, ITEMS AND VARIABLES INCLUDED IN THE RESEARCH

Using the Internet of Things B	**B1**	The security challenges posed by IoT are explored in communication channels between IoT gateways and cloud infrastructure.
	B2	An Internet of Things Architecture for Collecting Pollution Metrics in a Smart City Using Best Practices in Software Development Technologies
	B3	Emphasizes component architecture, data flow implementation details, and edge connectivity to the IoT cloud
	B4	IoT wired sensors (integrated circuit (I2C), serial peripheral interface (SPI) and receiver) play a central role
	B5	IoT gateway pollution monitoring stations are subscribed to MQTT broker topics

3.1 Descriptive statistics and demographic variables

In this section, the information related to the individual characteristics and demographic findings of the research units are examined and evaluated.

Gender: according to the output of the software and Table 2, out of a total of 55 people in the research unit, 27 people, equal to 49.1%, were women and 28 people, equal to 50.9%, were men.

TABLE II. FREQUENCY DISTRIBUTION OF RESEARCH UNITS BY GENDER

Percent	Number	gender
49.1	27	Female
50.9	28	Man
100	55	Total

Age: According to the output of the software and Table 2, out of the total of 55 people in the research unit, 9 people are equal to 16.4% in the age group of twenty to thirty years, 32 people are equal to 58.2% in the age group of thirty to forty years, 0 people are equal to 16.4 The percentage is in the age group of forty to fifty years and 5 people, equivalent to 9.1%, are in the age group of more than fifty years. Most of the participants in this survey were between thirty and forty years old.

TABLE III. FREQUENCY DISTRIBUTION OF RESEARCH UNITS ACCORDING TO AGE

Percent	Number	Age
16.4	9	From 20 to 30 years
58.2	32	From 31 to 40 years
16.4	9	From 41 to 50 years
9.1	5	More than 50 years
100	55	Total

Field of work: According to the output of the software and Table 3, of the total 55 people in the research unit, 24 people equal to 43.6% were employees, 26 people equal to 47.3% were supervisors, and 5 people equal to 9.1% were managers.

TABLE IV. FREQUENCY DISTRIBUTION OF RESEARCH UNITS ACCORDING TO LIFE STATUS

Percent	Number	area of expertise
43.6	24	Employee
47.3	26	supervisor
9.1	5	the manager
100	55	Total

Education: According to the output of the software and Table 4, we can see that out of 55 people in the research unit, 29 people (52.7%) have a bachelor's degree, 19 (34.5%) have a master's degree, 4 (7.3%) have a PhD, and 3 (5.5%) have a post-graduate degree. have a Ph.D.

TABLE V. EXAMINING THE EDUCATION OF PEOPLE PARTICIPATING IN THE RESEARCH

Percent	Number	education
25.7	29	Master
34.5	19	Masters
7.3	4	doctor
5.5	3	Postdoctoral
100	55	Total

Table 5 shows the number of different responses of the survey participants to each of the questions. By looking at this table at a glance, it is possible to get the number of opposite and completely opposite answers compared to other answers for each question, and this number is zero in most questions. Also, other descriptive indicators such as mean and standard deviation have been specified for all research questions. As can be seen from Table 6, the highest standard deviation is related to question 4, and this means that the participants have more disagreement on this question. The lowest standard deviation is related to question 11, which means that the respondents were more in agreement about this question than other questions.

TABLE VI. DESCRIPTIVE STATISTICS OF RESEARCH QUESTIONS

I complet ely disagree	I disagr ee	I do not know	I agree	I quite agree	**Research questions**	**item**
6	14	14	14	21	The security challenges posed by IoT are explored in communication channels between IoT gateways and cloud infrastructure.	**B1**
2	1	17	19	16	An Internet of Things Architecture for Collecting Pollution Metrics in a Smart City Using Best Practices in Software Development Technologies	**B2**
2	9	13	17	15	Emphasizes component architecture, data flow implementation details, and edge connectivity to the IoT cloud	**B3**
3	7	17	10	18	Wired IoT sensors (integrated circuit (I2C), serial peripheral interface (SPI) and receiver) play a fundamental role	**B4**
0	3	12	18	22	IoT gateway pollution monitoring stations are subscribed to MQTT broker topics	**B5**
3	3	16	14	19	IoT communication middleware with security features to send data to IoT clouds	**M1**
2	7	6	24	16	- IoT cloud solution for mathematical, statistical and artificial intelligence (AI) models for data analysis and data science techniques; The authors are still working on these models	**M2**
0	4	11	17	23	Wired and wireless sensors for different measurements	**M3**
					The first one focuses on configuring the	

0	4	7	21	23	components - cloud services, MQTT broker, Node-RED and MongoDB database, as well as implementing the platform solution .through the gateway application	**M4**
3	2	11	14	25	To monitor air pollution levels and air quality, a development board records the following data with attached sensors	**M5**
0	2	11	18	24	Easy integration of vehicle traffic management system (for example, traffic lights), with the authors' proposed solution for API as a pluggable component	**P1**
0	4	16	06	19	APIs are easily exposed to any traffic management system to create different dynamic routes to avoid vehicle congestion.	**P2**
0	5	16	16	18	It is a software and hardware platform that is open source and includes a microcontroller that forms the main hardware of Arduino and can play a fundamental role in data processing.	**P3**
0	3	24	14	14	The Node-RED component maintains data through the MQTT protocol	**P4**
1	8	18	14	14	Security designed for IoT gateway and communications to IoT clouds than other sciences	**P5**

TABLE VII. VARIANCE EXPLAINED BY FOUR FACTORS TOTAL VARIANCE EXPLAINED

Component	Initial Eigenvalues		Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	41.302	41.302	6.195	41.302	41.302	3.828	25.517	25.517
2	18.535	59.837	2.780	18.535	59.837	3.562	23.747	49.264
3	9.924	69.761	1.489	9.924	69.761	2.140	14.269	63.533
4	7.956	77.717	1.193	7.956	77.717	2.128	14.184	77.717
5	5.282	83.000						
6	3.357	86.357						
7	3.053	89.409						
8	2.456	91.866						

9	2.352	94.218							
10	1.888	96.106							
11	1.483	97.589							
12	1.136	98.724							
13	0.703	99.427							
14	0.356	99.783							
15	0.217	100.000							

3.2 Extraction Method: Principal Component Analysis.

Based on Table 7, it can be seen that four items have an eigenvalue greater than one, and approximately 77% of the total variance of the items is explained by these four questions

After confirming the validity of the questionnaire, to measure the internal consistency (reliability) of the questionnaire, we use the Cronbach's alpha criterion based on the average covariance. According to the output of the software and Table 9, since the value of Cronbach's alpha coefficient is 0.881, the compatibility of the questionnaire questions is confirmed.

Data Analysis The research employs both qualitative and quantitative analysis methods to evaluate the system's performance. Data collected from IoT sensors will be processed using machine learning techniques to predict pollution levels. The prototype system consists of Arduino-based sensors connected to a microcontroller, which collects and stores pollution data for real-time analysis and decision-making.

Results and Discussion The prototype air pollution monitoring system successfully measured gas levels, temperature, and humidity in a controlled indoor environment. The collected data, processed using IoT technologies, was displayed through the ThingSpeak platform. The MQTT communication protocol proved effective for transmitting data securely. In hazardous conditions, the system alerted users through mobile notifications, indicating high pollution levels.

Conclusion This research presents a comprehensive IoT-based solution for monitoring air pollution in smart cities. The designed system integrates secure communication protocols, sensor technologies, and cloud platforms to ensure real-time pollution monitoring and data security. Future work will focus on extending the system to include additional environmental parameters and expanding its scalability for larger smart city deployments.

4. CONCLUSION

This paper established a scalable, secure IoT-based solution for air pollution monitoring in smart cities. By using Arduino sensors and the MQTT communication protocol, the system successfully displays key air pollutants, provides real-time alerts, and allows data to be analyzed for predictive pollution control. The incorporation of machine learning improves the system's capability to predict air quality trends and take proactive measures to reduce pollution, such as rerouting traffic or closing roads in highly polluted areas. The outcomes show the system's effectiveness in both controlled environments and in simulations for smart city applications. Future study will aim to expand the system by integrating additional sensors and exploring new AI techniques for more advanced pollution prediction and mitigation strategies.

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None.

Conflicts Of Interest

Authors declare that no conflict of interest exist within this work.

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